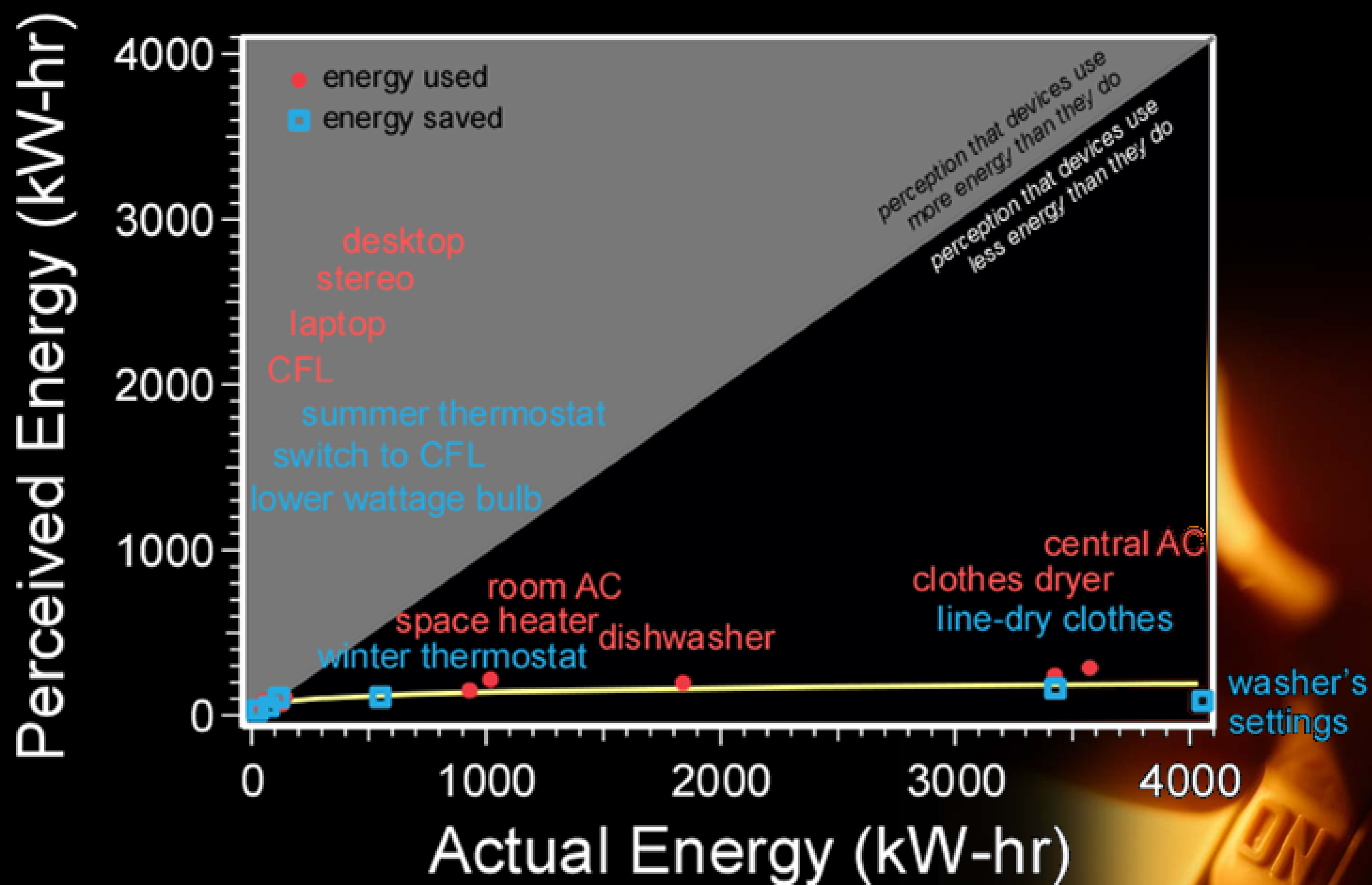
Application of Engineering to Various Business Propositions

William Banholzer
CBE Seminar
April 8, 2014

Rules for Business

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

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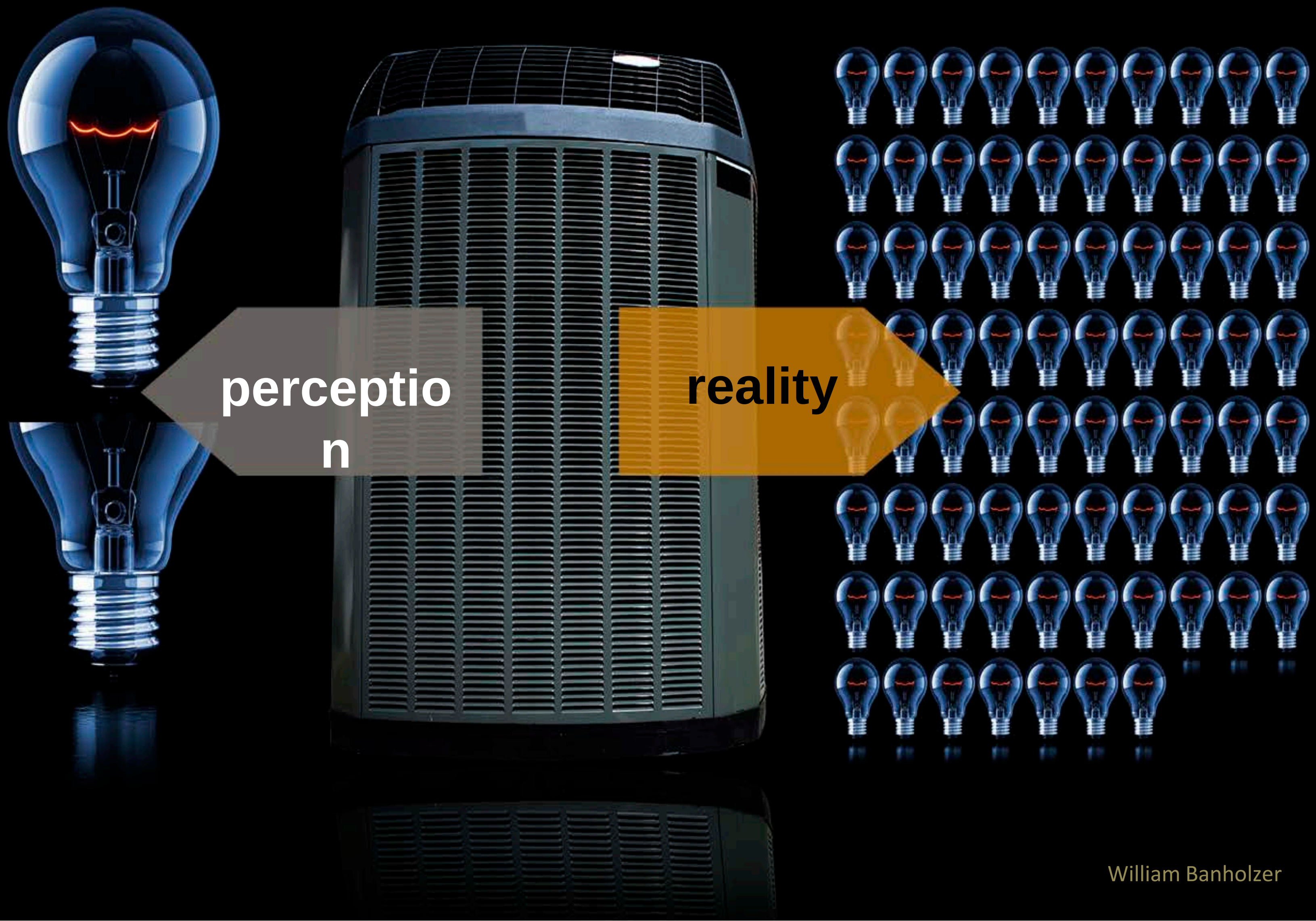
Energy Perception and Reality



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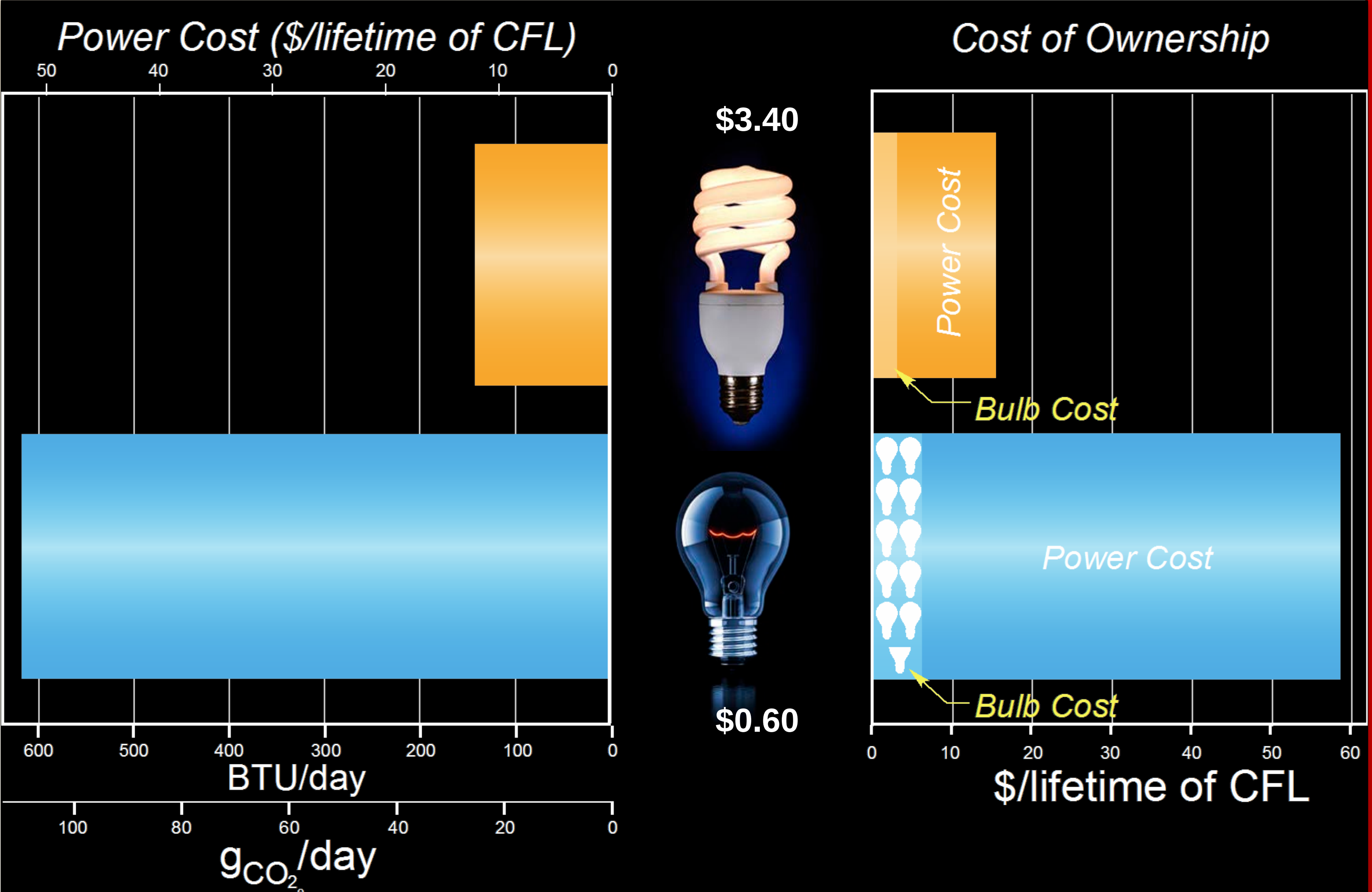
People Don’t Always Make Smart Choices



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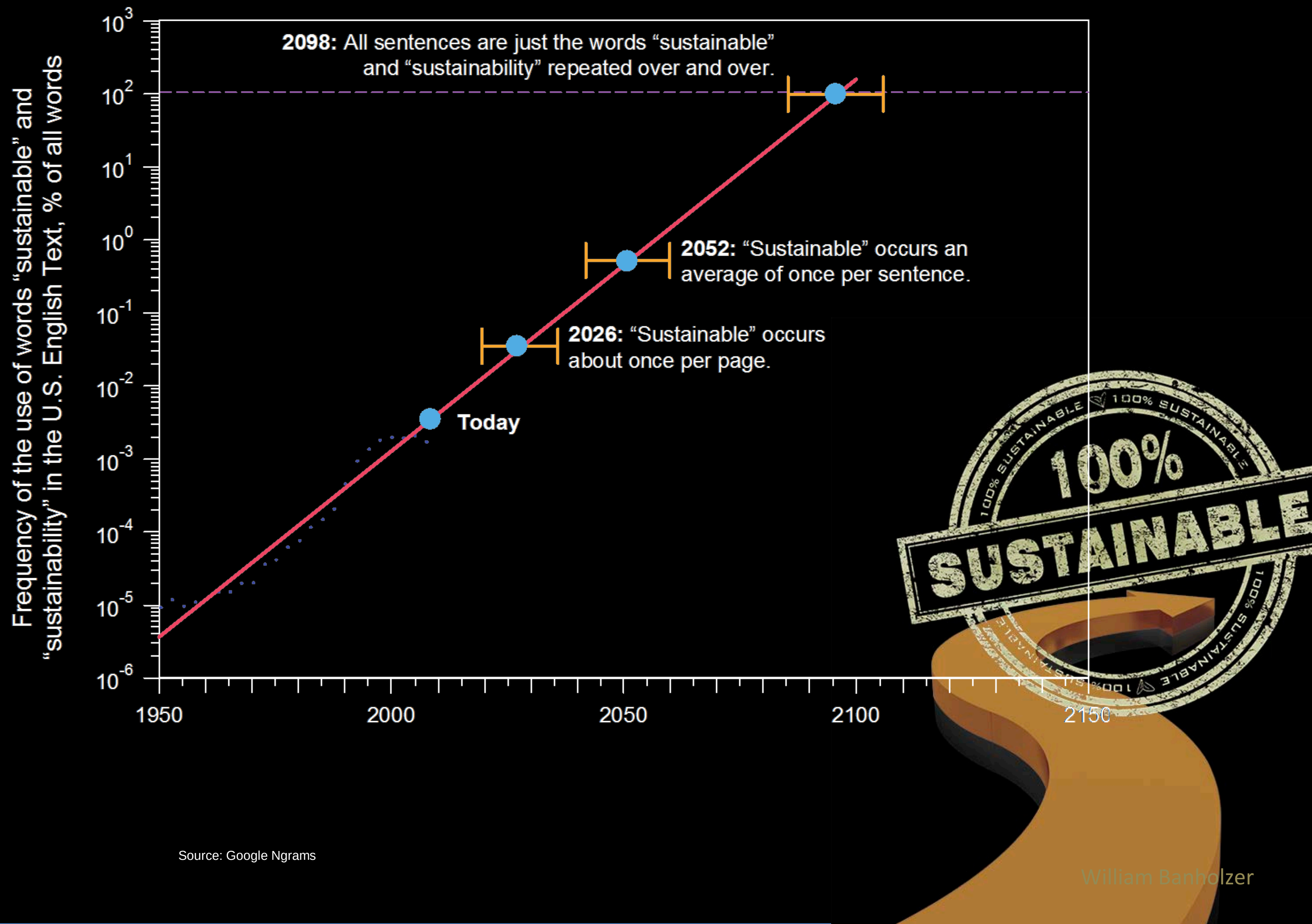
Ripe for Hype



Source: Google Ngrams

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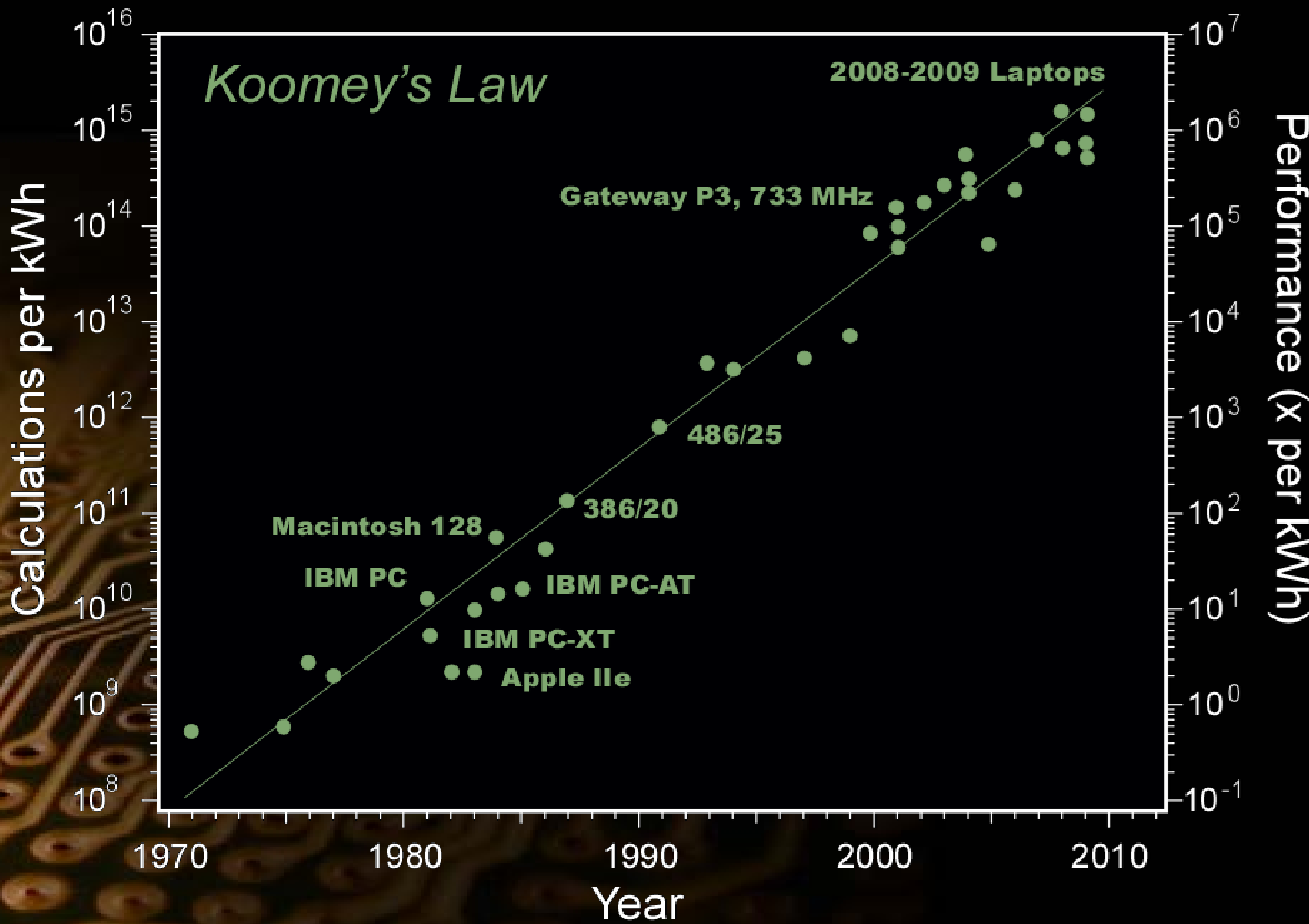
Engineering Triumph



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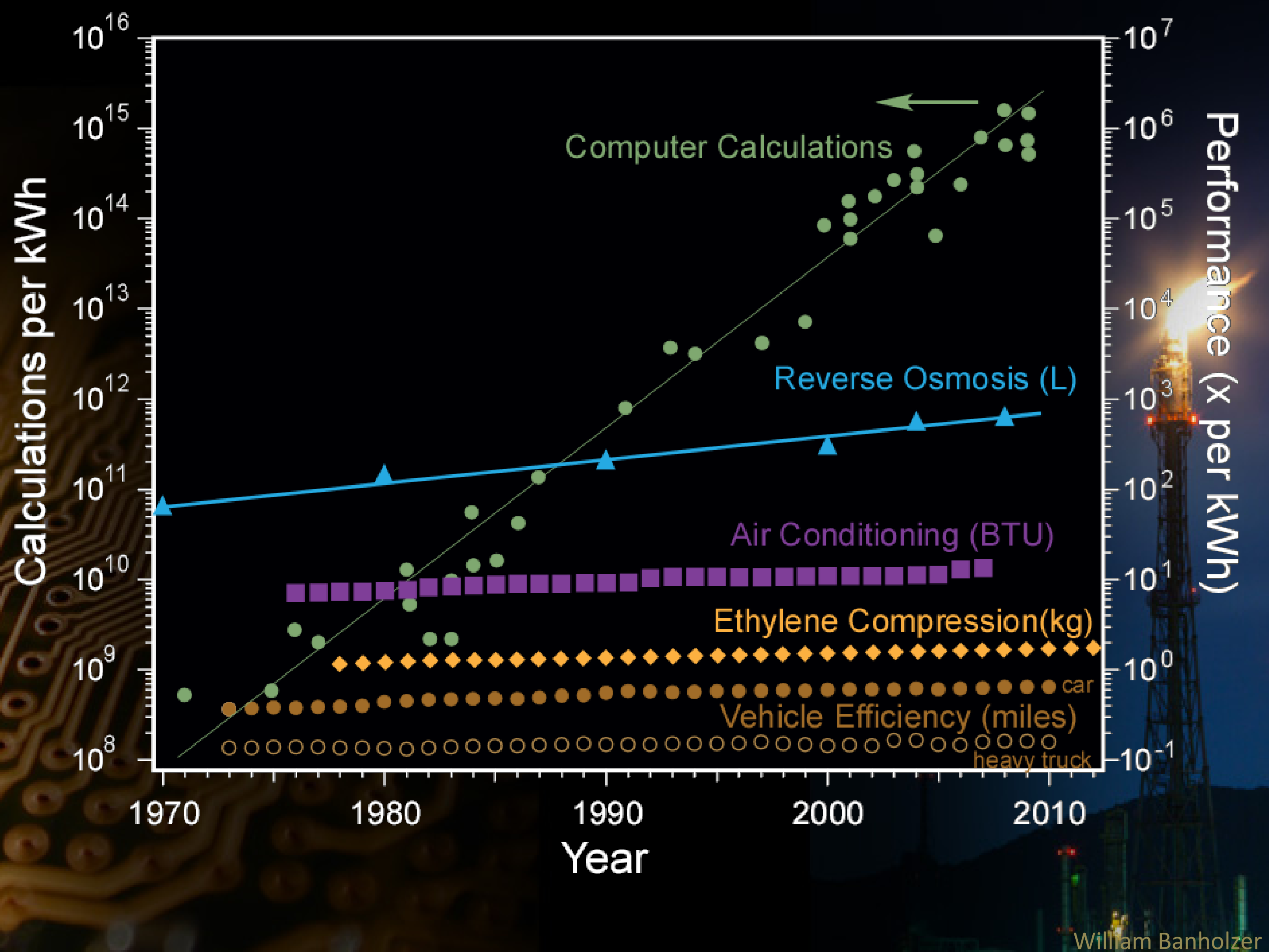
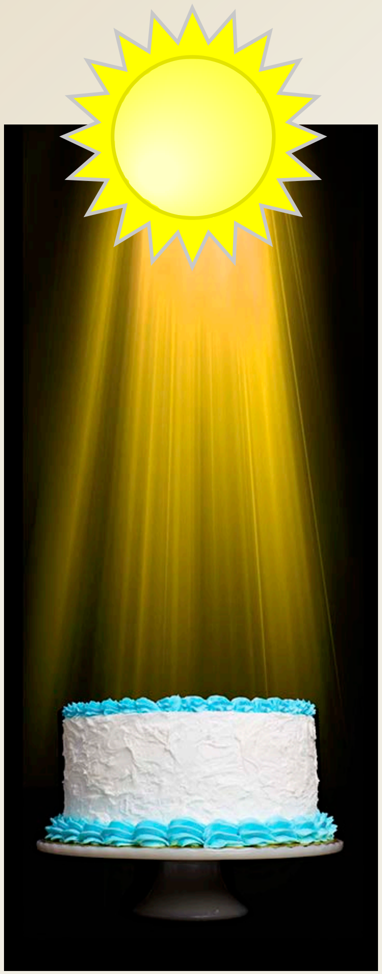
Moore's Law Sets Unrealistic Expectations



Solar Energy Quiz



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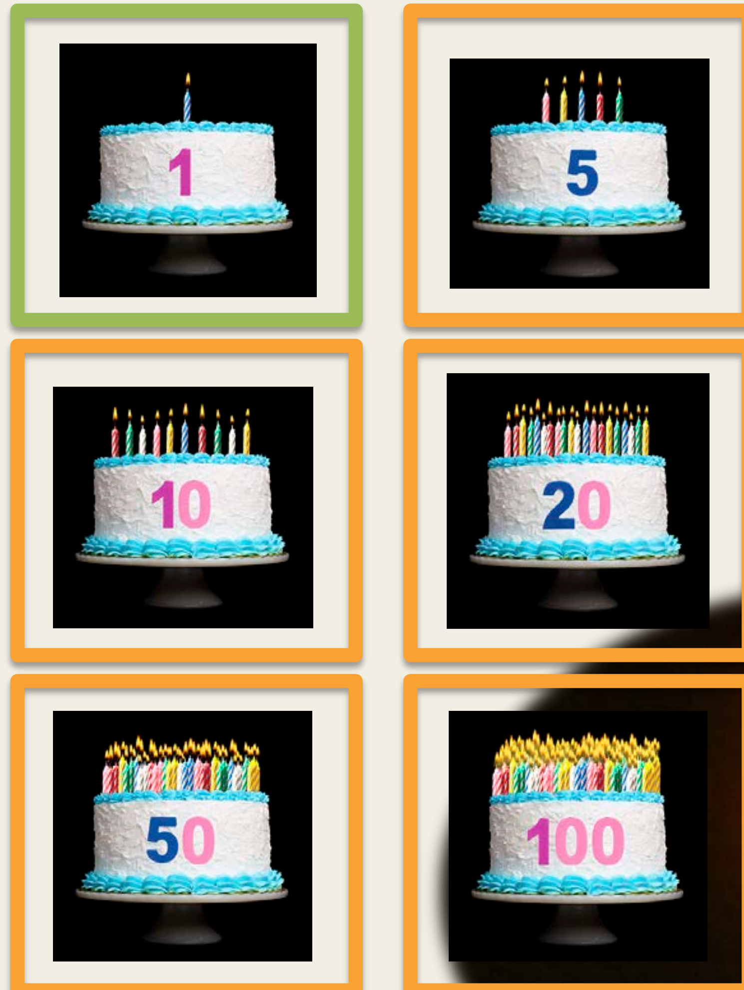

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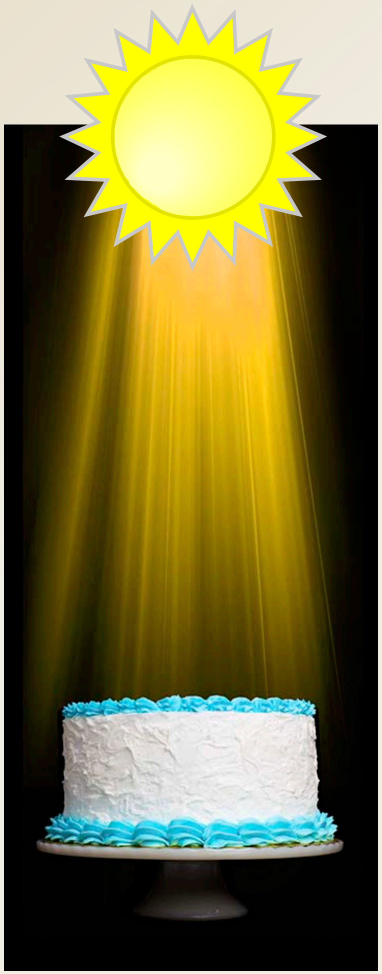
Solar Energy Quiz



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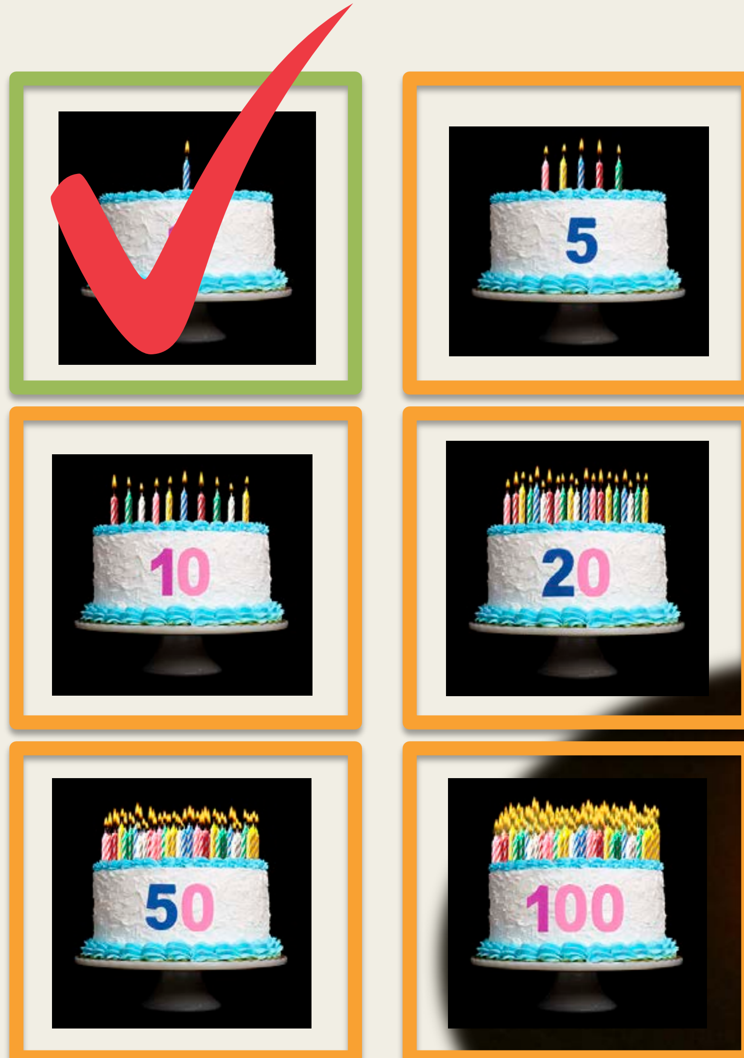
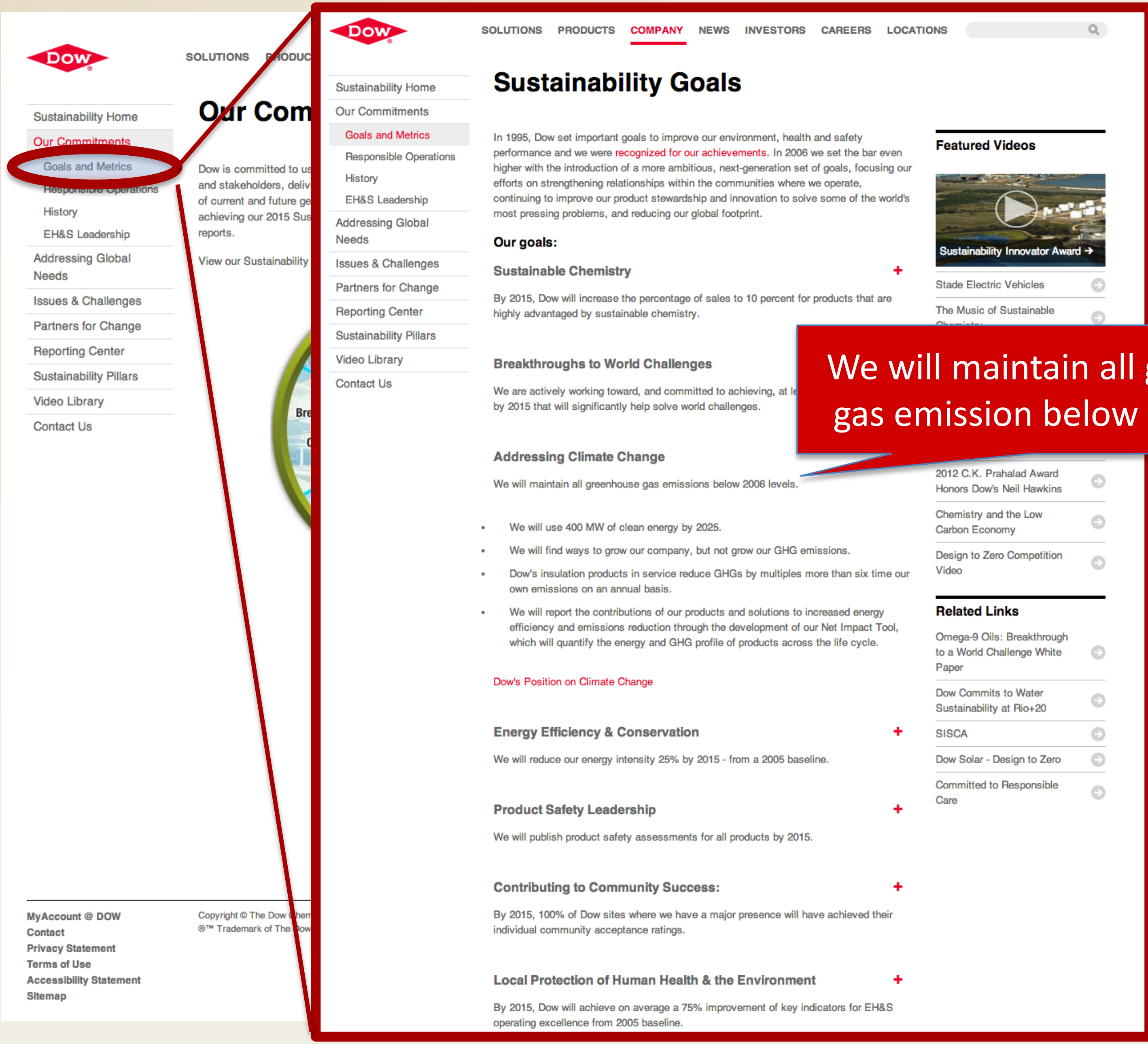


BUSINESS EVALUATIONS

CONGRATULATIONS! You have just been appointed the CTO of Dow Chemical.

- You must advance the company's mission
- You can't invent everything yourself
- When presented investment opportunities what questions would you ask?
    - Skyonic
    - Cool Planet
    - C Nanotubes & Graphene DeSalination
    - *BioPET (Time?)*

Dow's Sustainability Commitment



SOLUTIONS PRODUCTS COMPANY NEWS INVESTORS CAREERS LOCATIONS

Sustainability Home
Our Commitments
Goals and Metrics
Responsible Operations
History
EH&S Leadership
Addressing Global Needs
Issues & Challenges
Partners for Change
Reporting Center
Sustainability Pillars
Video Library
Contact Us

Sustainability Goals

In 1995, Dow set important goals to improve our environment, health and safety performance and we were recognized for our achievements. In 2006 we set the bar even higher with the introduction of a more ambitious, next-generation set of goals, focusing our efforts on strengthening relationships within the communities where we operate, continuing to improve our product stewardship and innovation to solve some of the world's most pressing problems, and reducing our global footprint.

Our goals:

Sustainable Chemistry +

By 2015, Dow will increase the percentage of sales to 10 percent for products that are highly advantaged by sustainable chemistry.

Breakthroughs to World Challenges

We are actively working toward, and committed to achieving, at le... by 2015 that will significantly help solve world challenges.

Addressing Climate Change

We will maintain all greenhouse gas emissions below 2006 levels.

- We will use 400 MW of clean energy by 2025.
- We will find ways to grow our company, but not grow our GHG emissions.
- Dow's insulation products in service reduce GHGs by multiples more than six time our own emissions on an annual basis.
- We will report the contributions of our products and solutions to increased energy efficiency and emissions reduction through the development of our Net Impact Tool, which will quantify the energy and GHG profile of products across the life cycle.

Dow's Position on Climate Change

Energy Efficiency & Conservation +

We will reduce our energy intensity 25% by 2015 - from a 2005 baseline.

Product Safety Leadership +

We will publish product safety assessments for all products by 2015.

Contributing to Community Success: +

By 2015, 100% of Dow sites where we have a major presence will have achieved their individual community acceptance ratings.

Local Protection of Human Health & the Environment +

By 2015, Dow will achieve on average a 75% improvement of key indicators for EH&S operating excellence from 2005 baseline.

Featured Videos

Sustainability Innovator Award →
Stade Electric Vehicles
The Music of Sustainable Chemistry
2012 C.K. Prahalad Award Honors Dow's Neil Hawkins
Chemistry and the Low Carbon Economy
Design to Zero Competition Video

Related Links

Omega-9 Oils: Breakthrough to a World Challenge White Paper
Dow Commits to Water Sustainability at Rio+20
SISCA
Dow Solar - Design to Zero
Committed to Responsible Care

We will maintain all greenhouse gas emission below 2006 levels

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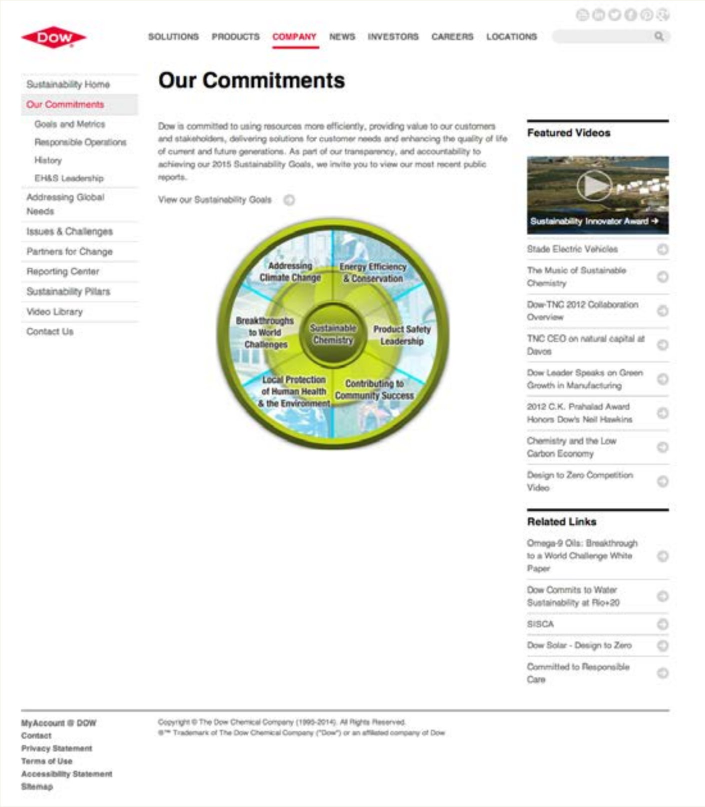
Technology Evaluation – Skyonics

In April 2008, Dow announced plans to build a 600 MW coal and gas fired power plant at its location in Stade, Germany. The 20 year old plant that is currently there can only meet 25%of the need for power.

Dow’s commitment to sustainability includes a pledge keep emissions below 2006



In 2008, a company by the name of <u>Skyonic</u> contacted Dow with a proposal to completely eliminate carbon dioxide emissions from its Power Generation facilities

Technology Evaluation – Skyonics

Who we are:

At Skyonic, we believe that clean air and economic growth are not mutually exclusive. We believe that mineralizing CO2 emissions is the best-available method for addressing global warming

Power Plant Waste Used to Make Cookies!

Skyonics Web

Cookies from Coal?

Technology Evaluation – Skyonic Process

Founded in 2005. Announced $128MM in Funding, Broke Ground Sept 2013 on 75Kt CO_2 Capture plant

$NaOH$	+	CO_2	→	$NaHCO_3$
Caustic		**Carbon Dioxide**		**Baking Soda**

This technology appears to be a natural fit for Dow, the world's leading manufacturer of caustic soda.

Should Dow:

1. **Collaborate with Skyonic to implement this technology at the Stade plant?**
2. **Ignore the offer?**

What questions would you ask?

Technology Evaluation – Skyonic Process

How is caustic made?

NaCl	+	H_2O	→ (electricity)	NaOH	+	½ Cl_2	+	½ H_2
Salt		Water		Caustic		Chlorine		Hydrogen

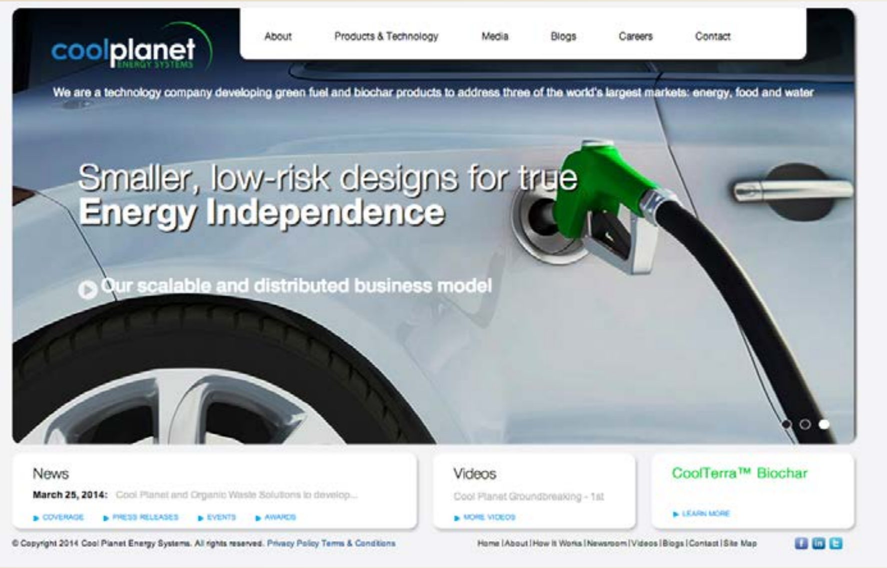
How much NaOH is needed to capture the CO_2 from a power plant?
7 billion lb/yr ***This is 5% of the world market.***

Capital required to build this NaOH capacity?
$4 billion- ***4 times the capital required to build a power plant.***

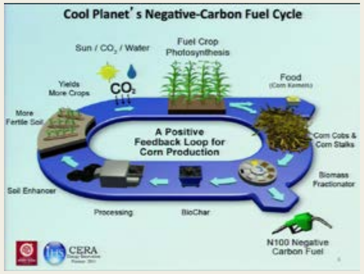
How much electricity is required to make this NaOH?
1000 MW plant ***This is 400 MW more than the plant will produce.***

How much chlorine byproduct is made?
7 billion lb/yr ***This is 50% of Dow's annual production.***

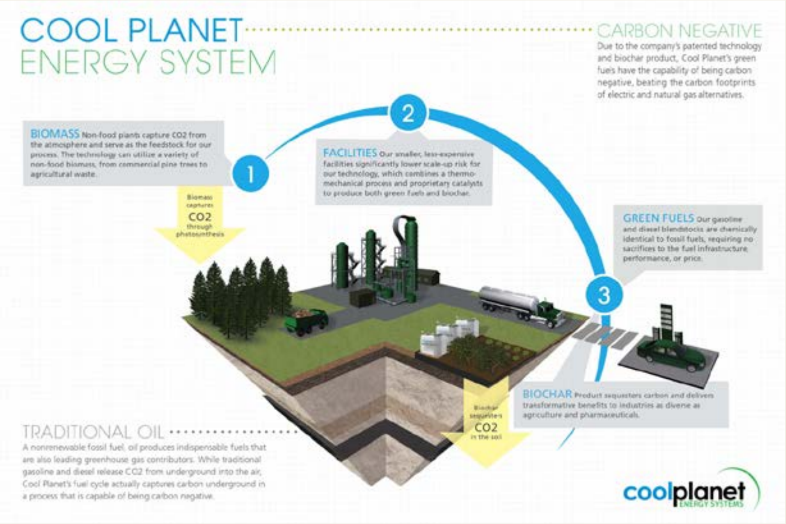
Technology Evaluation- Cool Planet



Solve for X Link https://www.youtube.com/watch?v=zkYVlZ9v_0o



screen capture from Mike Cheiky on wesolveforX.com; 24 February 2012



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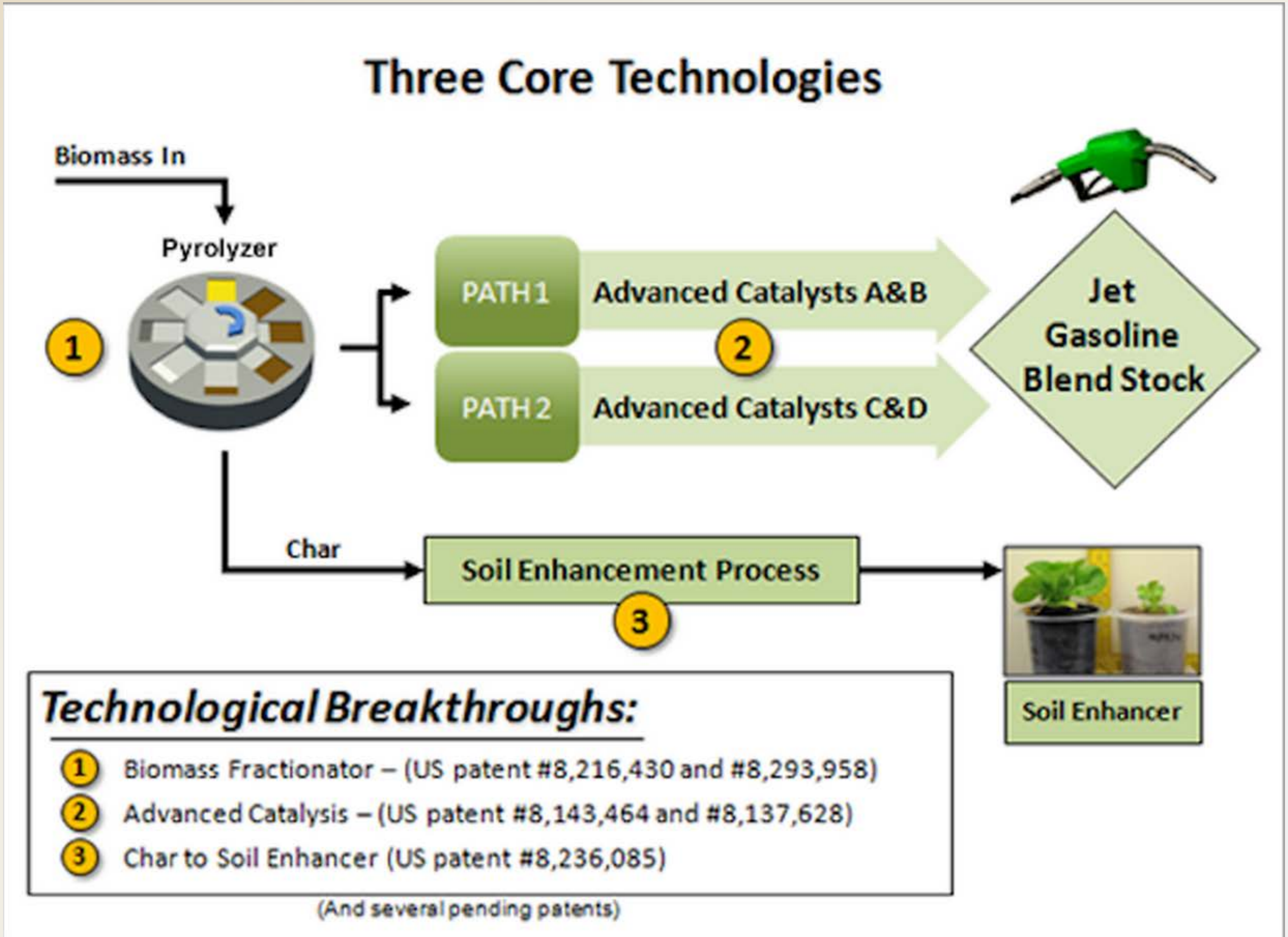
Core Technologies



screen capture http://www.forbes.com/sites/peterdetwiler/2014/03/31/cool-planet-closes-100-million-series-d-capital-raise-for-biofuels/

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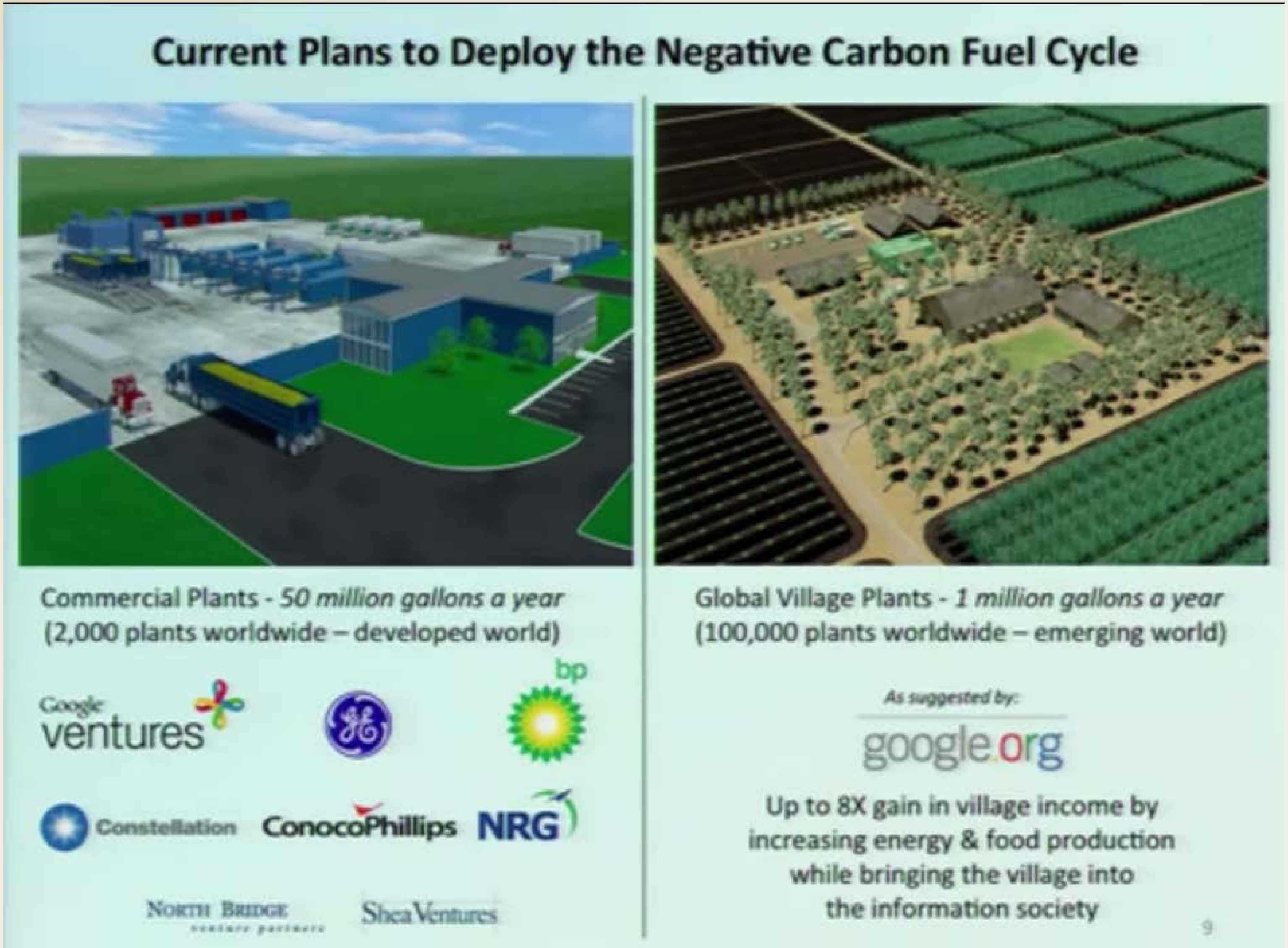
Plans



screen capture from Mike Cheiky on wesolveforX.com; 24 February 2012

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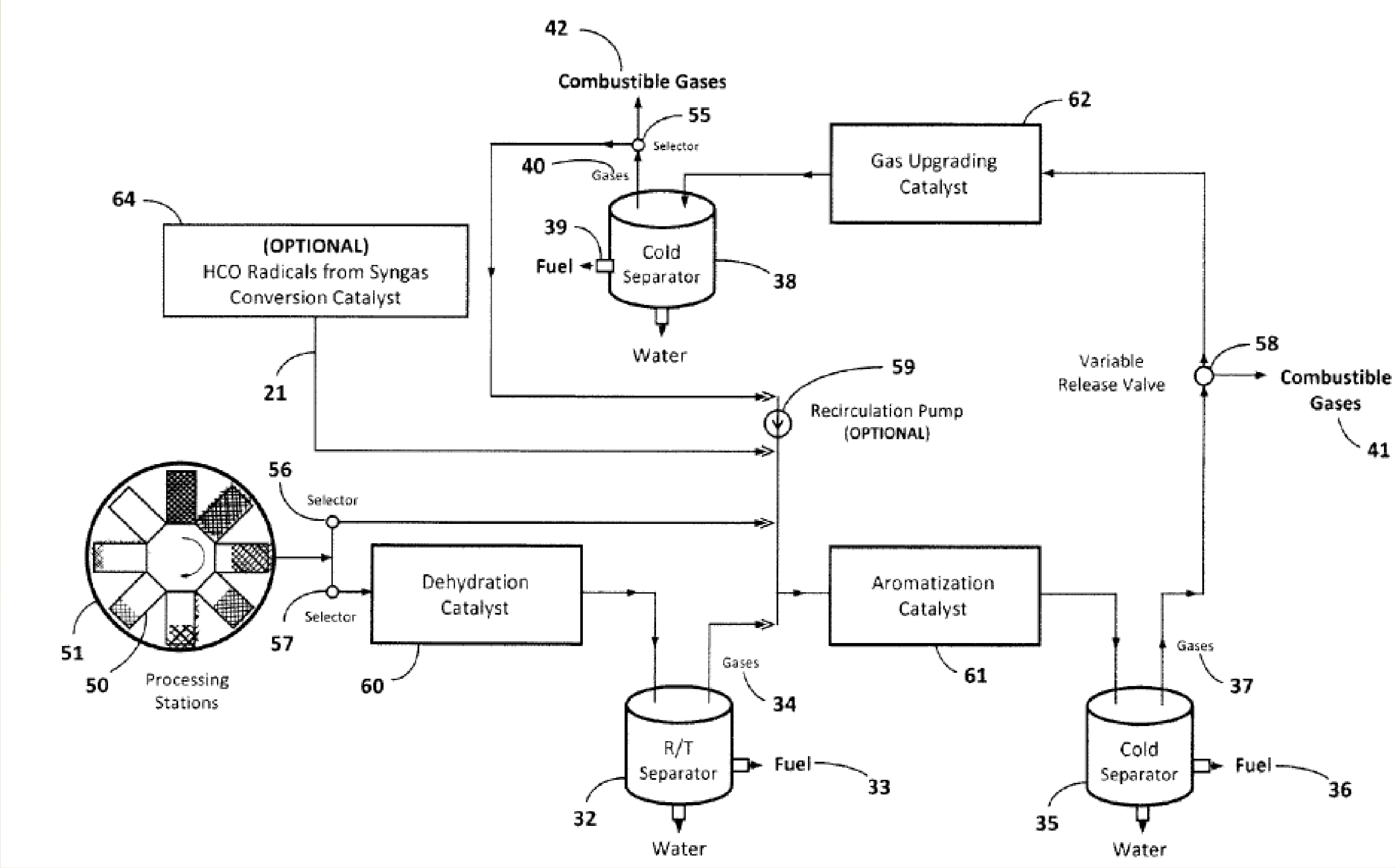
Key Technology Developments

- 4000 gallons of biofuel per acre with energy crop
- 1000 gallons per acre for residue
- 109 octane gasoline oxygen-free, drop-in
- Plants capture carbon that goes back to atmosphere when plants die
- C3 plants are grossly inferior to C4 plants
- New carbon *negative carbon fuel cycle*
- 2 week carbon treatment, stored for centuries
- Improves the soil; 4-8 years to upgrade land

Key Technology Developments

- “Biomass fractionator strips off accessible hydrocarbon radicals, all plant have a few loose hydrocarbons”
- “Quantum catalyst with sub-nanometer quantum wells”
- Fungal protein coating on carbon
- 1 MM gal plant + 60 kW for $1 MM in capital
- 10-50 MM gal plants

What is the process?



from US20110212004

What is the Fuel?

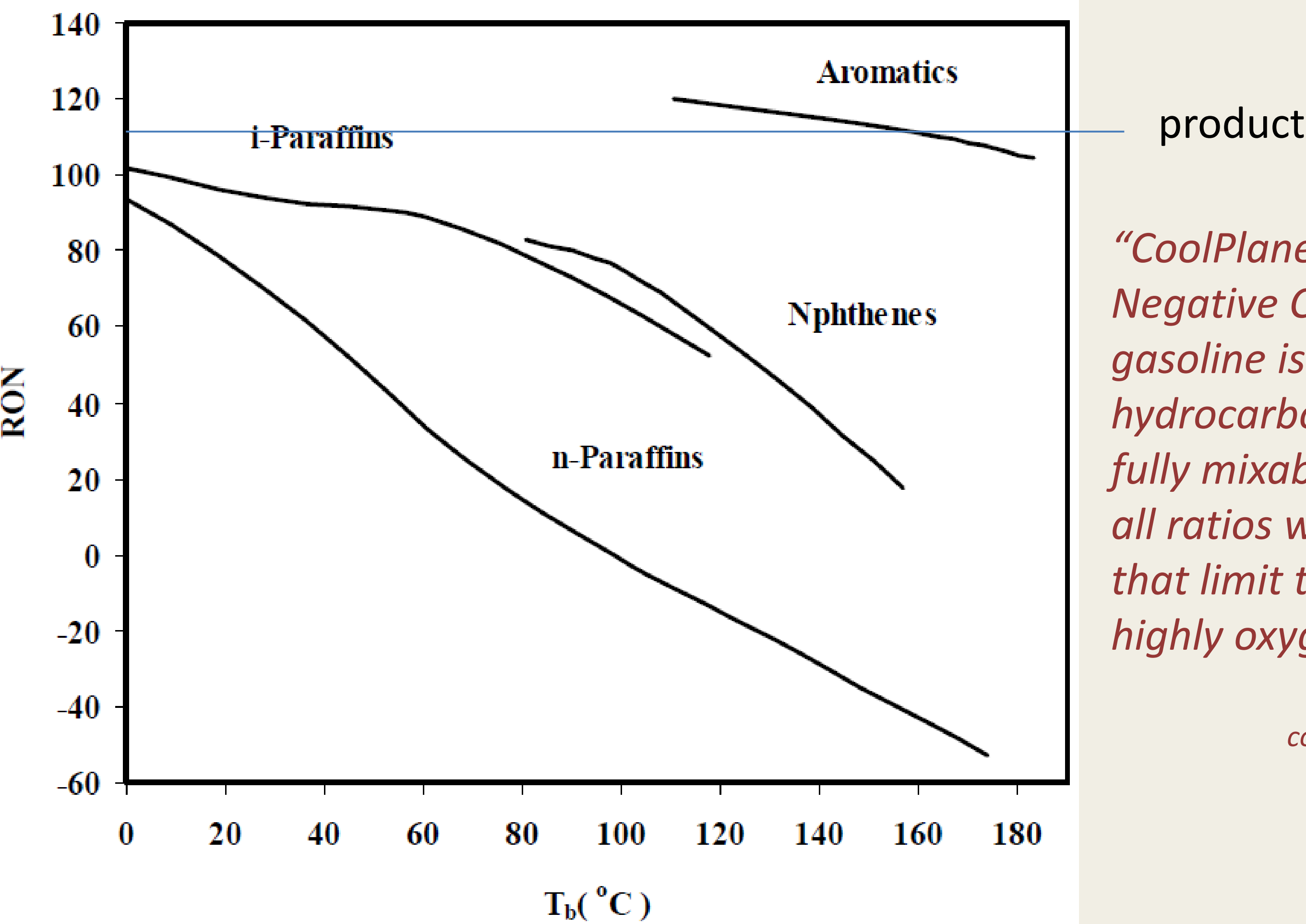


Figure 1. Research Octane Number of Pure Hydrocarbons from Different Families.

"CoolPlanet BioFuels' Negative Carbon "N100" gasoline is completely hydrocarbon based and is fully mixable with gasoline at all ratios without the issues that limit the usefulness of highly oxygenated biofuels."

coolplanetbiofuels.com

Cool Planet

Should you Invest?

What questions should you ask?

Energy Balance

- Hydrocarbon fuel between 17000 and 21000 BTU/lb with a density of ~6.1 lb/gal (gasoline is between 6.0 and 6.5 lb/gal; higher = more aromatic)
- ~116,000 BTU/gal * 4,000 gal/acre = 646 MM BTU/acre
- *dry* biomass is 7700 BTU/lb
- **30 tons / acre required just to balance energy @ 0 loss!**
- *carbon going to char makes this bigger*

Mass Balance

$$CH_2O \longrightarrow CH + HO$$

fuel loss

4000 gal/acre biomass

6.5 lb/gal = aromatic

27 tons/acre required at 100% yield just to balance C

10 tons/acre is a more reasonable approximation for productivity but doesn’t account for char or energy!

Biomass Residue

super crops with very high yields may be possible but biomass residues are a know quantity

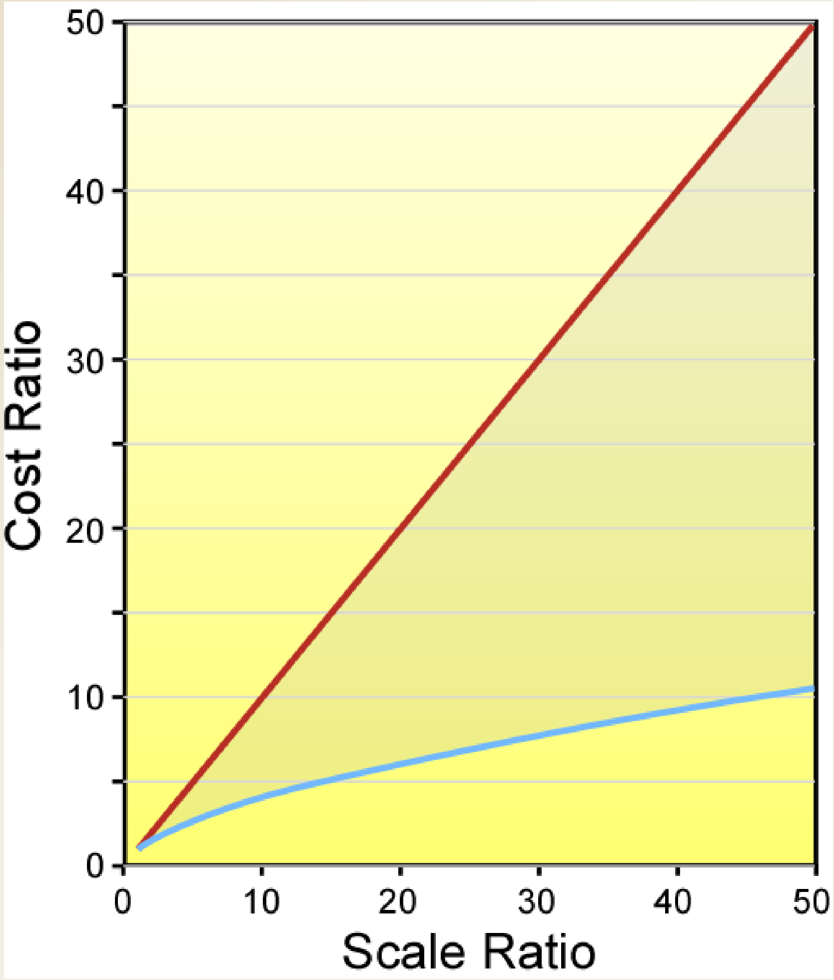
NRC RFS report concludes stover is available at between 0.7 and 3.8 dry tons/acre

1000 gal/acre is *impossible* on biomass alone

	low	high	
stover yield	0.7	3.8	dry tons/acre
biomass HHV	7700	7700	BTU/lb
fuel density	6.5	6.5	lb biofuel/gal biofuel
theo. energy based	93	504	gal/acre
theo. mass based	93	507	gal biofuel/acre

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

Capital Scaling



Bigger means less unit capital

n ~ 0.6

$$\frac{cost_{size_2}}{cost_{size_1}} = \left(\frac{capacity_{size_2}}{capacity_{size_1}}\right)^n$$

The Importance of Scale

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

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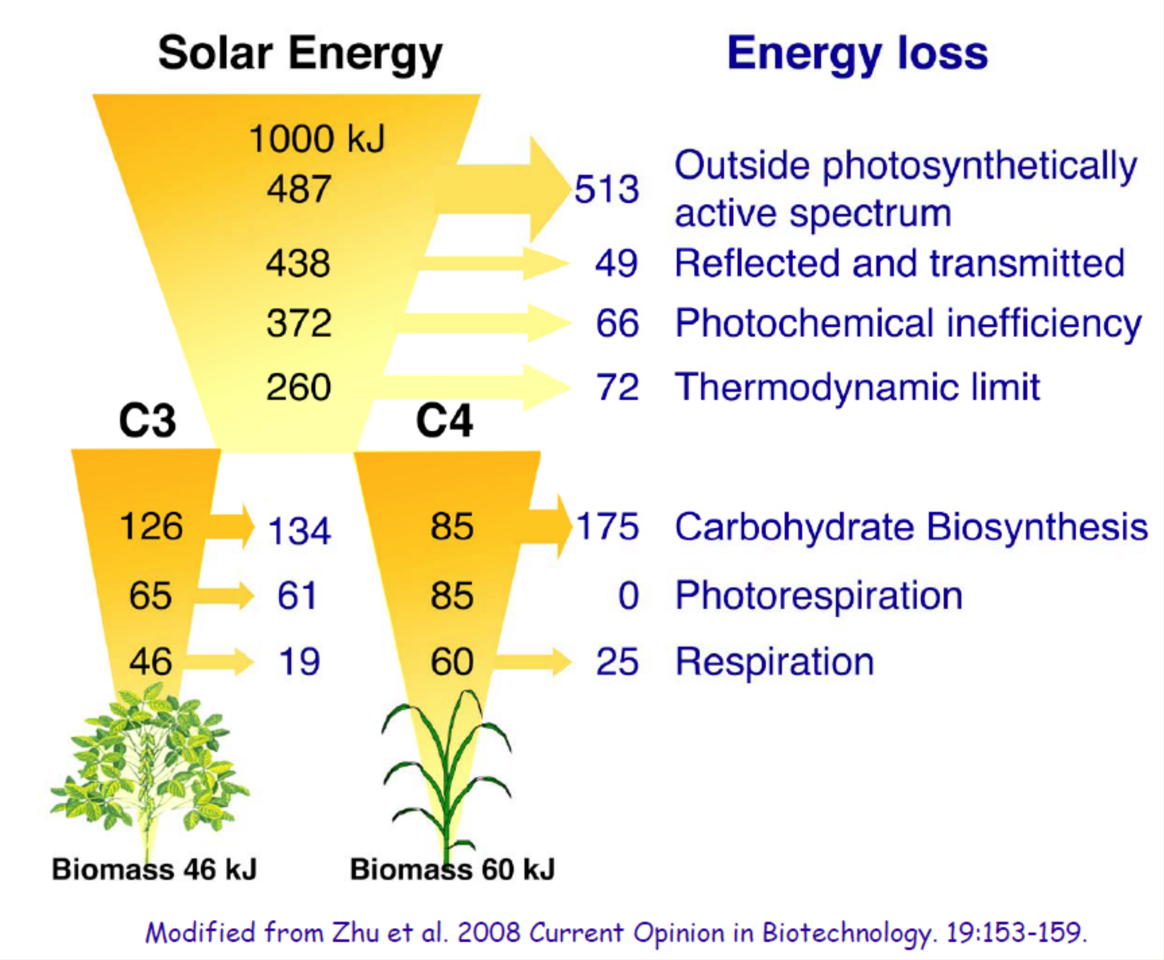
Capital

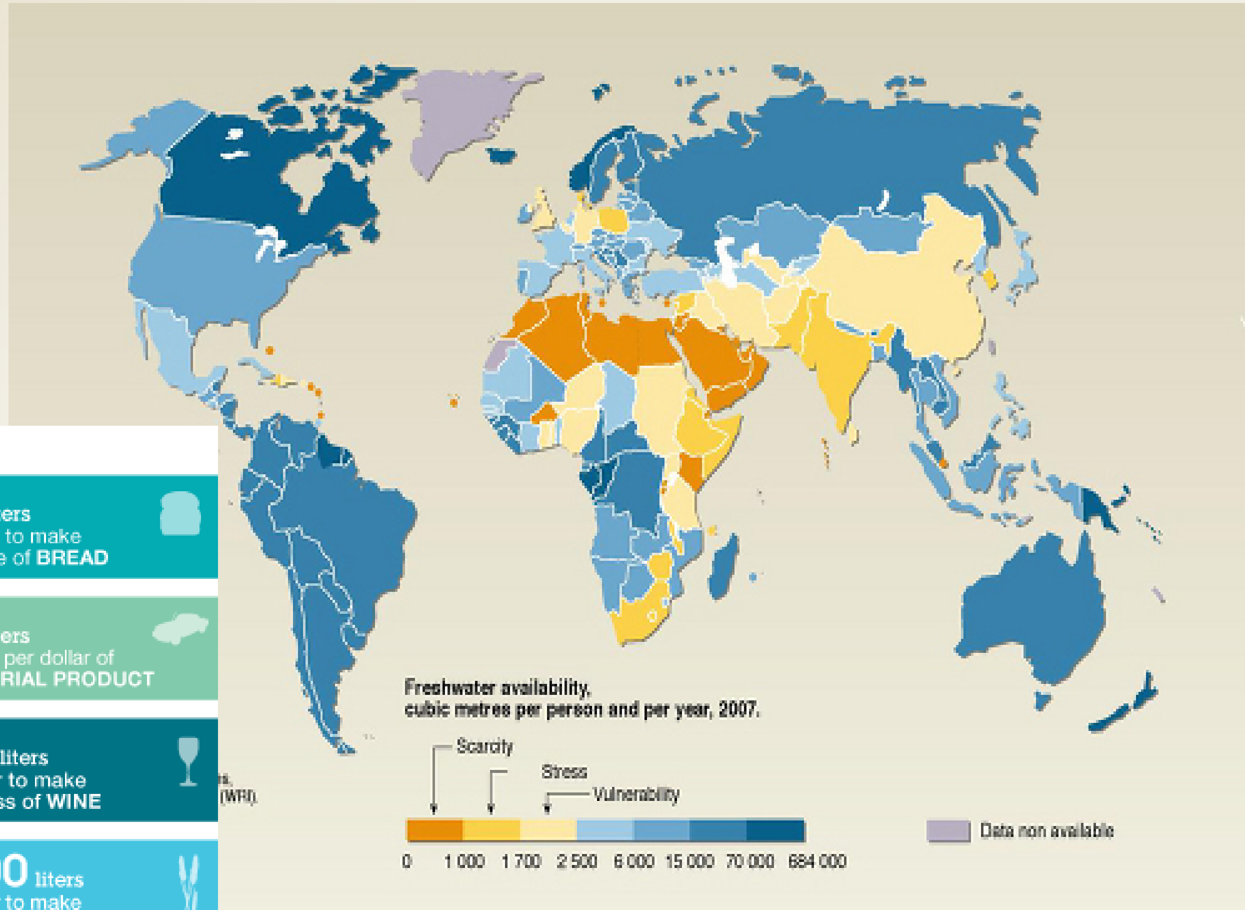
- 1 MM gallons for $1MM with 60 kW of electricity generation included - *$1/annual gallon*
- Published pyrolysis units are in the $4-5/annual gallon range at scales of 50 MM gallons - Cool Planet raised $100MM to be used "mainly for the construction of the first plant 10,000 Gallons
- The idea of scaling down a chemical plant to fit in a shipping container completely ignores economies of scale.
- Typical biomass pyrolysis and hydrogenation yield around 66% energy return on biomass with H_2 added externally

Photosynthesis



Not sure about the quotes in the presentation. Most reports don't give the large changes quoted.

World Challenge – Water



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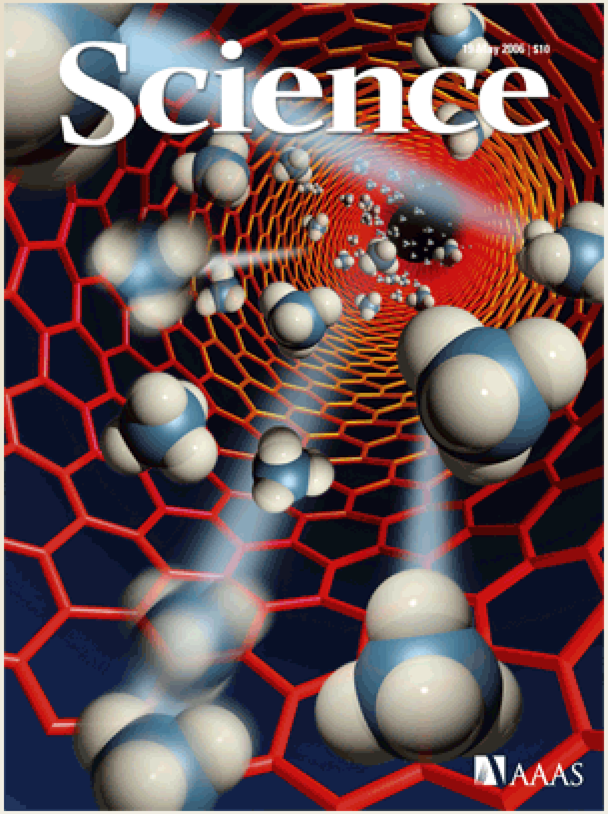
Nanotubes for Desalination



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.

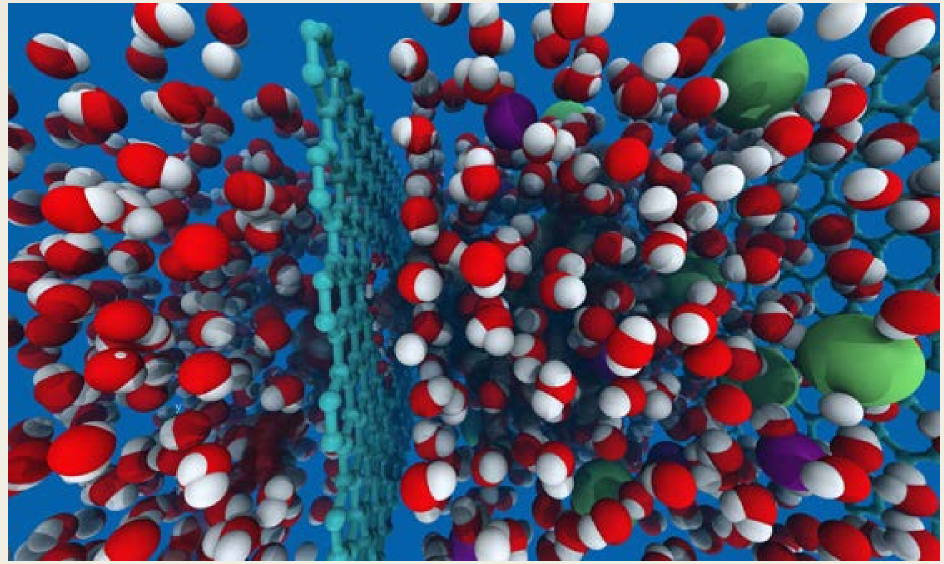
"NanOasis proposes to utilize carbon nanotubes (CNTs) to make industrially-scalable reverse osmosis (RO) membranes ….We target a ten-fold permeability increase compared to today's commercial state-of-the-art, resulting in a 30-50% energy savings…"

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 mu less energy to push the seawater through the filter with the force required to separate the salt from the wat 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."

Technology Evaluation- Desalination

What are key technical questions you would ask as CTO?

Dow Water and Process Solutions

World-Class Solutions. Worldwide Impact.

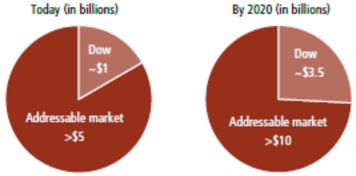
The global leader in sustainable separation and purification technology, **Dow Water and Process Solutions** is making a clear impact in every corner of the globe – from developing countries to the most advanced industrialized nations. Building on its 50-year legacy of providing innovative water and process solutions to consumers, communities, municipalities and industries alike, Dow Water and Process Solutions is spearheading the development of sustainable technologies that integrate water and energy requirements. Today, its technologies are helping to make water safer and more accessible, food taste better, pharmaceuticals more effective and industries more efficient. In addition to being one of the world's largest manufacturers of reverse osmosis water purification membranes, the business also is a leading provider of a broad portfolio of ion exchange resins, ultrafiltration membranes and electrodeionization products.

ELEMENTS OF MARKET SUCCESS

- #1 position in reverse osmosis and ion exchange resin technologies
- Only manufacturer to offer a complete portfolio of advanced water treatment technologies
- Advances in technology have significantly reduced the cost of water by lowering our customers' energy consumption by as much as 50 percent over the past 15 years
- Expanded manufacturing and R&D footprint increases service levels to regional customers, strengthening global competitiveness
- Positioned to address rapidly rising demand for safer water, energy and food supplies due to an increasing global population and urbanization

MARKET GROWTH OPPORTUNITIES

- By 2015, 5 billion people will live in areas of significant water stress. Dow Water & Process Solutions' addressable market is projected to double by 2020.



RECENT STRATEGIC ACHIEVEMENTS

- July 2011: Announced construction of a new reverse osmosis manufacturing facility in Saudi Arabia to enable the production of drinking water from seawater
- June 2011: Opened a Desalination Technology Development Center in Tarragona, Spain
- 2009–2011: Expanded R&D capabilities in India and Brazil and announced collaboration with the King Abdullah University of Science and Technology on water treatment technologies at the Dow R&D Center in Saudi Arabia

KEY INSTALLATIONS FOR DOW MEMBRANES

- Soreq, Israel – Membranes used in the world's largest desalination plant, currently under construction
- Ashkelon, Israel – Provide up to 15 percent of Israel's clean water
- Perth, Australia – Largest desalination facility in the Southern Hemisphere, treat 144,000 m³ of seawater per day
- Florida, United States – Produce 25 million gallons of safe water per day at largest desalination plant in the United States
- Shoaiba, Saudi Arabia – One of Saudi Arabia's largest reverse osmosis seawater desalination plants

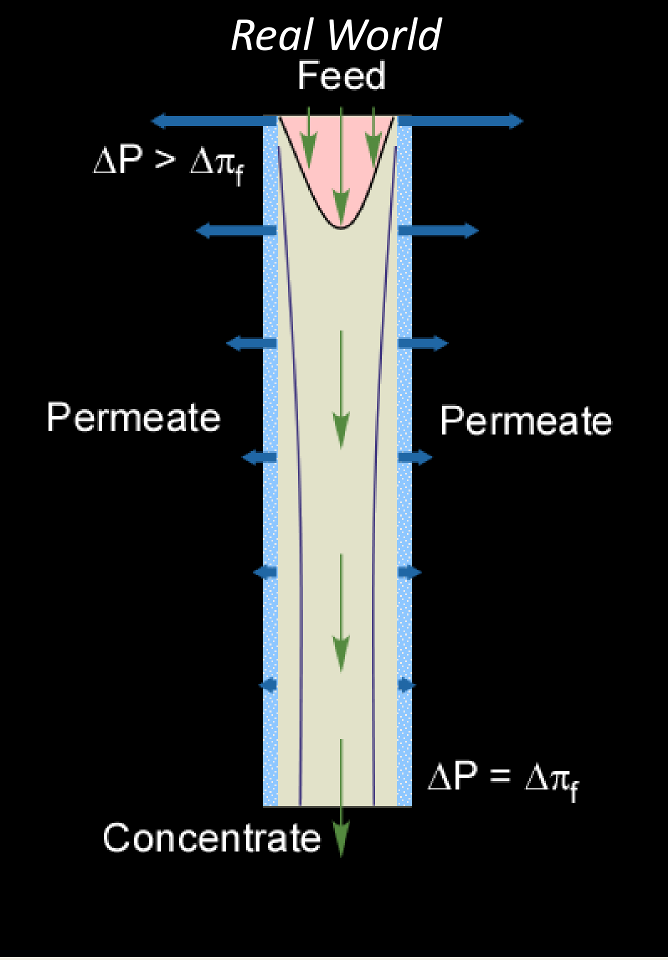
The Dow Chemical Company

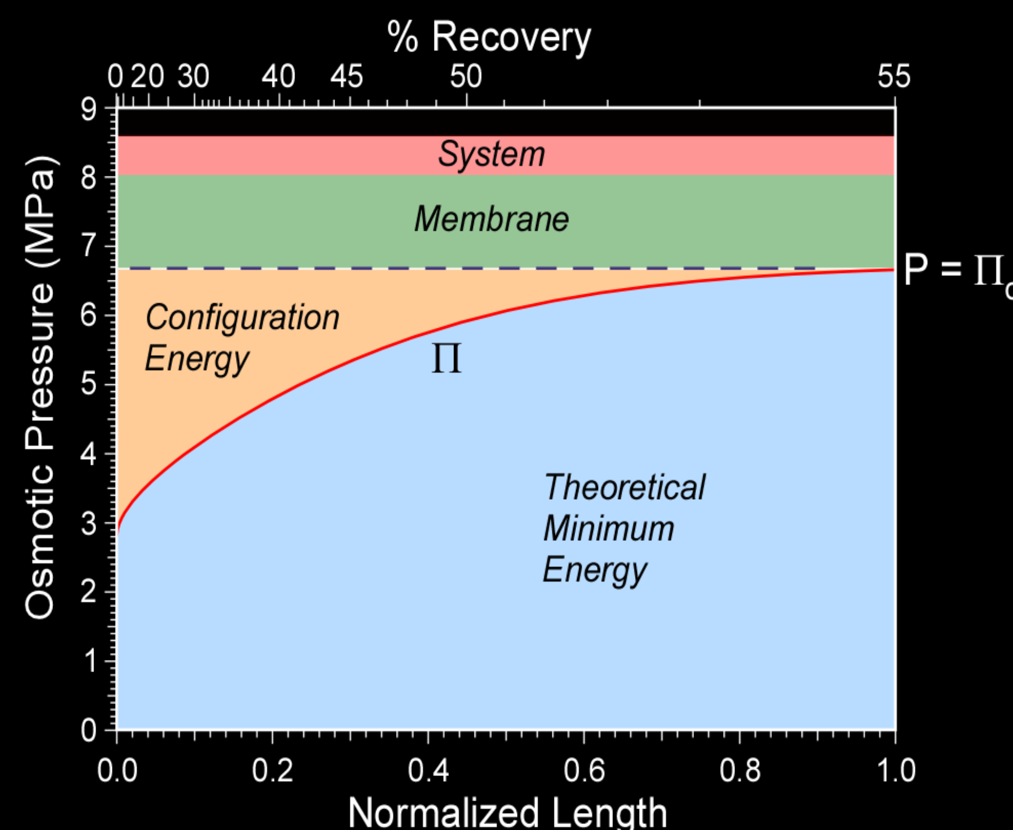
Thermodynamics

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

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

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





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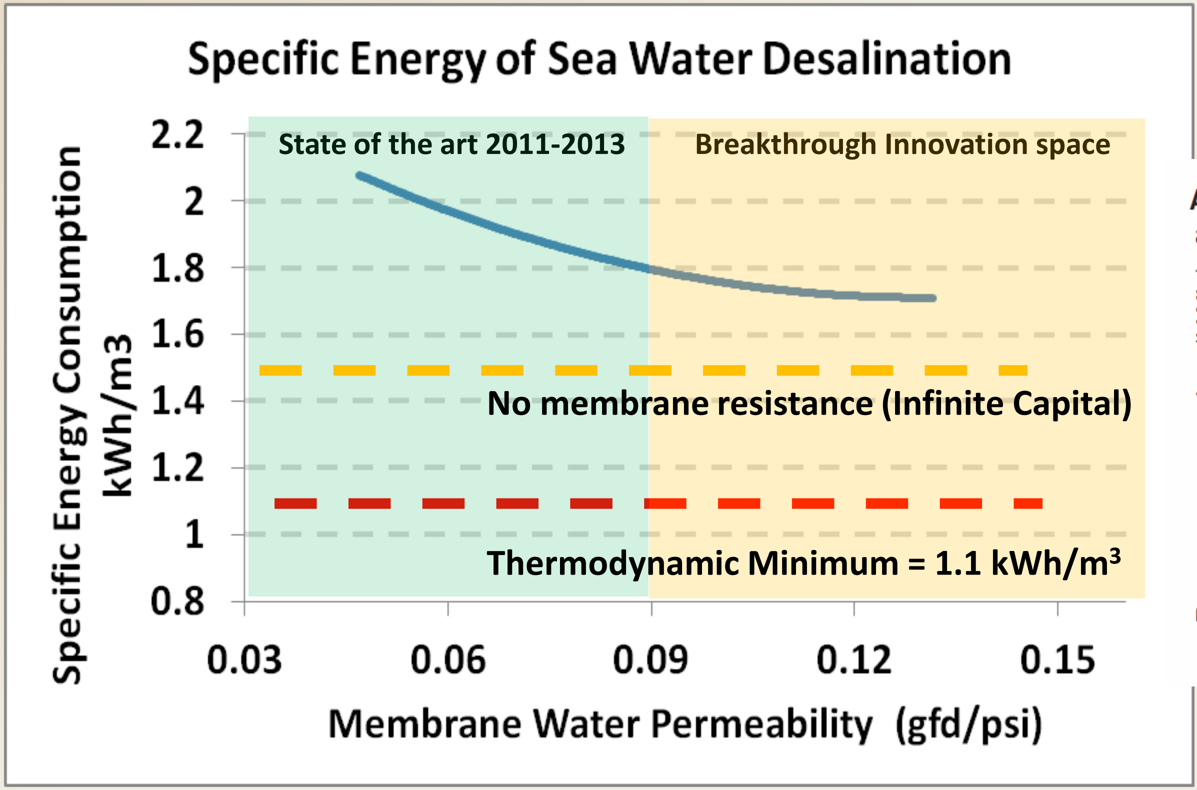
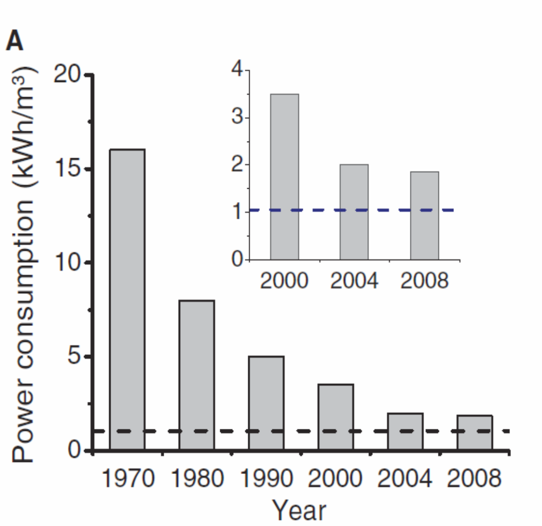
Membrane Improvements





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

Environment

- **Cola Wars Revisited: Coke and Pepsi Duel Over Bottles Made from Plants**
- By: Nick Carbone (9 days ago)

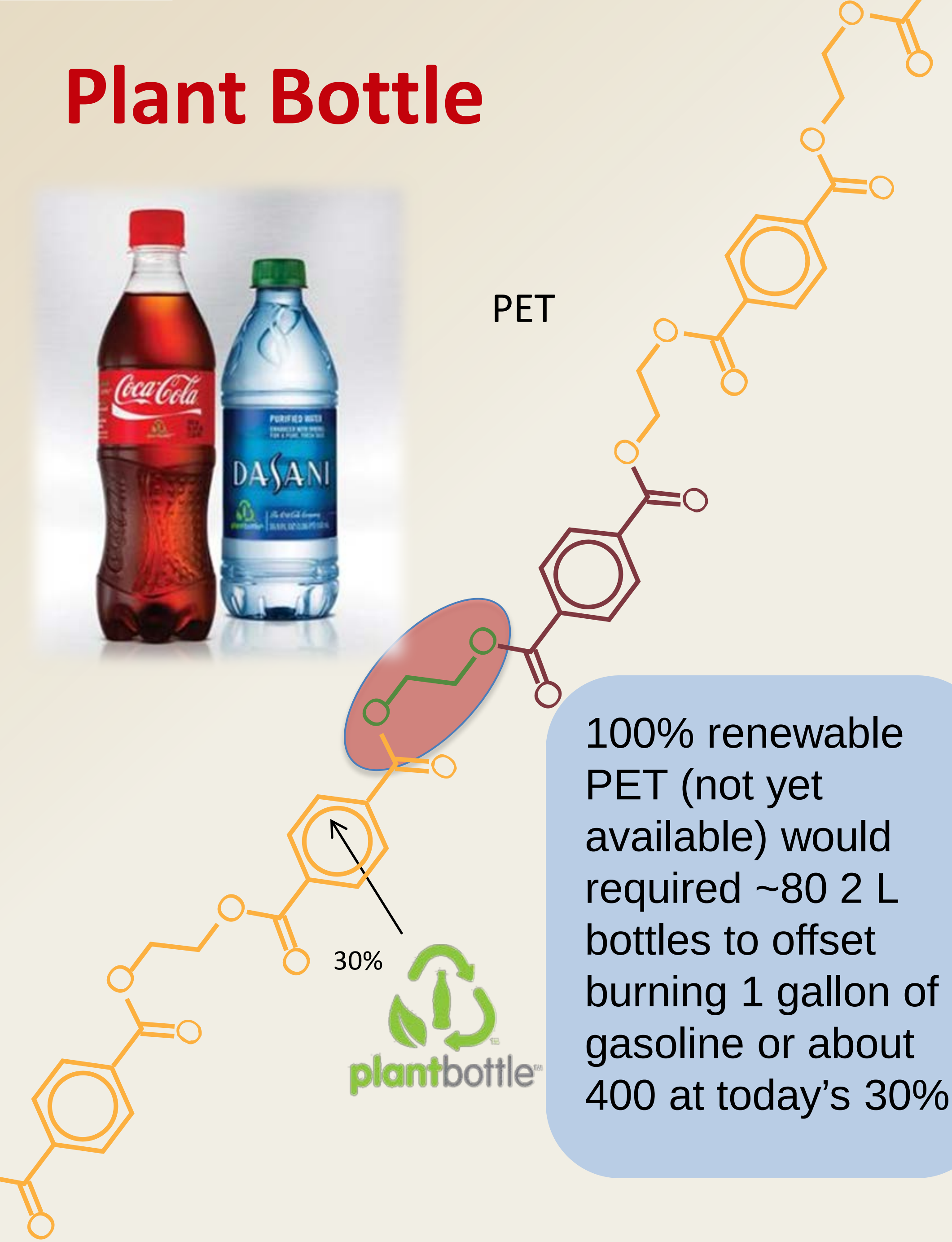
- **Topics: battle, Bottle, coke, ecofriendly, Environment, Pepsi, pet, plastic**
-

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*

Plant Bottle

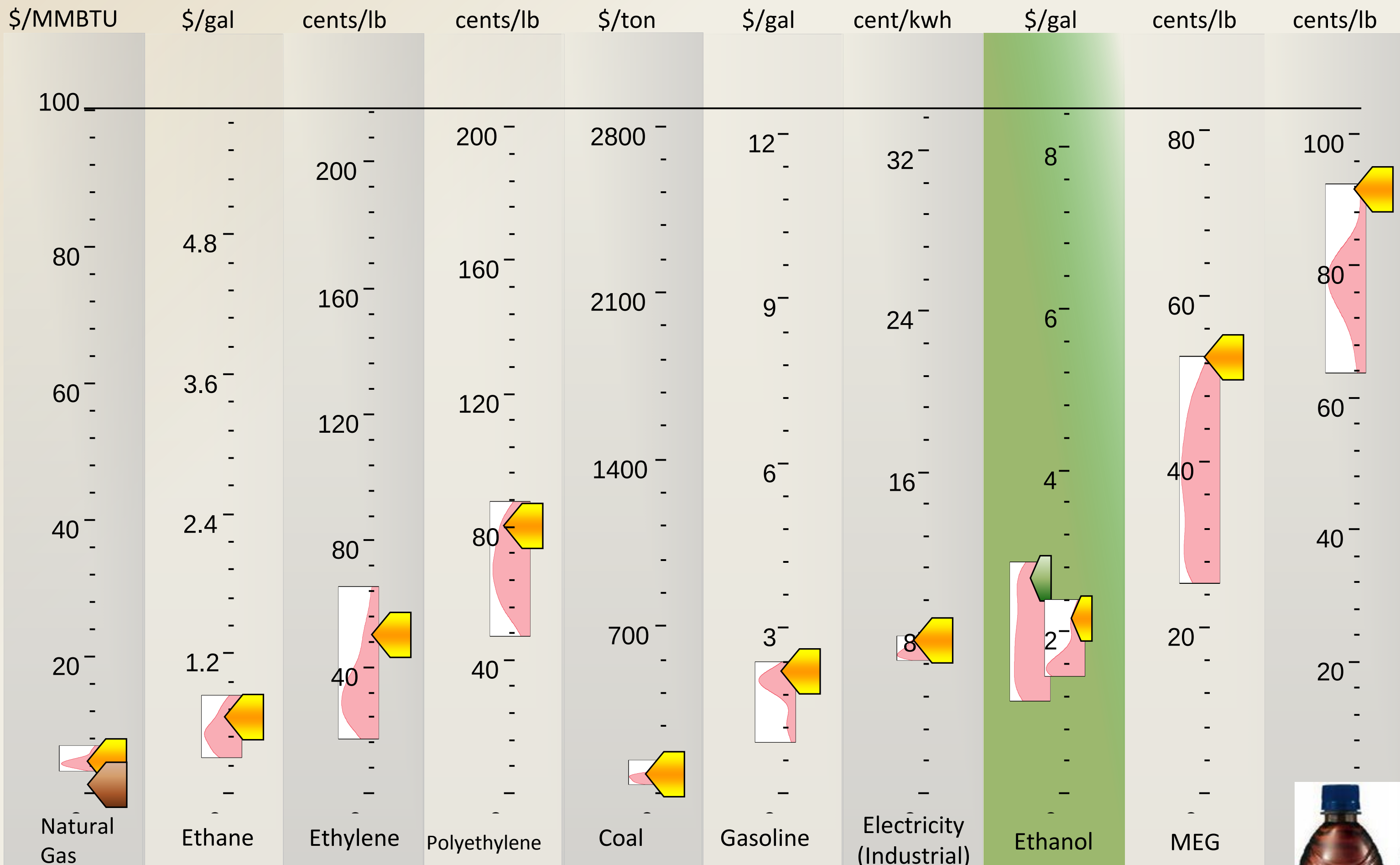


100% renewable PET (not yet available) would required ~80 2 L bottles to offset burning 1 gallon of gasoline or about 400 at today's 30%

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

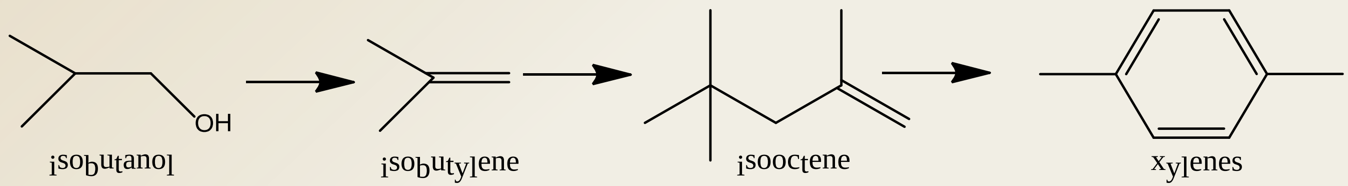
Managing “Green” Fads – Green PET

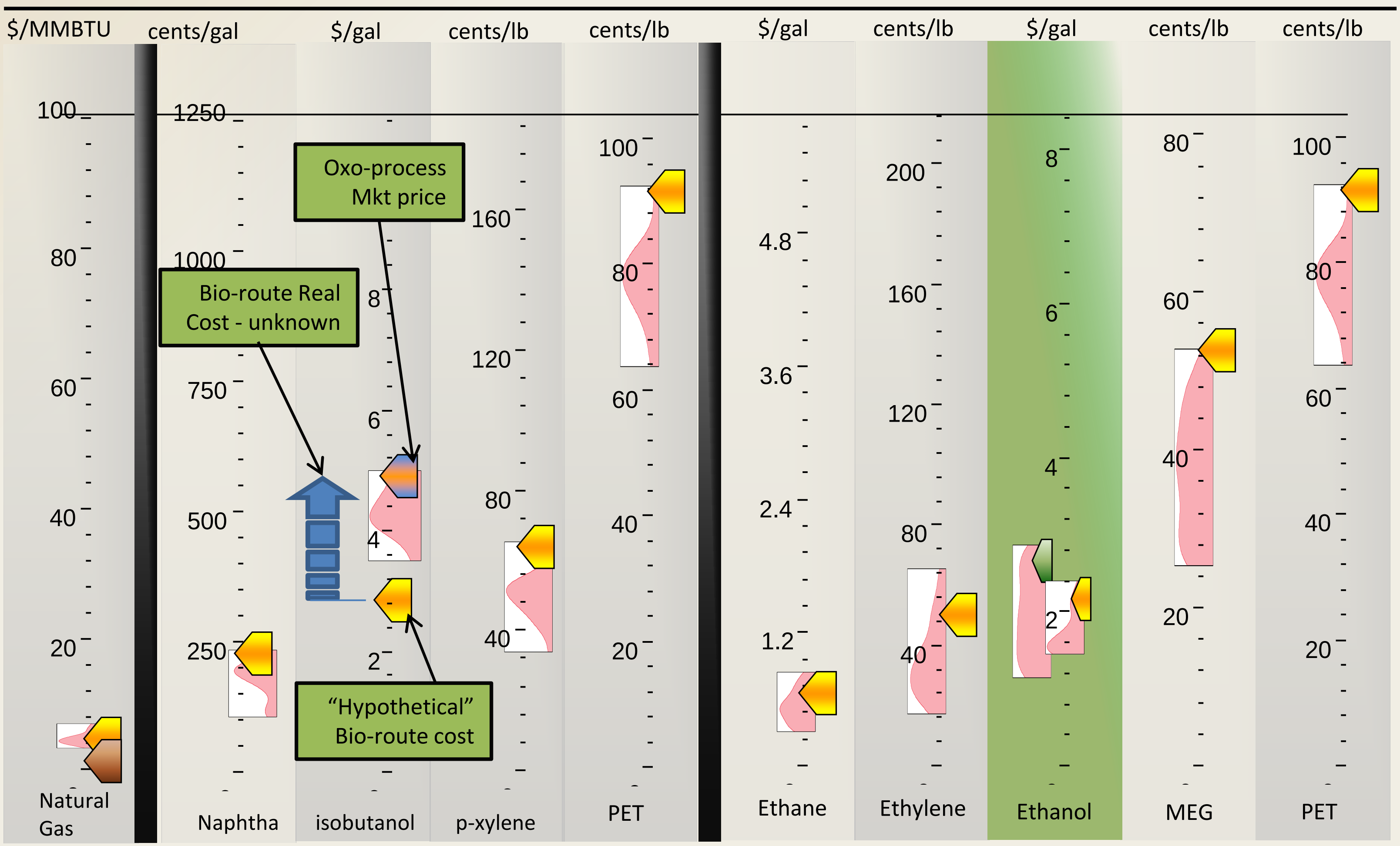


USA Brazil Middle East

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

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

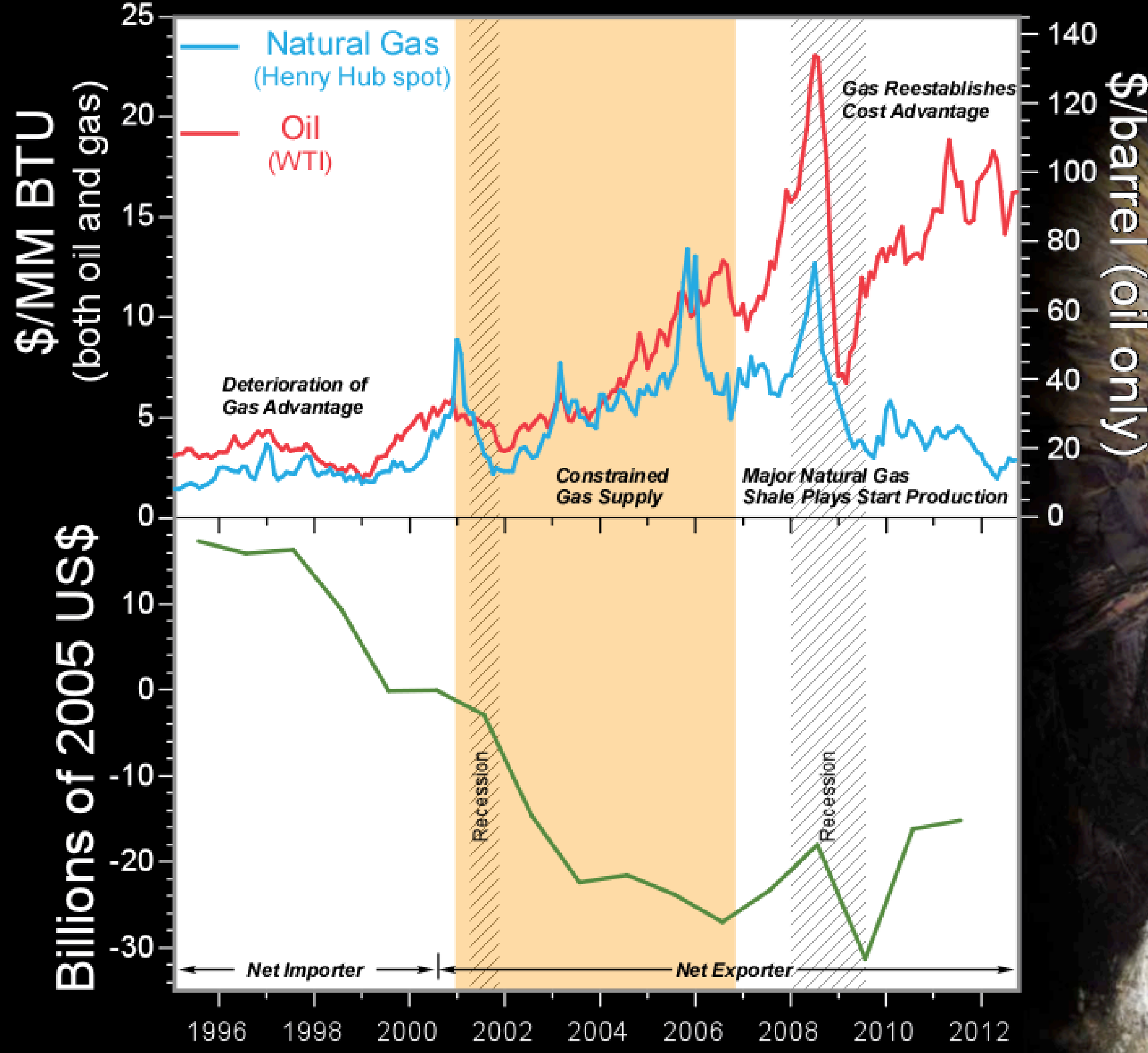
Green Design and LCA Rankings Don't Match Up

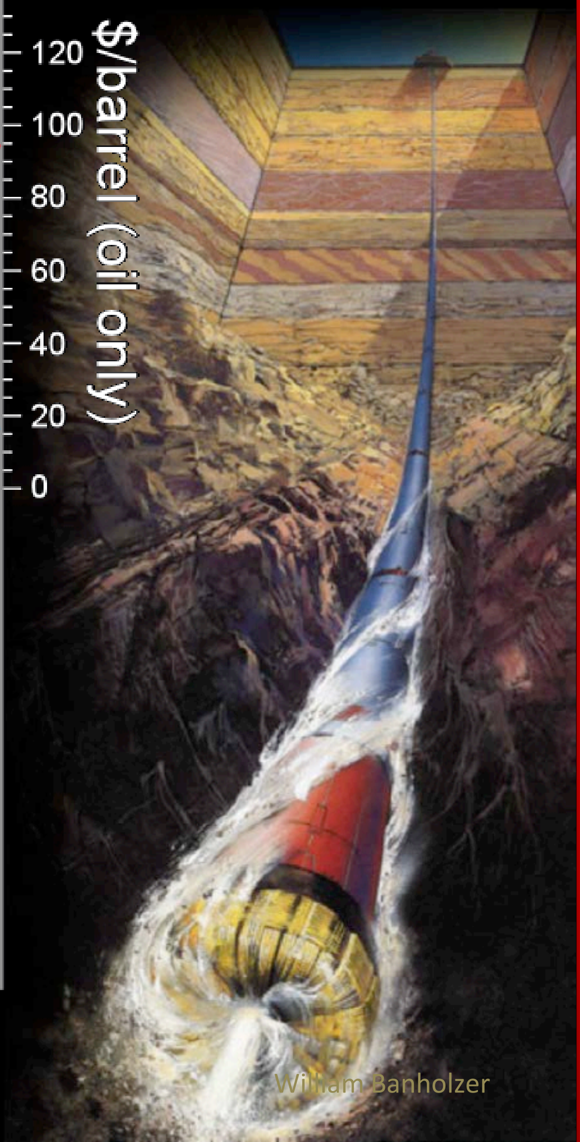
Biopolymers rank in the middle of LCA rankings

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

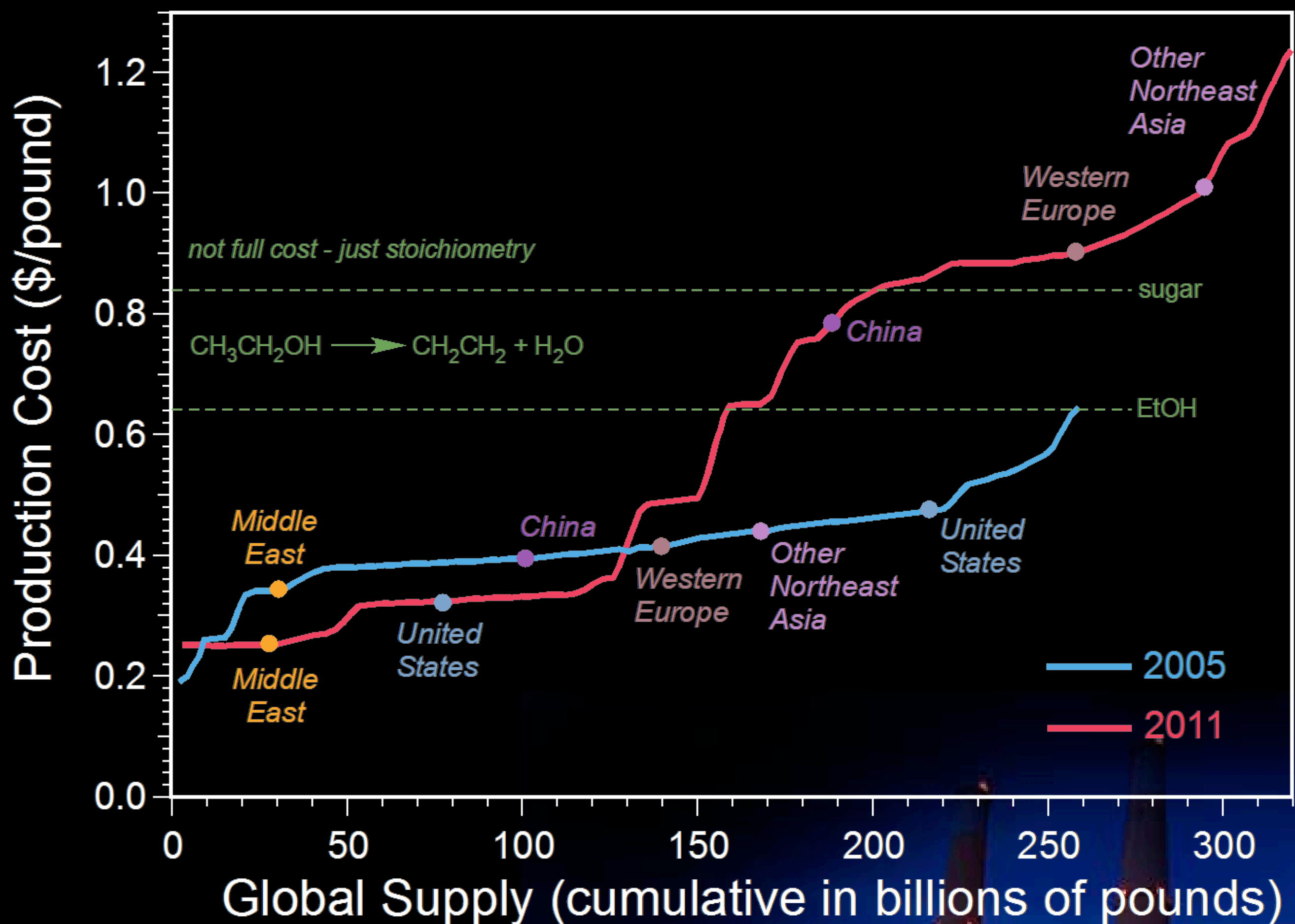
Tabone, MD; Cregg, JJ; Beckman, EJ; Landis, AE. Environ. Sci. Technol. 2010, *44*, 8264-9.

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.

William Banholzer

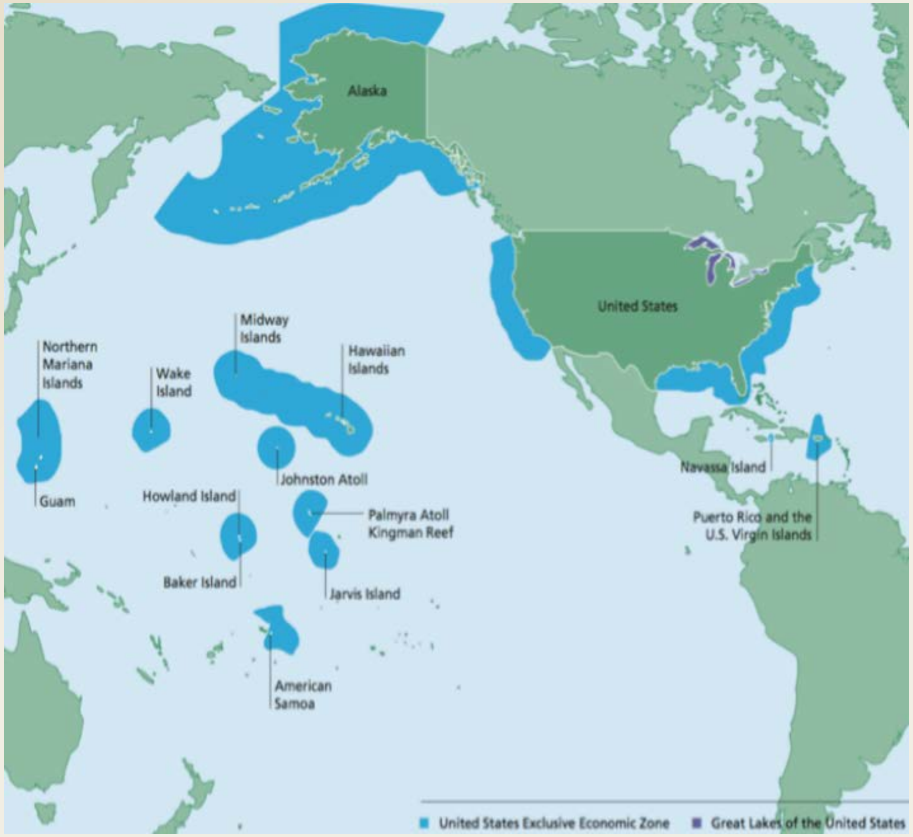
Thank You

Ponder what is possible but work on what is *practical*

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

Proposed Advantages



alginate only about a third of sugars present

U.S. owns more ocean area than any other country

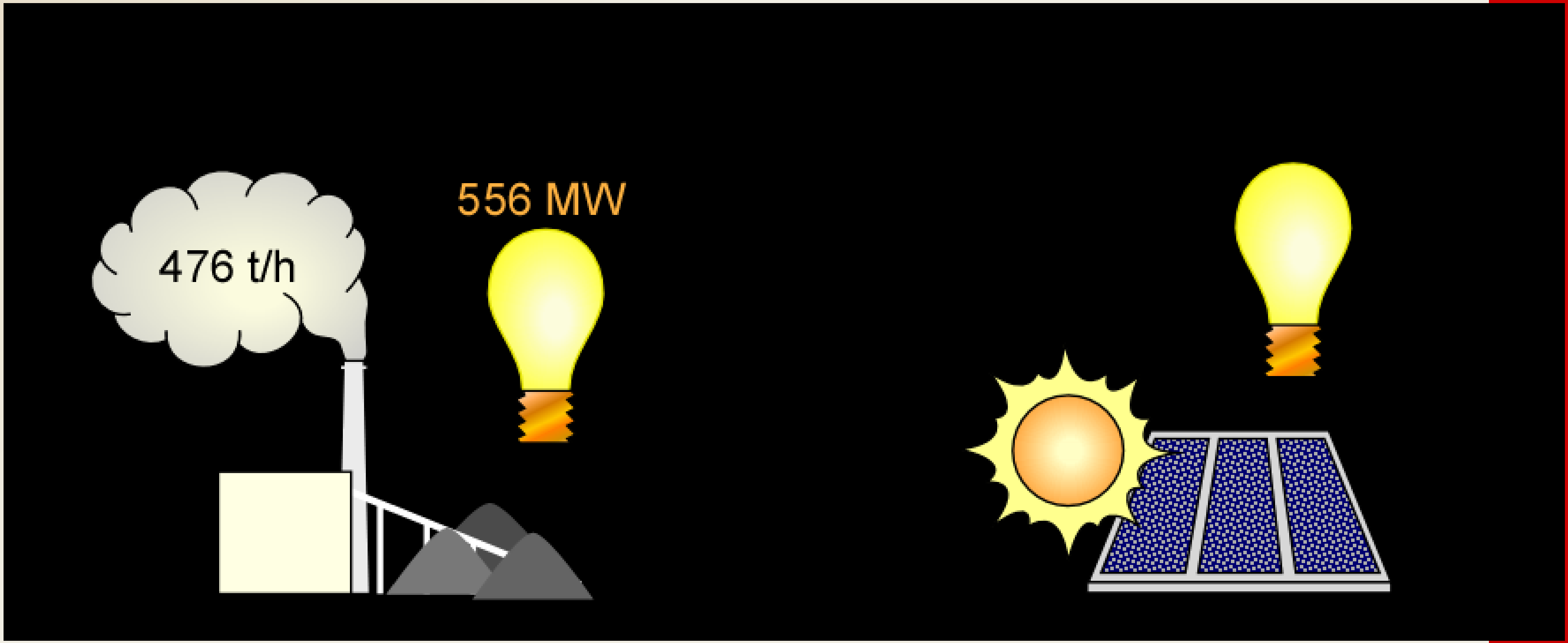
"no land, (no) fresh water or (no) fertilizer"

Erik Stokstad, Science, 20 January 2012, page 273

Problem not solved

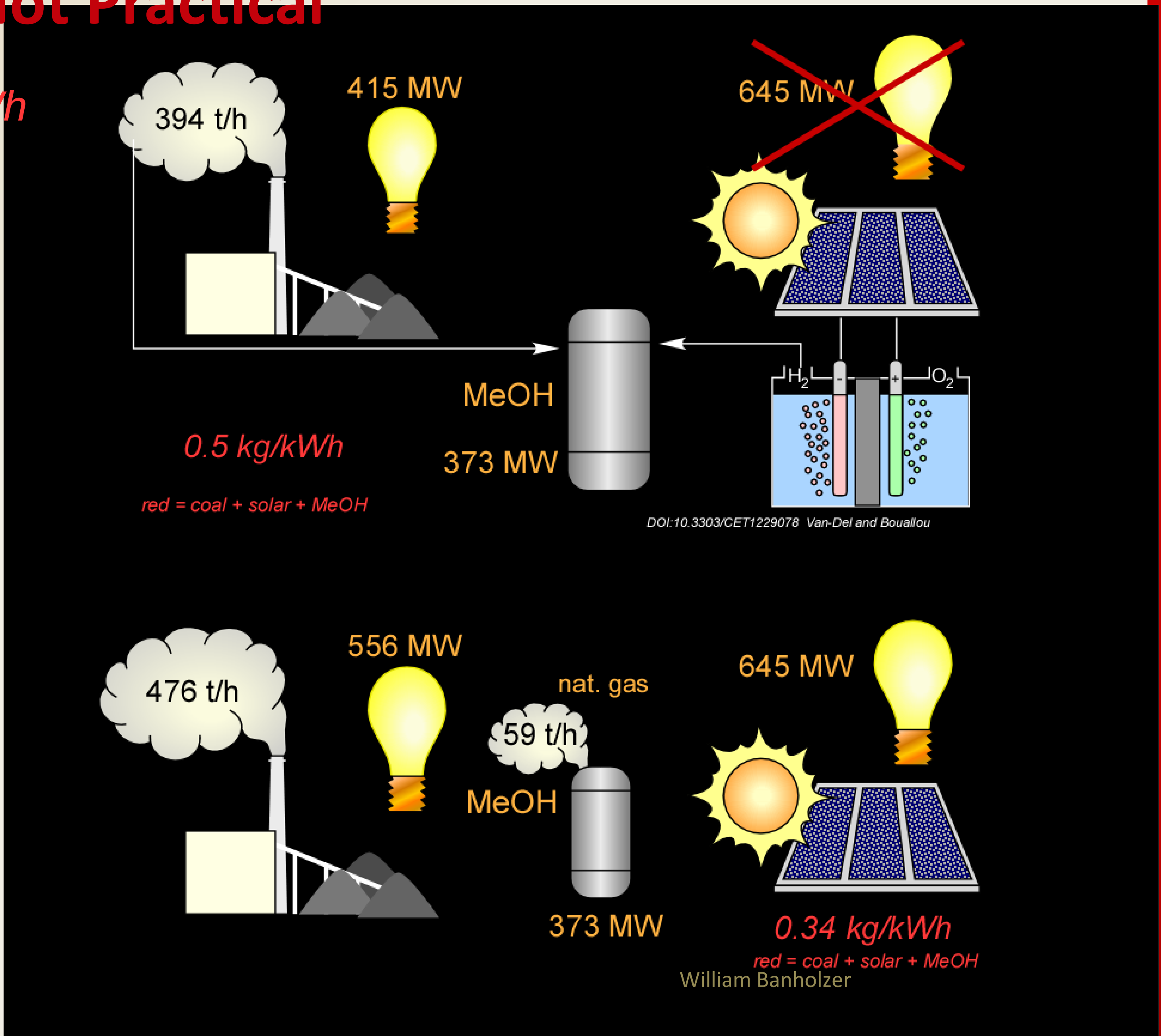
- Harvested for over 400 years
- Cost for wet biomass are >$400/ton at water levels >70% *more expensive than corn!*
- Redfield ratio still required
- *Arable ocean* (analogy to arable land) needed

CO_2 Utilization



Just Not Practical

0.4 kg/kWh



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Possible, Not Economical

image from carbonengineering.com, 14 Jan 2013.

Skyonic

CALERA
Green Cement for a Blue Planet

Carbon Engineering seeks to scrub atmospheric CO_2 by using alkaline solutions that are dried and thermally regenerated.

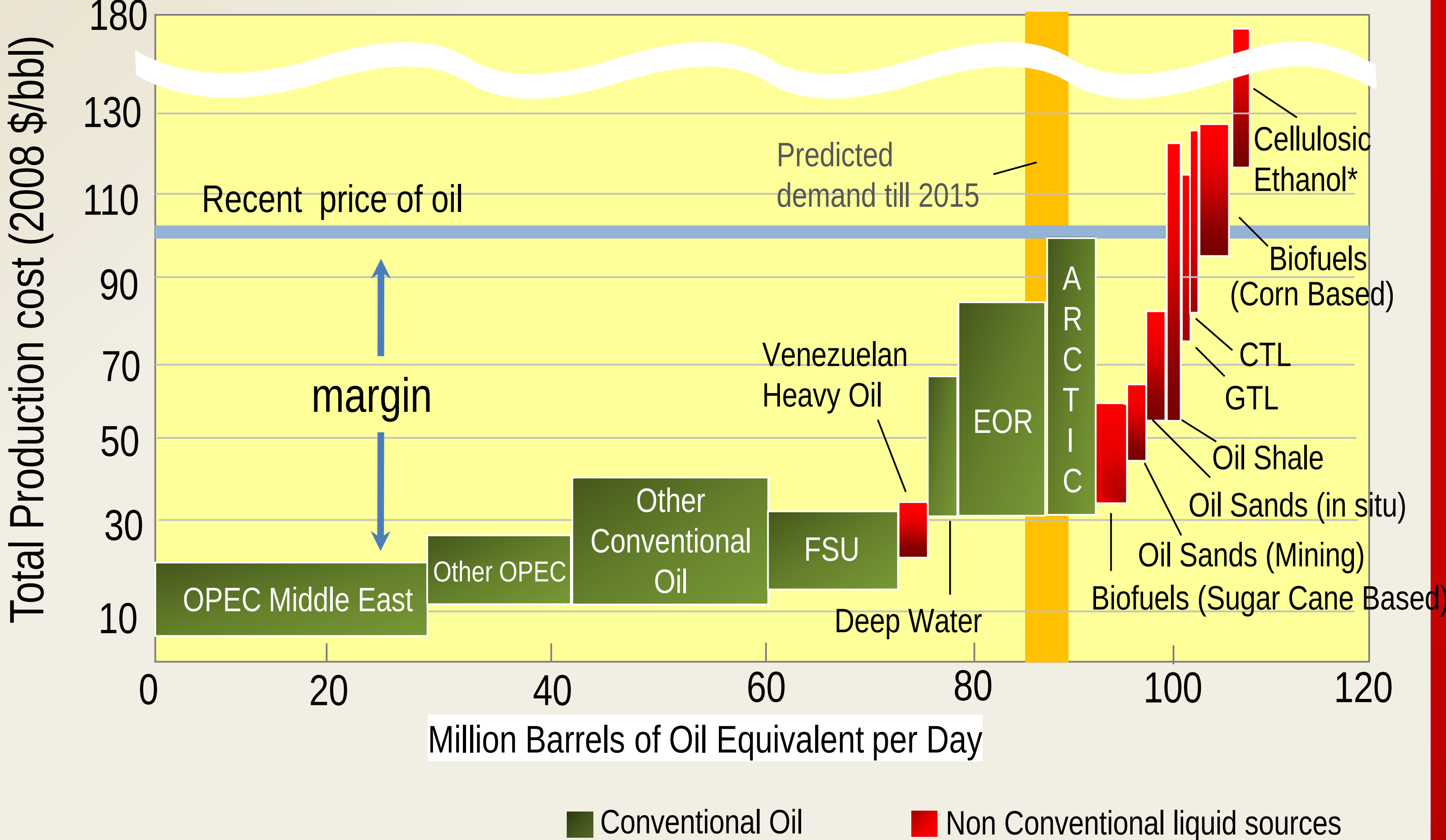
$$2\,NaOH_{(aq)} + CO_{2(aq)} \rightarrow Na_2CO_{3(aq)} + H_2O_{(l)}$$

$$Na_2CO_{3(aq)} \xrightarrow{heat} 2\,NaO + CO_2$$

$$2\,NaO + H_2O_{(l)} \rightarrow 2\,NaOH_{(aq)}$$

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

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

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The Fundamentals are…FUNDAMENTAL

<u>You can NEVER lose sight of these considerations:</u>

- Thermodynamics → In Your Favor
- Kinetics → Fast
- Catalysis → Controlled
- Separations/Transport → Easy/Lower Energy
- Unit Operations → Lower Capital

There isn't a useful process in the world that is exempt from these fundamentals

William Banholzer

Hype Around Cleantech

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

September 28, 2012 cleantechnica.com

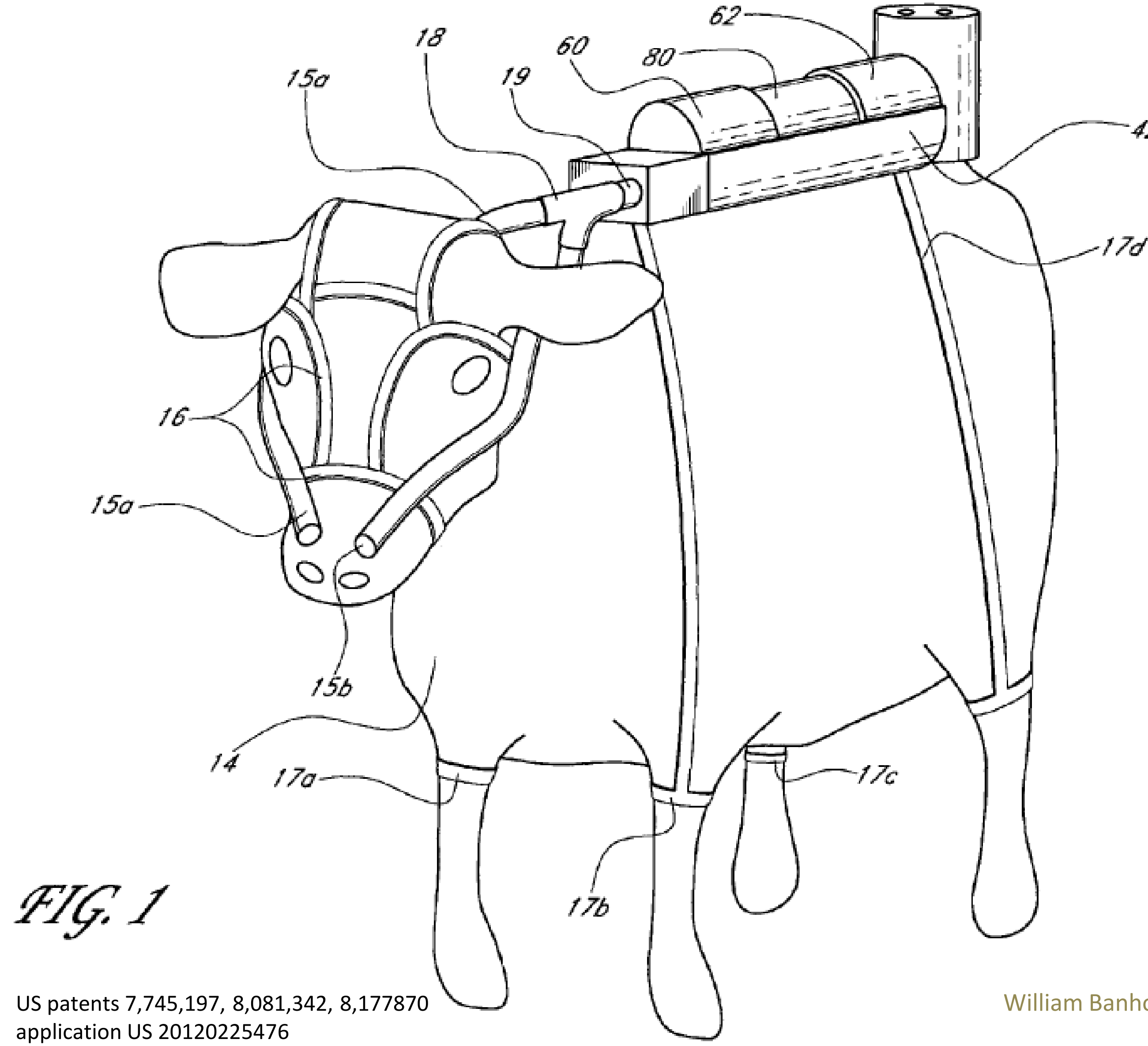
Two graduates from Princeton University and Northwestern University have developed a process for converting greenhouse gases from sewage treatment plants, landfills, and power plants into a biodegradable plastic called Airflex™

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



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

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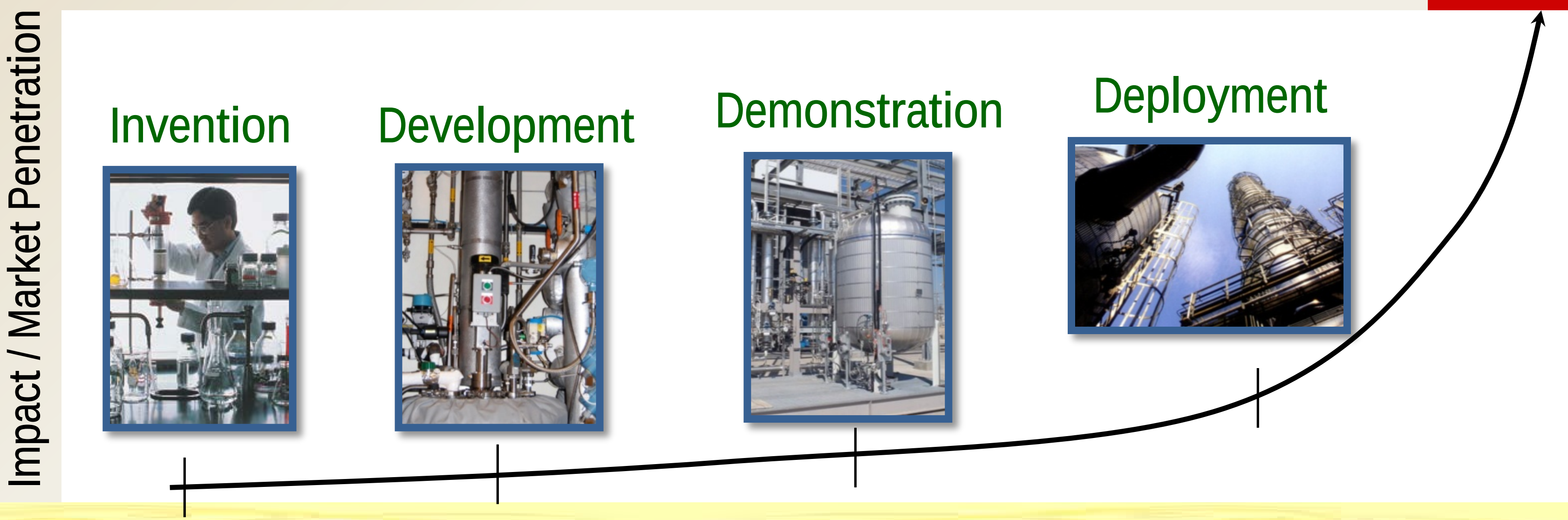
Timeline for Impact

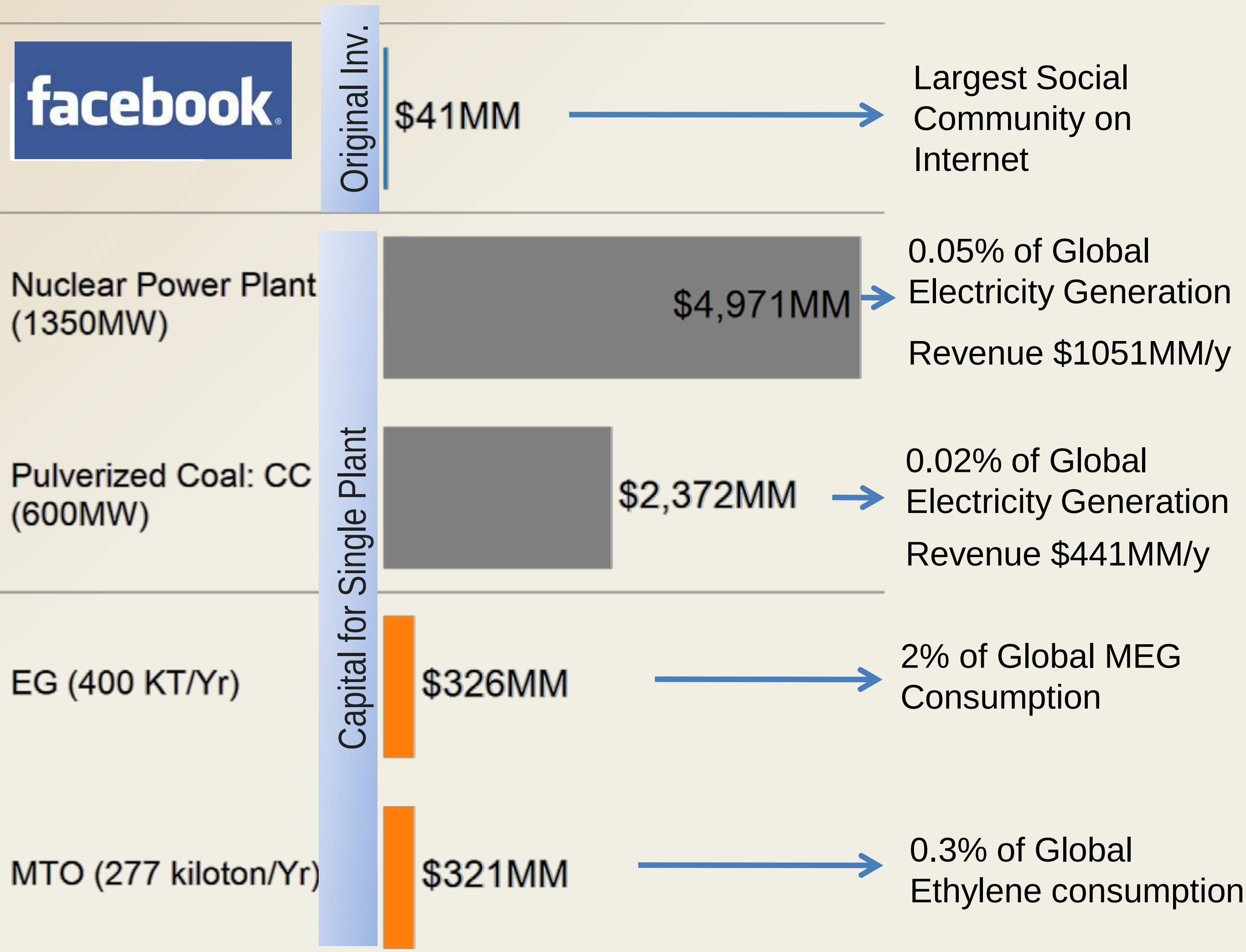


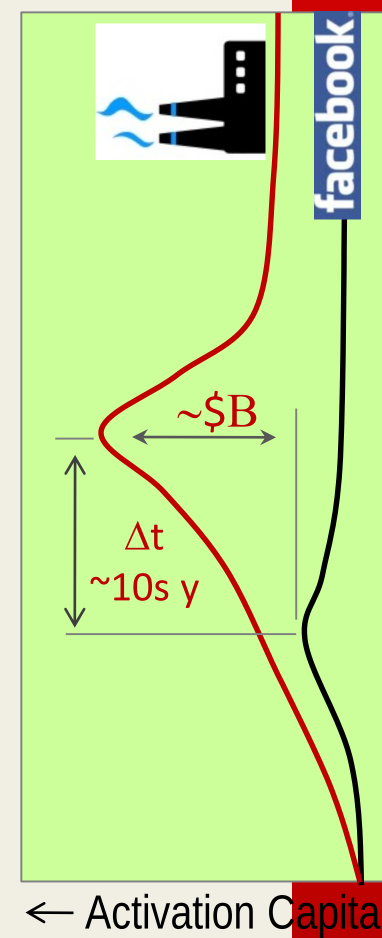
		Invention	Development	Demonstration	Deployment	
Single Site Catalysis	$		~$10s MM	~$50 MM	~$150 MM*	
	t	1957, 80	1980-90	1989	1991	Σ ~12 yrs
Super Critical Coal Power	$		~$100s MM	~$500+ MM	~$2 B**	
	t	1920	1930 -50s	1957	1970s	Σ ~50 yrs

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

*400 mT LLDPE plant, 2008$ **600 MW plant, 2009$

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

Bio 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, 15, or 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

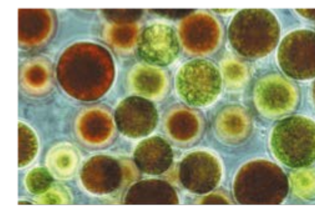
"…the need for trucks, machinery and manpower would come during harvest, already the busiest time of the year on the farm. And that's where a massive federal initiative into cellulosic ethanol may find its biggest bottleneck – on the farm."

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; we exited the JV in 2004.

NatureWorks

Dow Cargill

THE WALL STREET JOURNAL.

"Sun Chips Bag to Lose Its Crunch"

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

Photo: Associated Press

Glycerin to Epi

Dow postponed in 2009 due to uncertain supply.

Dow

Natural Oil Polyols

RENUVA™

Dow launched in 2007, exited in 2010.

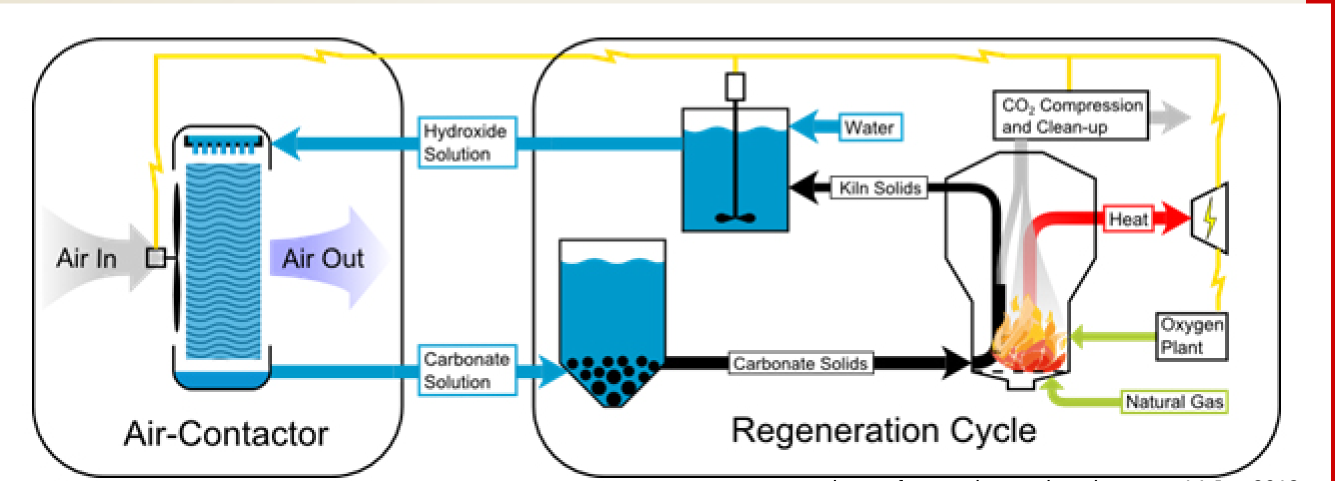
Dow

ADM-Metabolix

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

Metabolix

Possible, Not Economical



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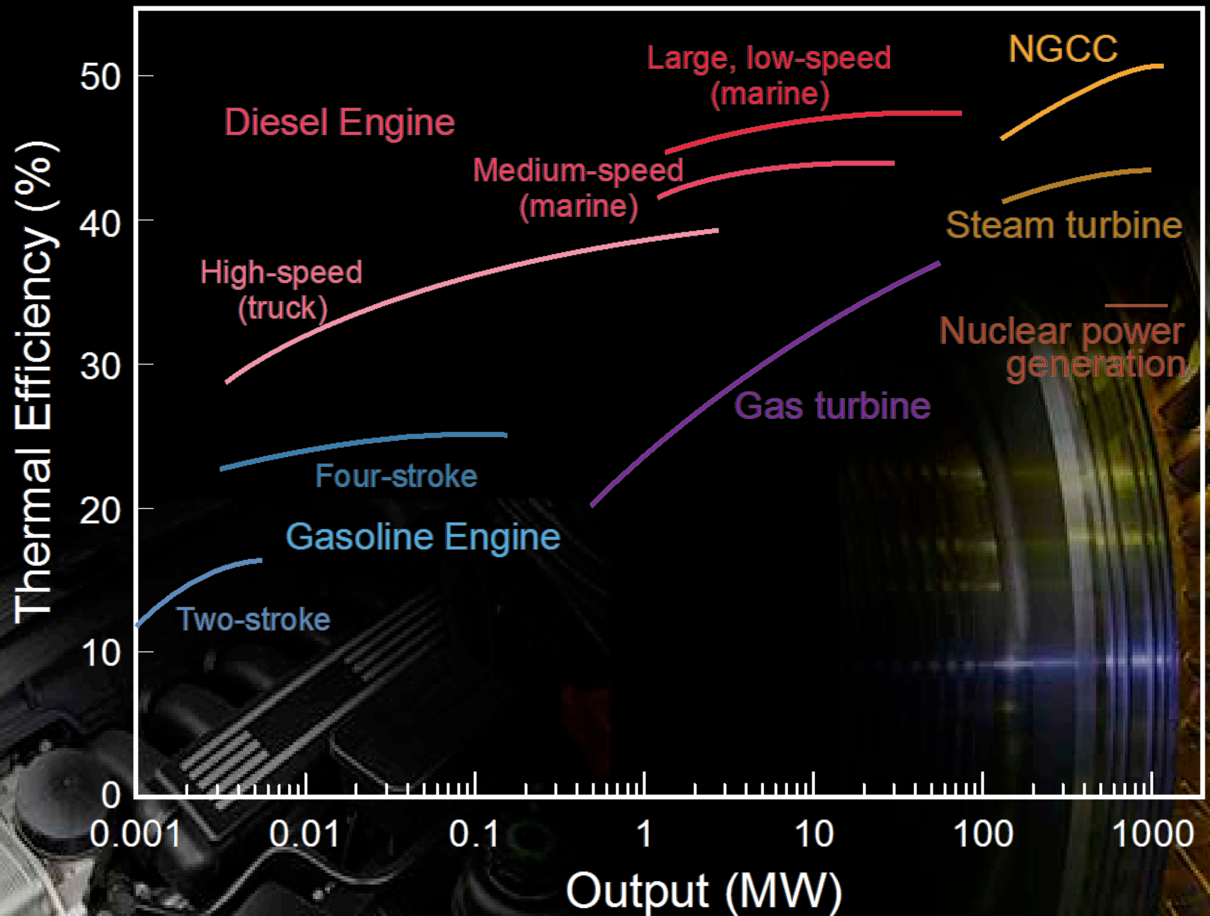
$$Na_2CO_{3(aq)} \xrightarrow{heat} 2\ NaO + CO_2$$

$$2\ NaO + H_2O_{(l)} \longrightarrow 2\ NaOH_{(aq)}$$

Problem: fuel use makes >50% of the CO_2 the system can scrub

Problem: CO_2 has no value (this is an added COST)

Scale Improves Efficiency



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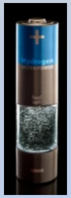
Recognizing Fads

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

Hydrogen Car



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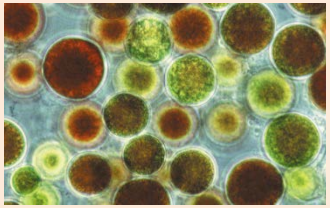

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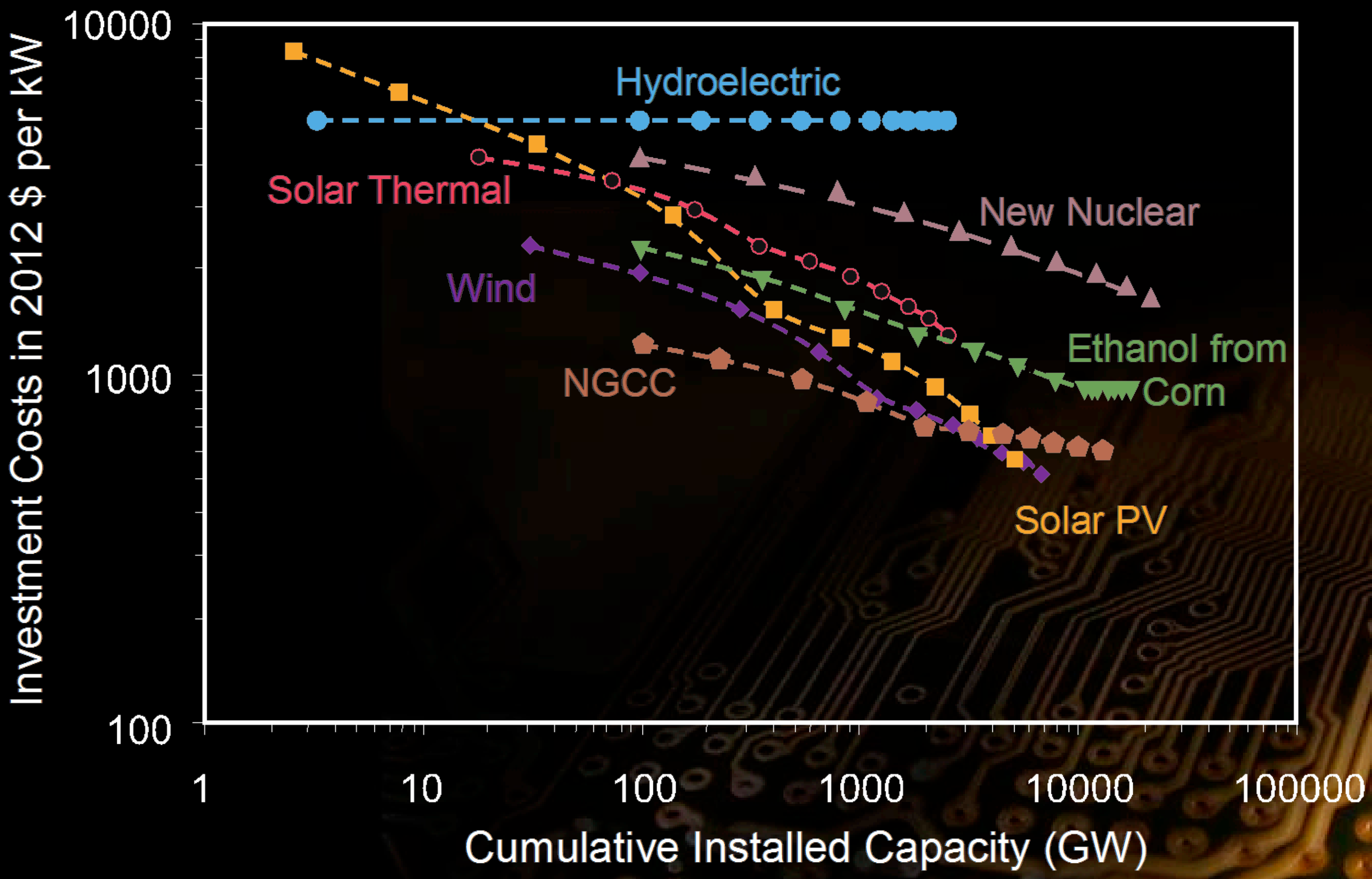
Experience Curves



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

William Banholzer

Energy Happens at Large Scale