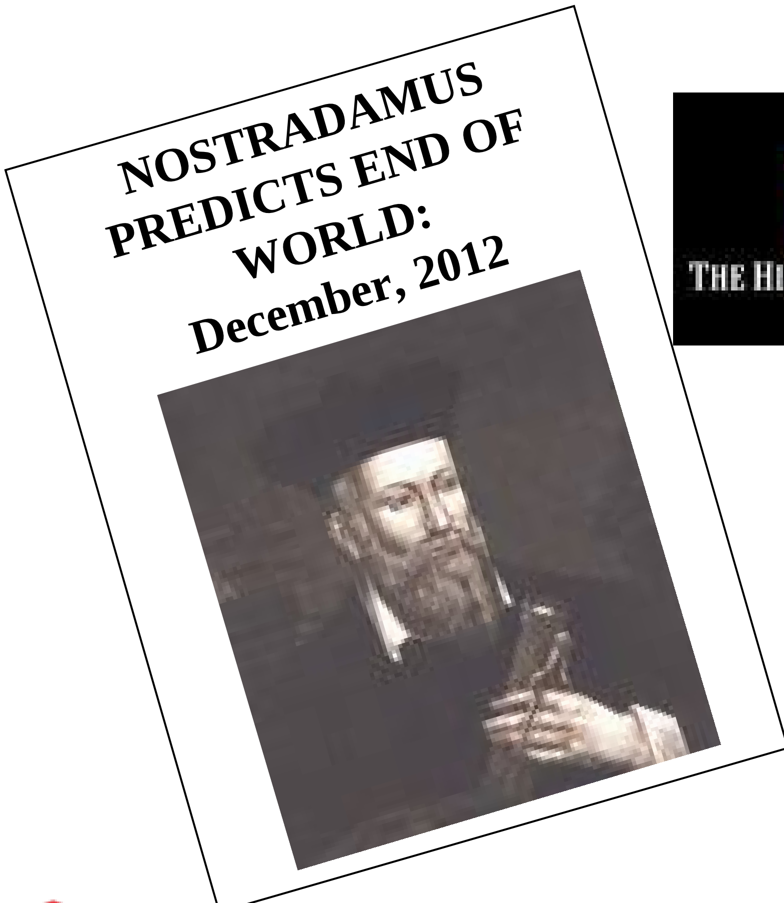
How Chemical Engineers Will Save the World

William F. Banholzer, PhD
Executive Vice President & Chief Technology Officer
The Dow Chemical Company

United Nations Declares 2011 "International Year of Chemistry"

…AND JUST IN TIME!



THE HISTORY CHANNEL

Response to Challenges

"In order to save the world, I choose to live green."

OR

"In order to save the world, I choose to work on solutions."

Chemical Engineers Have Saved the World Before

World War II

- **Synthetic fuel**
  - –Catalytic cracking
- **Synthetic rubber**
  - –Polymerization chemistry
- **Synthetic insulation**
  - –Polystyrene

Chemical engineers operate at the nexus between necessity and invention

Keith J. Watson, PhD

Chemical Engineers Feed the World

Nitrogen Fertilizers

- **Most plants do not engage in nitrogen fixation**
- **Thus, nitrogen has to be added to the soil**
- **Chemical engineers make nitrogen for soil**

Haber Process

- **Methane as a feedstock to make synthesis gas**
- **Mechanism:**

$$N_2(g) \longrightarrow N_2(\text{adsorbed})$$
$$\mathbf{N_2(\text{adsorbed}) \longrightarrow 2N(\text{adsorbed})}$$
$$H_2(g) \longrightarrow H_2(\text{adsorbed})$$
$$H_2(\text{adsorbed}) \longrightarrow 2H(\text{adsorbed})$$
$$N(\text{adsorbed}) + 3H(\text{adsorbed}) \longrightarrow NH_3(\text{adsorbed})$$
$$NH_3(\text{adsorbed}) \longrightarrow NH_3(g)$$

Today's World Challenges

Energy

Production | Transmission | Use

Water

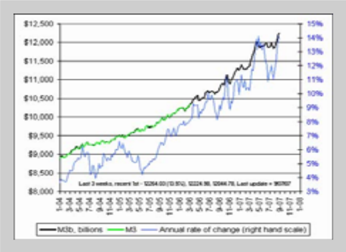
Availability | Distribution | Purity

Food

Land | Productivity | Quality

Sustainable Prosperity

Cost of Goods | Environmental Impact



The Fundamentals are just as Important Now

Never lose sight of these considerations:

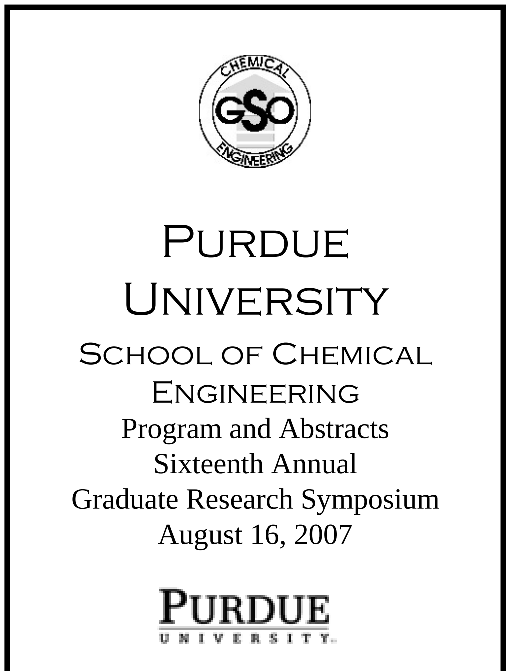
Thermodynamics	›	**In Your Favor**
Kinetics	›	**Fast**
Catalysis	›	**Controlled**
Separations/Transport	›	**Easy/Lower Energy**
Unit Operations	›	**Lower Capital**

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

Proper Balance of Fads and Fundamentals?

"The energy business is ruthlessly policed by the immutable laws of thermodynamics. And those laws have snuffed out many promising ideas."

- Robert Bryce, author of Gusher of Lies


PURDUE UNIVERSITY

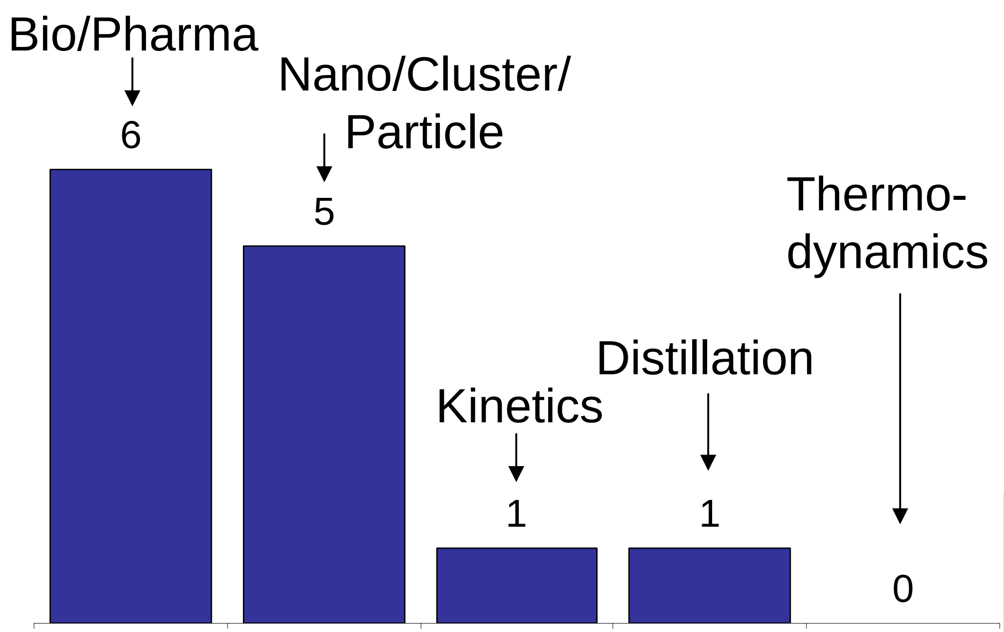
SCHOOL OF CHEMICAL ENGINEERING

Program and Abstracts

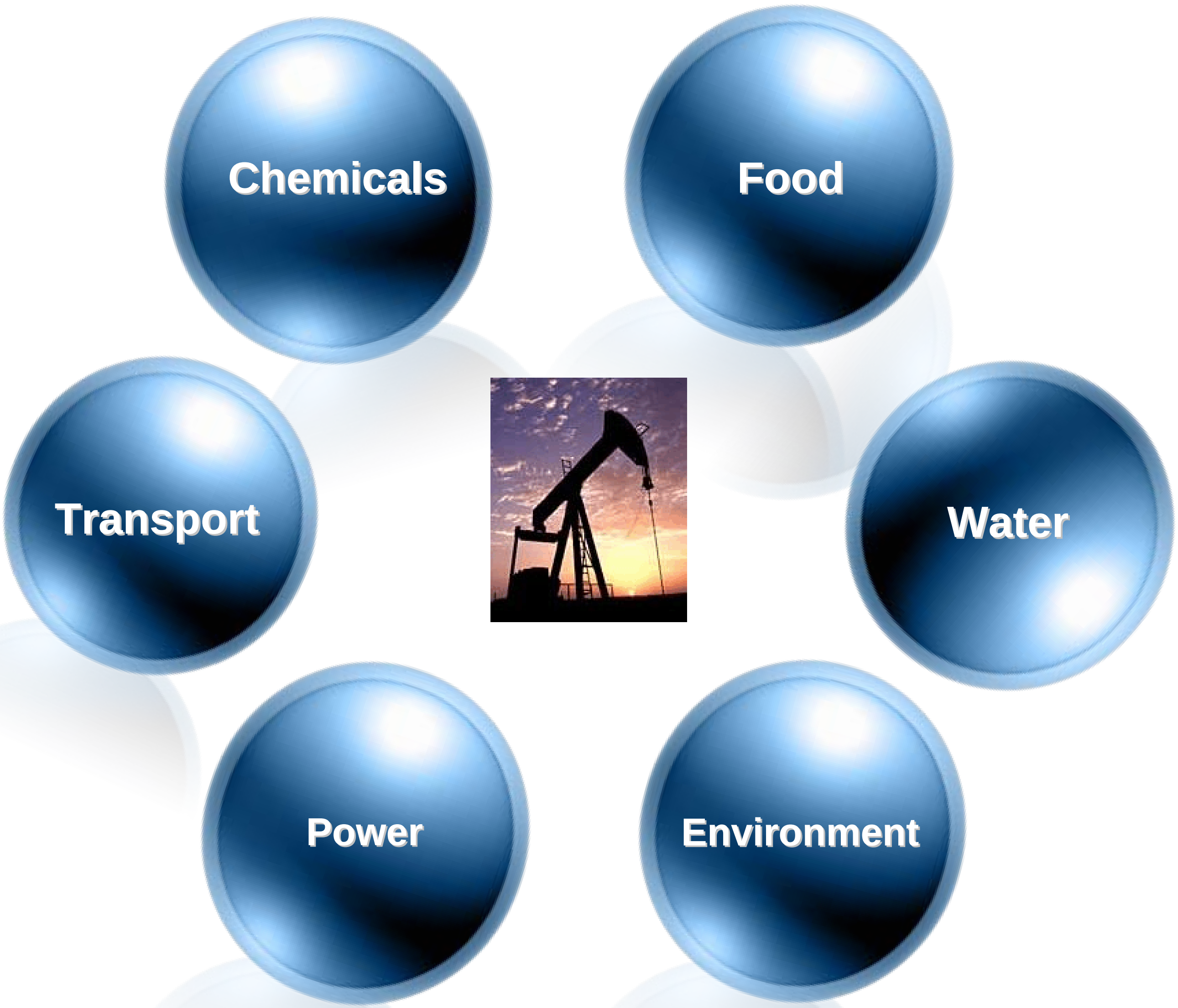
Sixteenth Annual

Graduate Research Symposium

August 16, 2007



Energy is Everything



Change the World Breakthrough?

Is Solar Water Splitting the Answer?

What People Hope:		What Chemical Engineers Know:
Unleashes a solar revolution	>	Getting to the end-use is impractical
pH = 7 matters	>	Not on the critical path
Just like photosynthesis	>	Leaves do not make hydrogen
Replacing Pt matters	>	Coated stainless steel
100% current efficiency	>	Neglects overall energy balance
Novel discovery	>	Exists in the patent literature
Water splitting needed	>	There are better ways to use electrons

Unit Operations Reality

Solar Cell

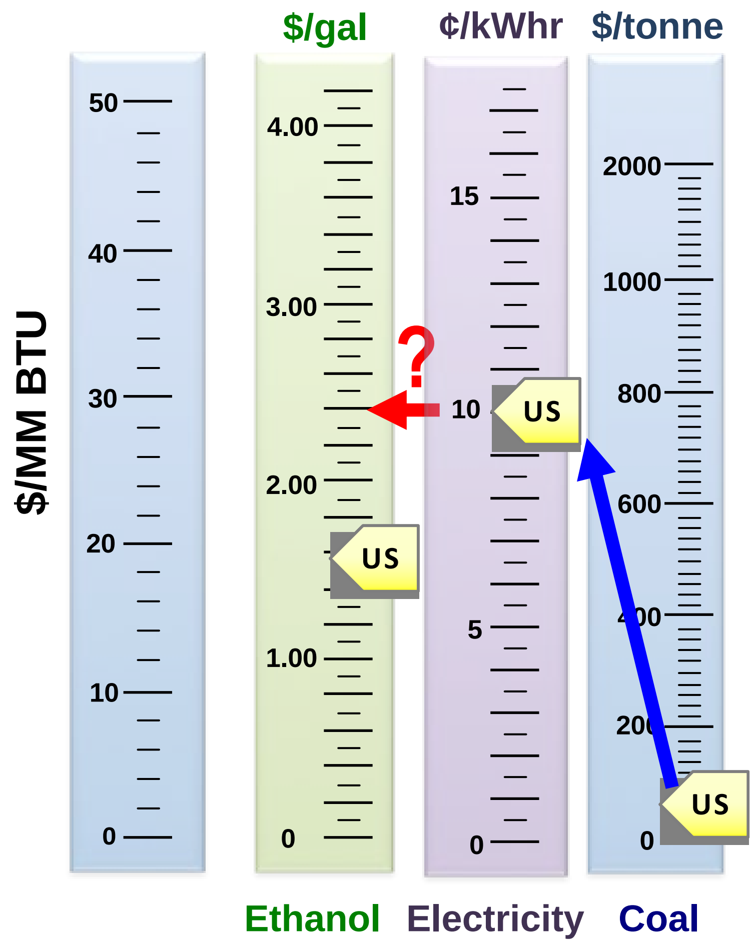
Electrolyzer

H_2 Storage Facility

Fuel Cell

Point Of Use

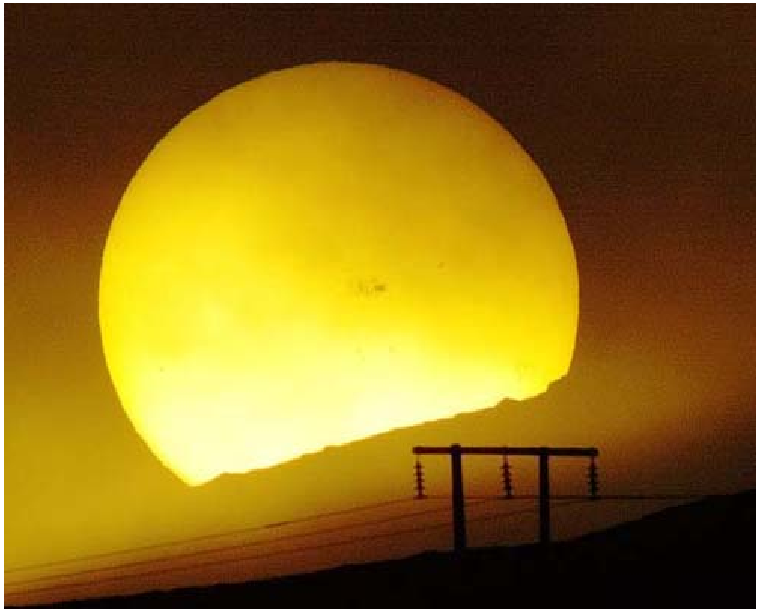
Thermodynamic Considerations

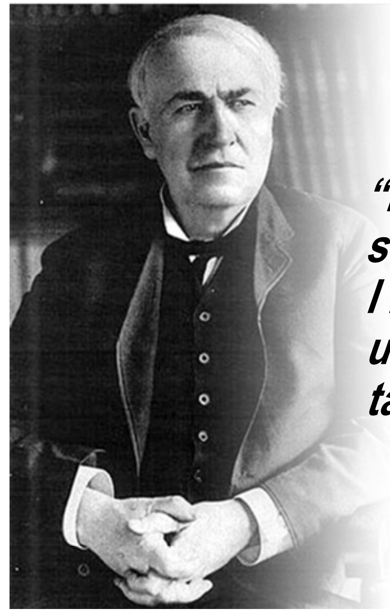


Solar at $0.22/kWhr and conversion efficiency of 50% yields ~$11/gallon ethanol

You make electricity from fuels, not the other way around

Solar is the Answer – Earth is Not a Closed System





"I'd put my money on the sun and solar energy. What a source of power! I hope we don't have to wait until oil and coal run out before we tackle that."

— Thomas Edison

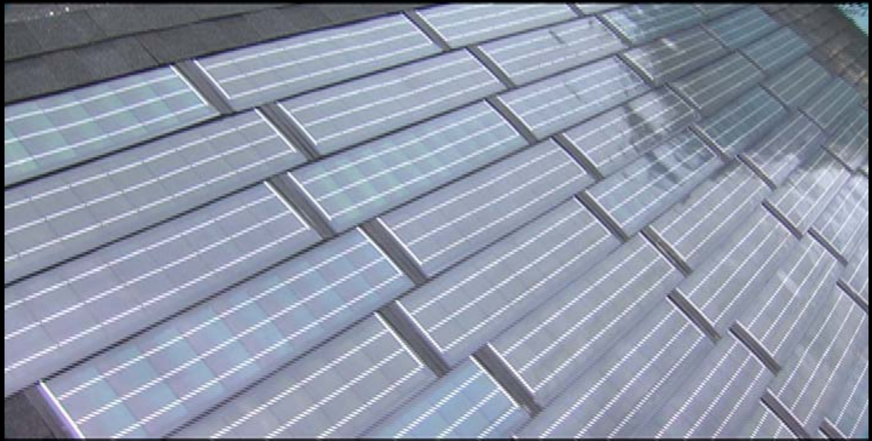
The year – 1931.

Global power burn rate ~ 13 TW
Global solar incidence > 120,000 TW

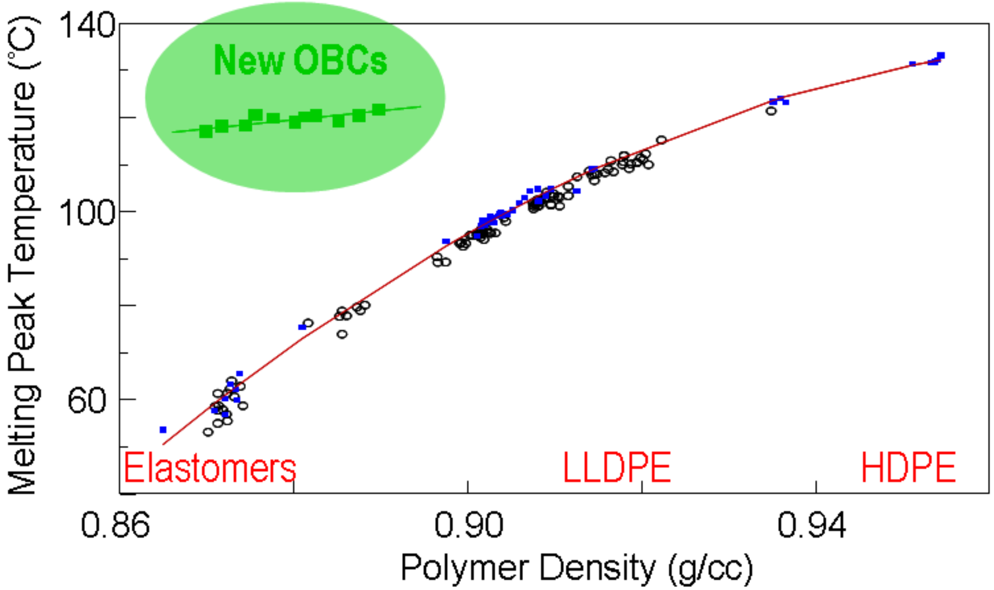
Conventional Solar Installations:
$40 Billion the Hard Way

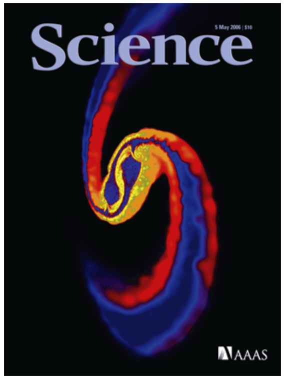

RENEWABLE ENERGY WORLD.COM
Chief Technology Officer,
Duke Energy

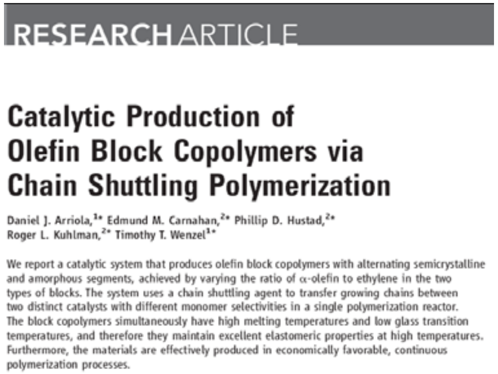
Solar Shingle Installation Feedback Session



INFUSE™ Olefin Block Copolymers







RESEARCH ARTICLE

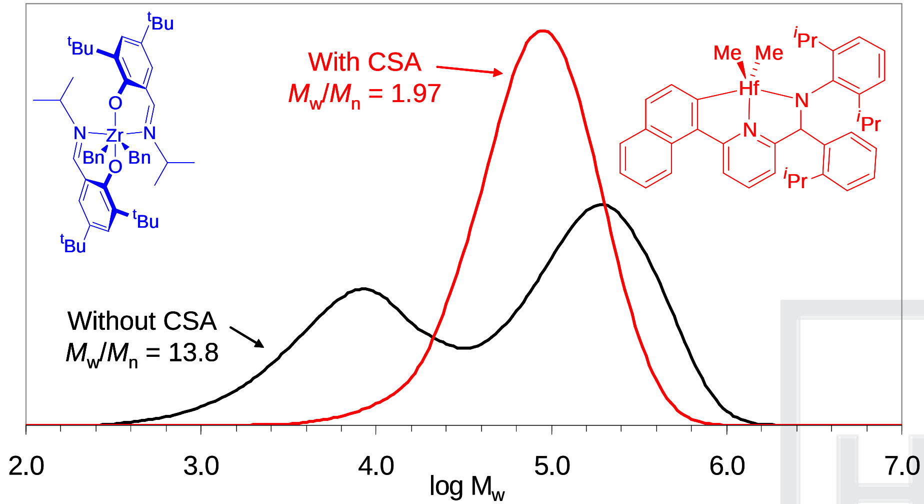
Catalytic Production of Olefin Block Copolymers via Chain Shuttling Polymerization

Daniel J. Arriola,[1*] Edmund M. Carnahan,[2*] Phillip D. Hustad,[2*] Roger L. Kuhlman,[2*] Timothy T. Wenzel[1*]

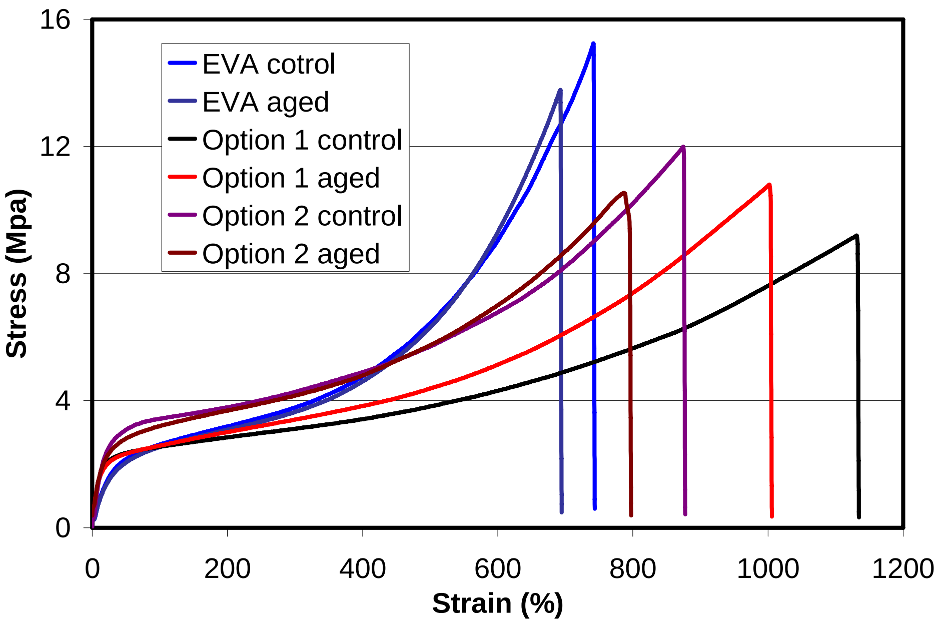
We report a catalytic system that produces olefin block copolymers with alternating semicrystalline and amorphous segments, achieved by varying the ratio of α-olefin to ethylene in the two types of blocks. The system uses a chain shuttling agent to transfer growing chains between two distinct catalysts with different monomer selectivities in a single polymerization reactor. The block copolymers simultaneously have high melting temperatures and low glass transition temperatures, and therefore they maintain excellent elastomeric properties at high temperatures. Furthermore, the materials are effectively produced in economically favorable, continuous polymerization processes.

From lead article in Science to commercial launch in the same calendar year!

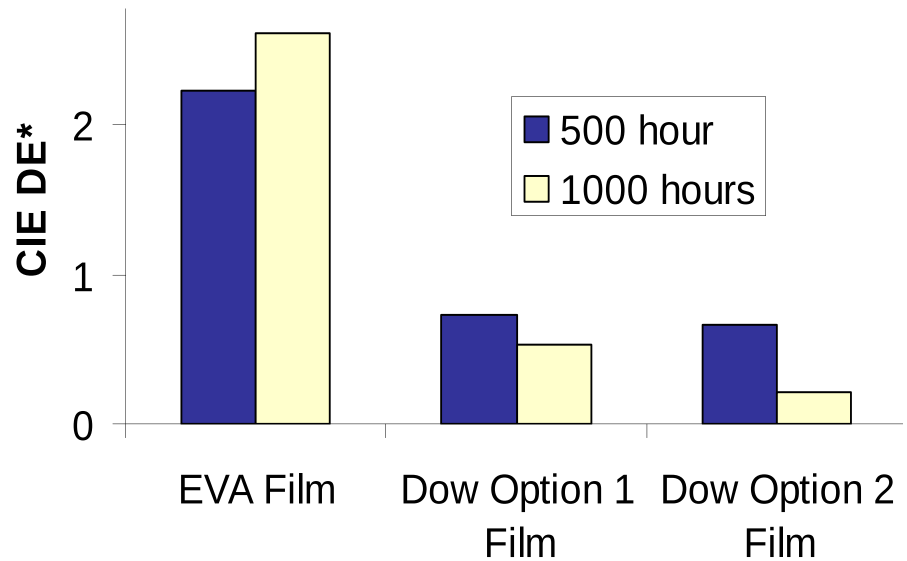
Kinetics!



INFUSE™ Encapsulant Films



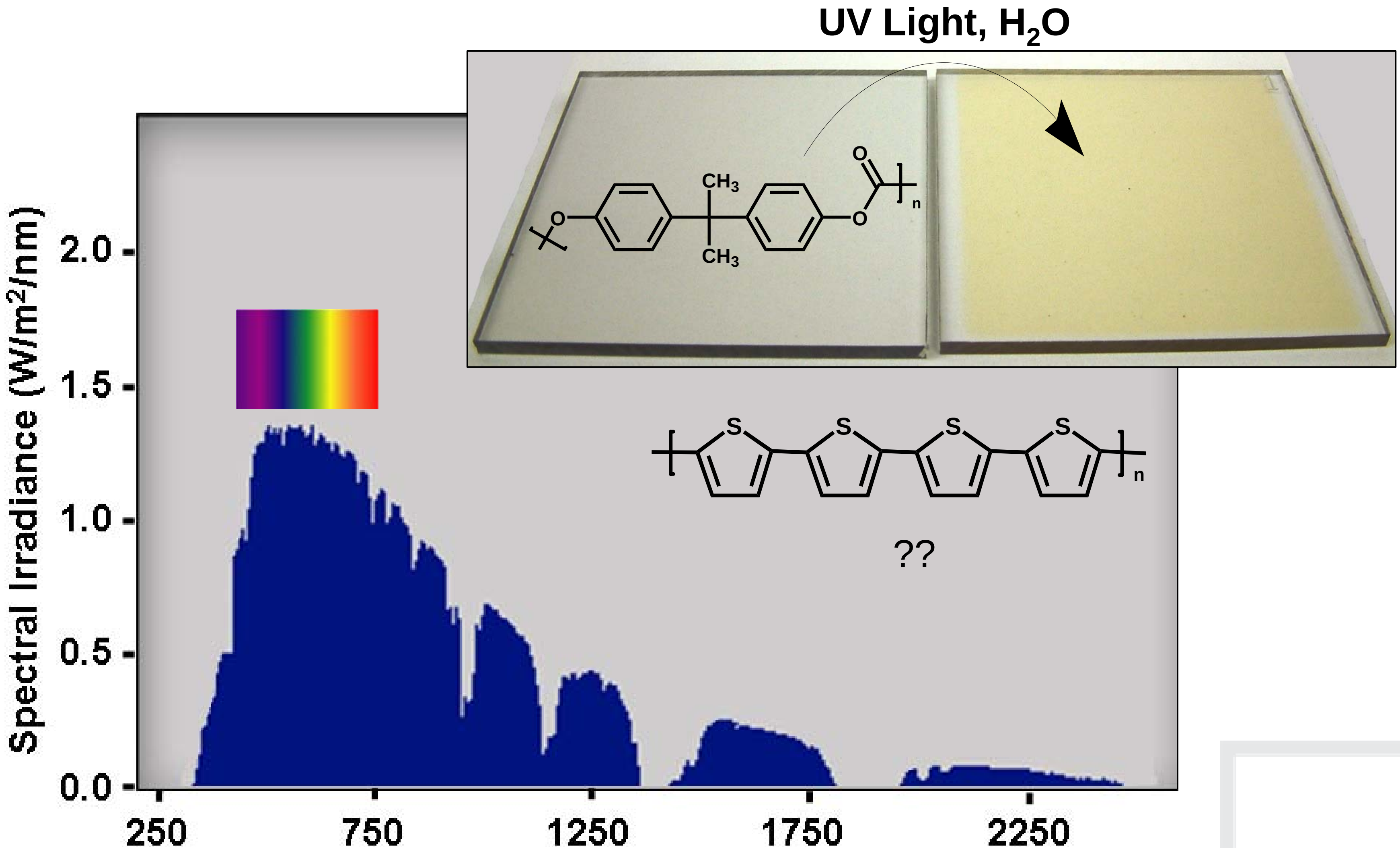
Mechanical Properties After Damp Heat (85C, 85%RH)



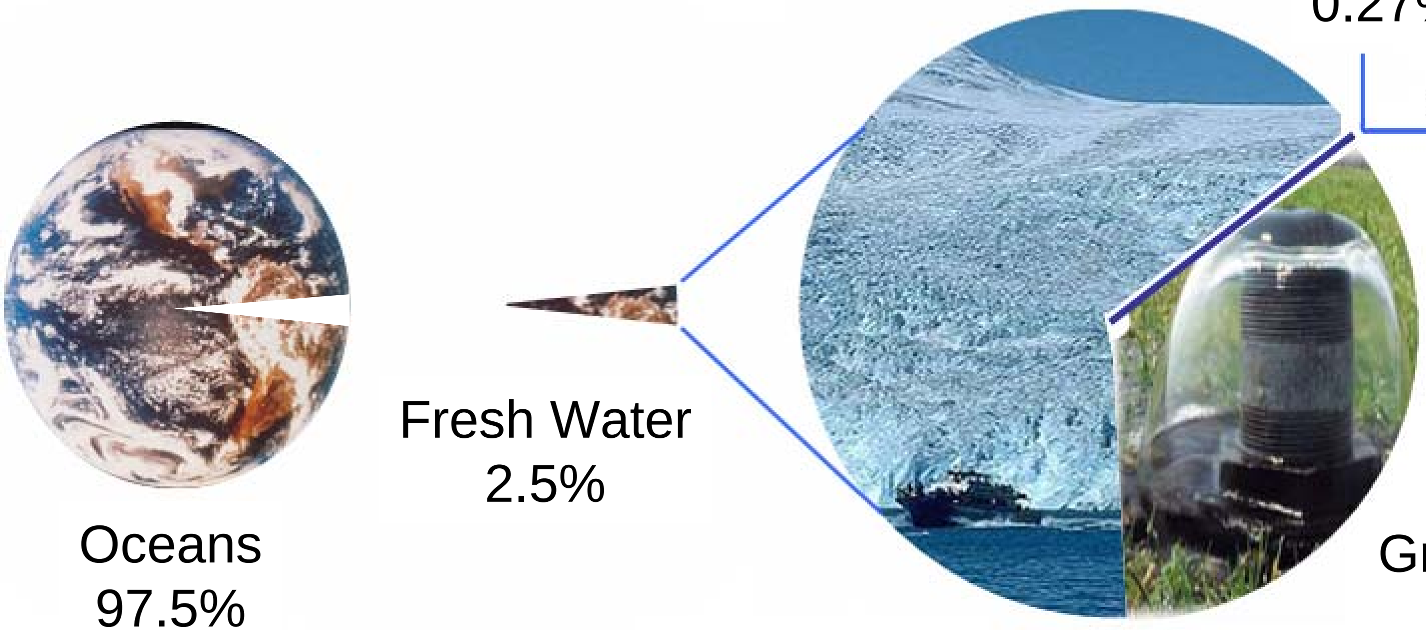
Color Change Under UV (Xenon Arc, 63C, 50%RH)
Post 500 & 1000 Hrs Damp Heat (85C, 85%RH)

INFUSE™ OLEFIN BLOCK COPOLYMERS

Organic PV? Aromatics Don't Weather Well!

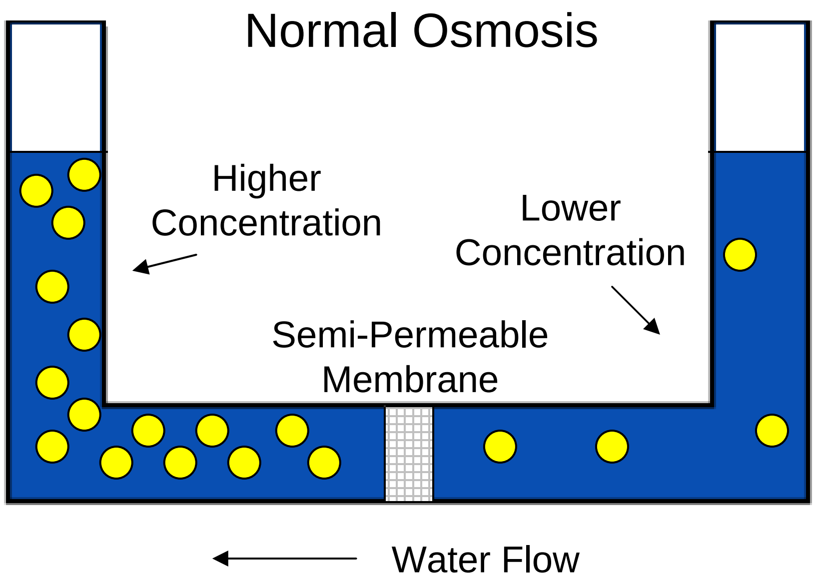


World Challenge – Water



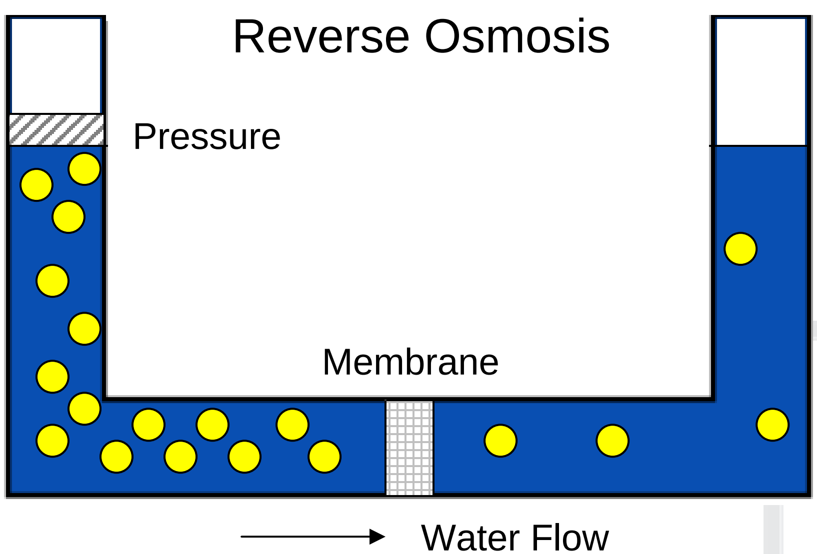
The Mother of all separations problems

Fundamental of Reverse Osmosis

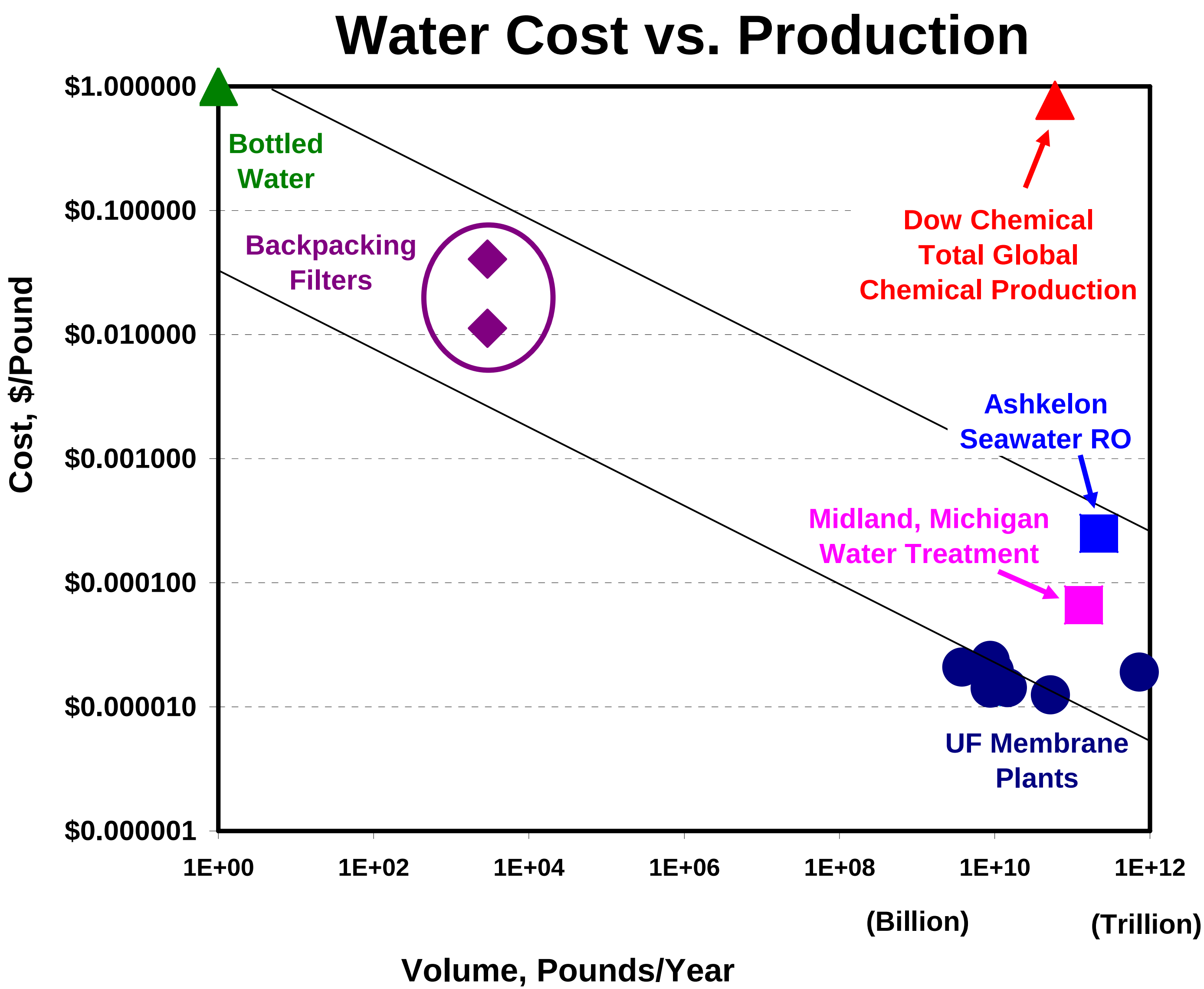


In Osmosis a concentration gradient "pumps" water across a permselective membrane.

In Reverse Osmosis pressure is applied, overcoming the osmotic pressure, and "pumps" water backwards.



Water Desalination Plants – Massive Scale



Where are the Losses?

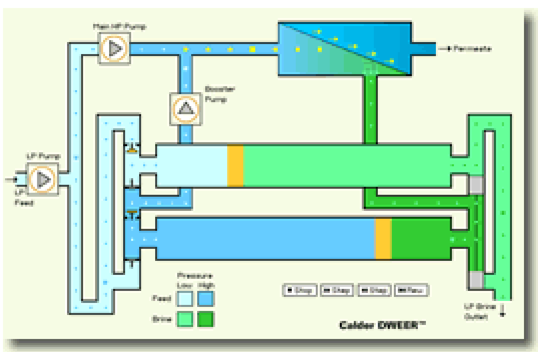
Quantity	RO
Exergy input, kW	76.95
Min work of separation	1.224
Total exergy destruction, kW	70.82
Mechanical energy of product water, kW	4.91
2nd-law efficiency	8.0%
Exergy destruction in various components:	
-Discharged raw water	0.93 (1.3%)
-Bag filters	1.66 (2.4%)
-Static mixer	0.60 (0.8%)
-Separation unit (RO, NF, EDR)	25.62 (36.2%)
-Throttling of bypass water	7.49 (10.6%)
-Blending with bypass water	0.43 (0.6%)
-Mech. exergy of discharge brine	5.97 (8.4%)
-Pumps and piping system	28.11 (39.7%)

Source: Kahraman et. al. *Desalination* **171** (2004) 217-232

Improving the State-of-the-Art

Dual Work Exchanger Energy Recovery

Cylindrical vessel alternately filled with hp brine and lp feed
Brine and feed separated by a piston
DWEER has two cylinders so there is constant flow of hp feed to membranes
Flow is controlled via valves at both ends of cylinders



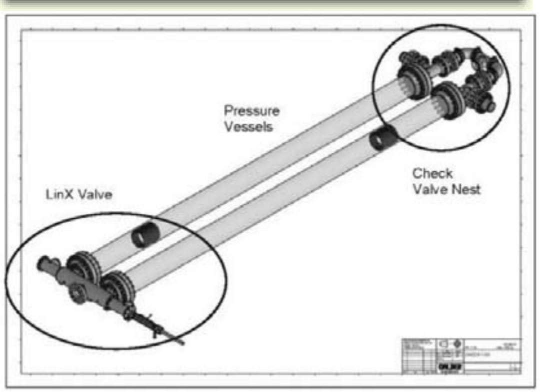
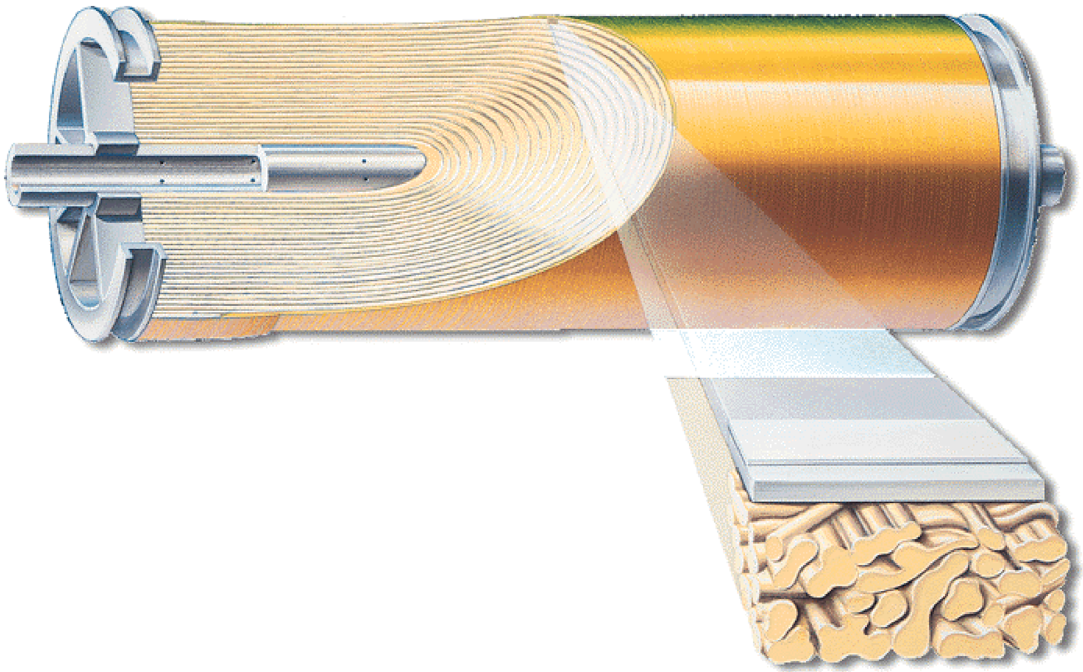
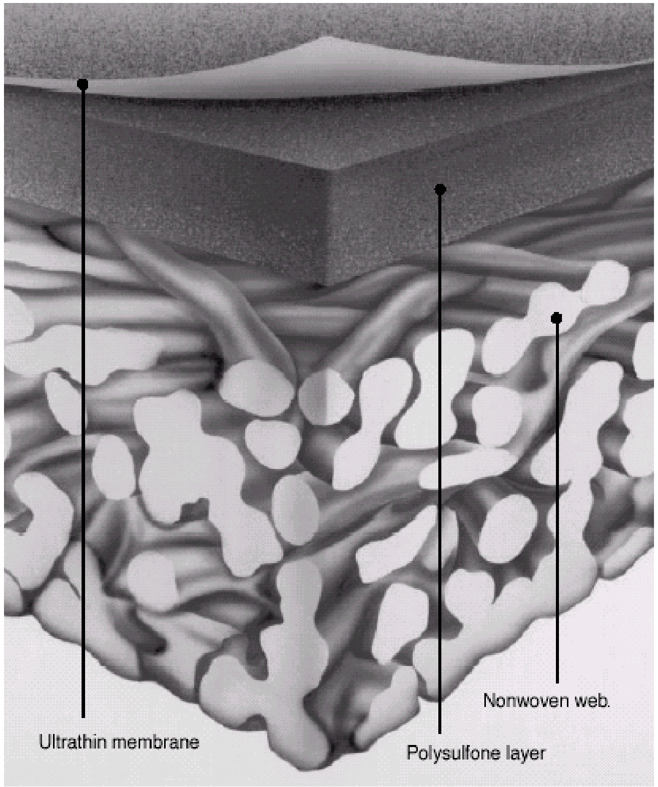


Fig. 3. The DWEER™ work exchange.

FILMTEC™ Reverse Osmosis Membranes





Hidden Problem – Industrial Water Use

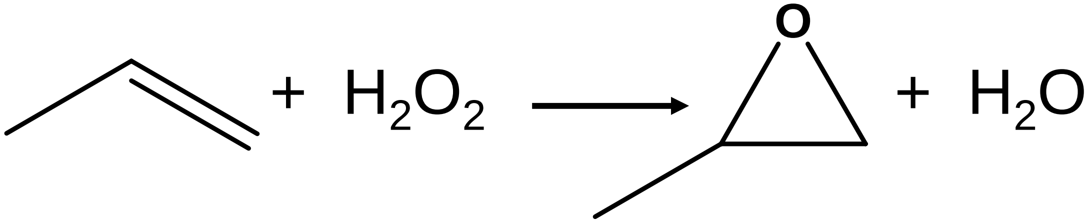
Dow/BASF Joint Venture - HPPO

Collaboration with BASF

Reduces waste water by 75-80% and energy by 30%

PO is a key chemical intermediate

Simplified process



One example of many ongoing projects to reduce water use

Food for Thought

<u>To produce 1 Kg of:</u>

Fish you need 1.5-3 Kg of grain

Chicken you need 2-3 Kg of grain

Beef you need 7-10 Kg of grain

The world is moving up
the food chain

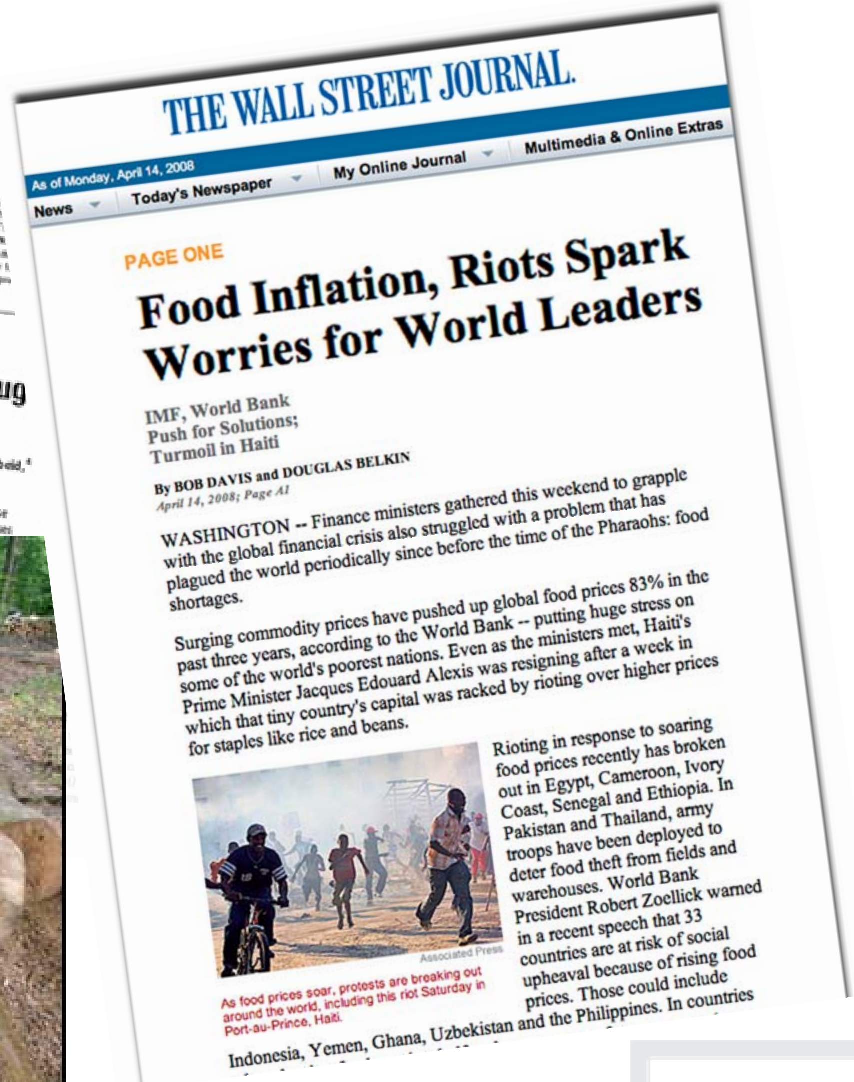
World Challenge – Food


REPORTS

Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Throug Emissions from Land-Use Change

Timothy Searchinger,[1*] Ralph Heimlich,[2] R. A. Houghton,[3] Fengxia Dong,[4] Amani Elobeid,[4] Jacinto Fabiosa,[4] Simla Tokgoz,[4] Dermot Hayes,[4] Tun-Hsiang Yu[4]

...found that substituting biofuels for gasoline will reduce greenhouse ... sequester carbon through the growth of the feedstock. These analyses ... carbon emissions that occur as farmers worldwide ...


THE WALL STREET JOURNAL.

As of Monday, April 14, 2008 | News | Today's Newspaper | My Online Journal | Multimedia & Online Extras

PAGE ONE

Food Inflation, Riots Spark Worries for World Leaders

IMF, World Bank Push for Solutions; Turmoil in Haiti

By BOB DAVIS and DOUGLAS BELKIN

April 14, 2008; Page A1

WASHINGTON -- Finance ministers gathered this weekend to grapple with the global financial crisis also struggled with a problem that has plagued the world periodically since before the time of the Pharaohs: food shortages.

Surging commodity prices have pushed up global food prices 83% in the past three years, according to the World Bank -- putting huge stress on some of the world's poorest nations. Even as the ministers met, Haiti's Prime Minister Jacques Edouard Alexis was resigning after a week in which that tiny country's capital was racked by rioting over higher prices for staples like rice and beans.

Associated Press

As food prices soar, protests are breaking out around the world, including this riot Saturday in Port-au-Prince, Haiti.

Rioting in response to soaring food prices recently has broken out in Egypt, Cameroon, Ivory Coast, Senegal and Ethiopia. In Pakistan and Thailand, army troops have been deployed to deter food theft from fields and warehouses. World Bank President Robert Zoellick warned in a recent speech that 33 countries are at risk of social upheaval because of rising food prices. Those could include Indonesia, Yemen, Ghana, Uzbekistan and the Philippines. In countries

SmartStax™ Deal with Monsanto

Redefining Seeds and Traits in Corn

First ever eight way gene platform

Target end of decade commercialization

Key attributes current in testing:

- Feasibility of full trait integration
- Viability of enhanced performance for insect and weed control

MONSANTO

Dow AgroSciences

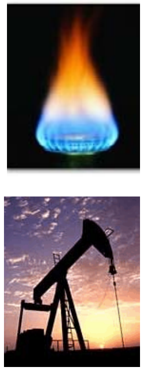
World Challenge – Sustainable Prosperity

The Chemical Industry Converts Feedstocks into Essential Products

NaCl + **e^-**

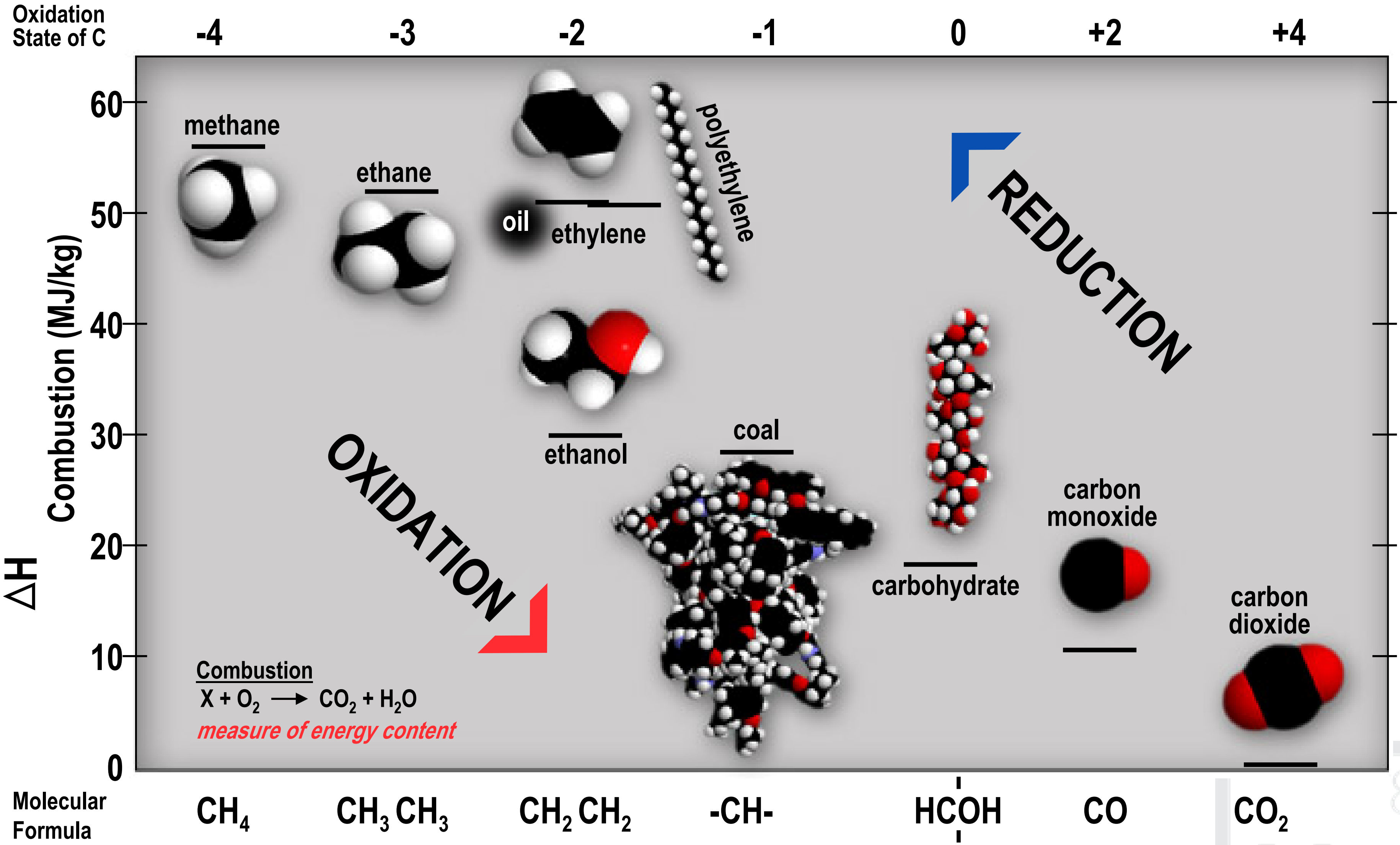
190 Bn lbs | 1.1 kWh per lb Cl_2

[Global Oil Consumption ~ 9700 Bn lbs]

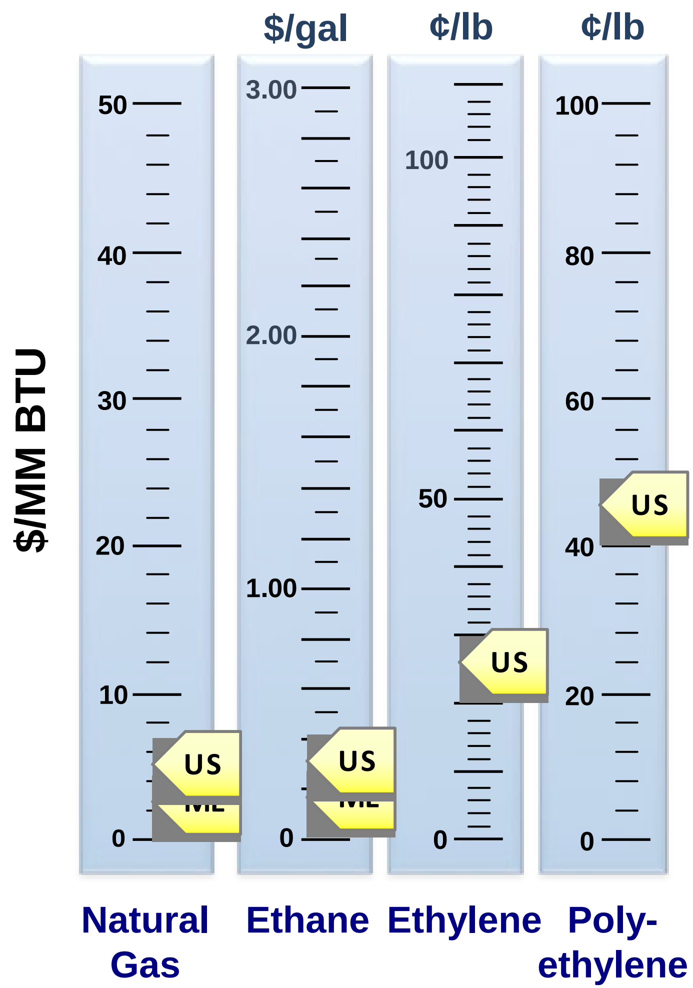


C_1 88 Bn lbs
C_2 256 Bn lbs
C_3 162 Bn lbs
C_4 22 Bn lbs
C_6 89 Bn lbs

Energetics of Feedstocks

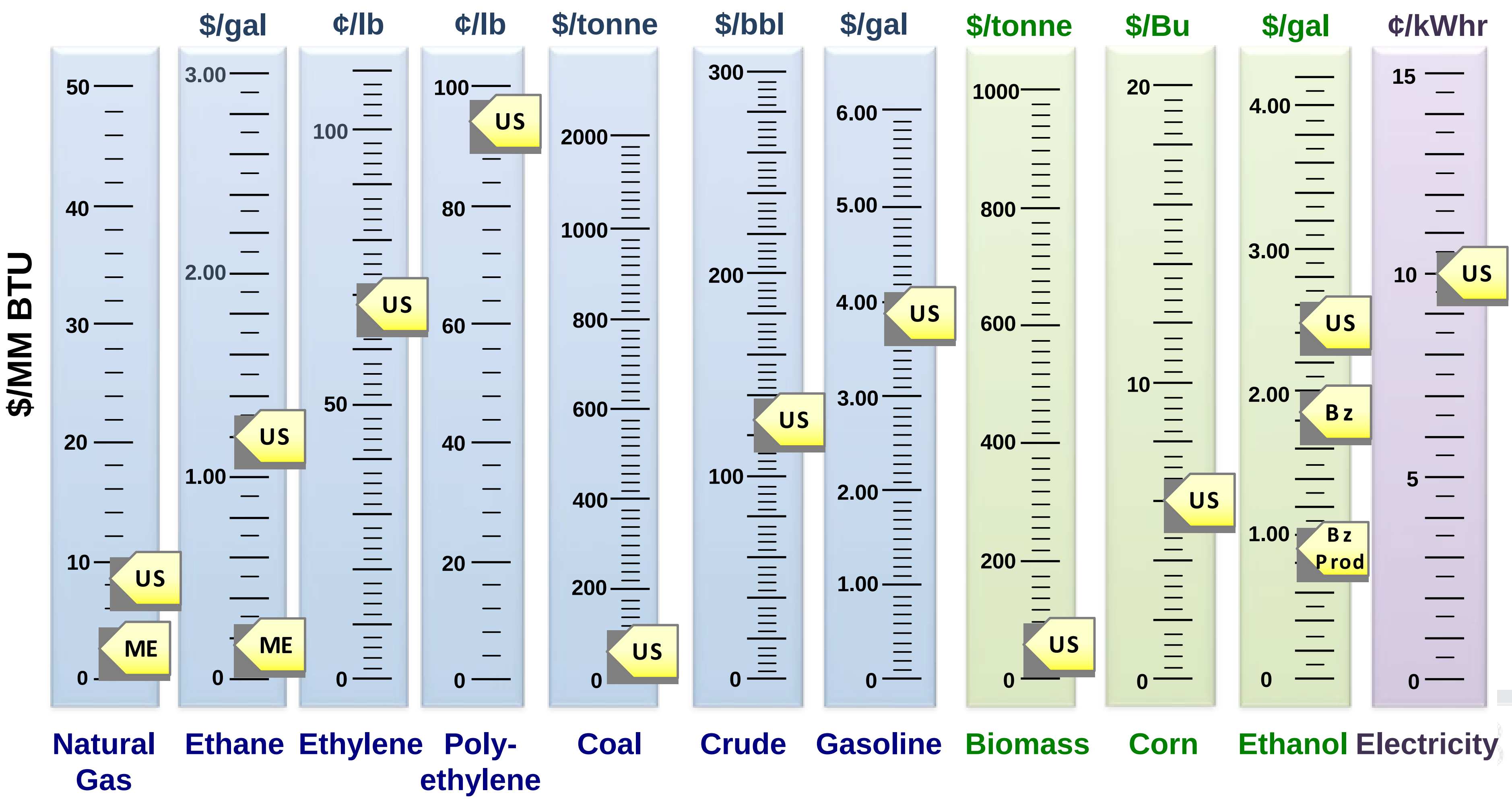


Price Per Unit Energy



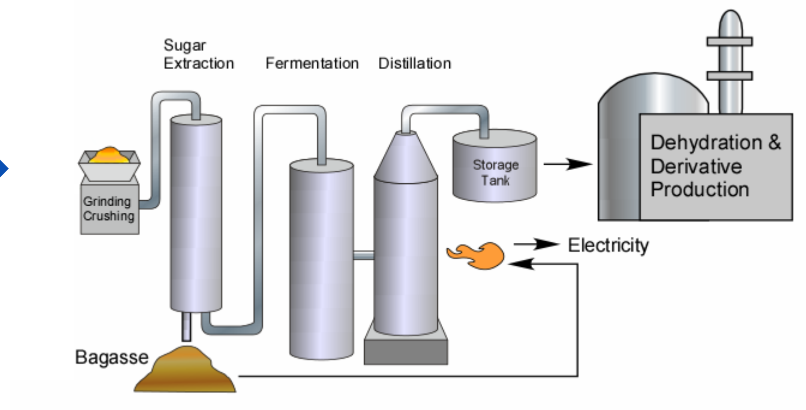
Price Per Unit Energy

AUG 2008 PRICES

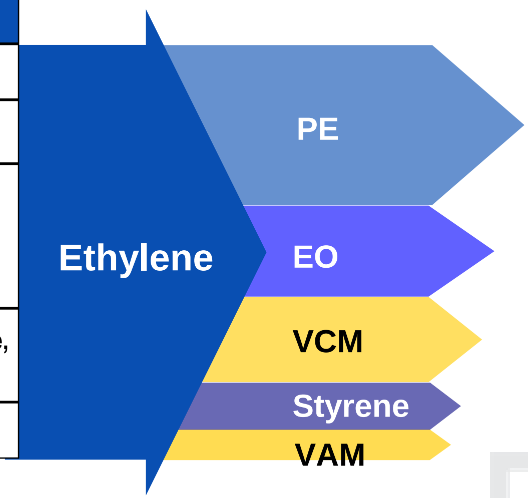


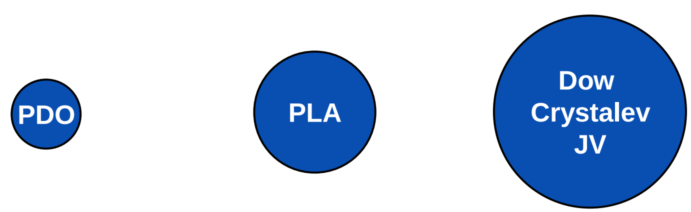
Solution - Ethanol to Polyethylene

CO_2



	DuPont Bio-PDO (Serona®)	NatureWorks™ PLA	Dow/Crystalev JV
Plant Scale	45 kTA	140 kTA	350 kTA
Fermented Product	1,3-Propanediol	Lactic Acid	Ethanol
Key Processes	Fermentation, Condensation Polymerization	Fermentation, Oligomerization, Ring-Closing, & Ring-Opening Polymerization	Fermentation, Dehydration, Polymerization
Initial Product	PDO/TPA Copolymer	Polylactic acid	Ethylene, Polyethylene, Copolymers
Flexibility	Moderate	Low	High





Benchmarking Land Use

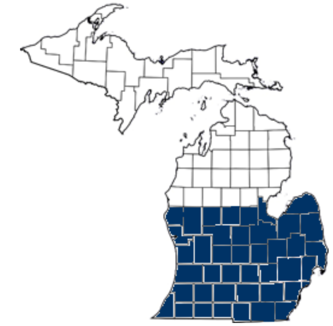
Dow Brazil Plant

Bay County

Dow LLDPE Capacity

Seven Local Counties

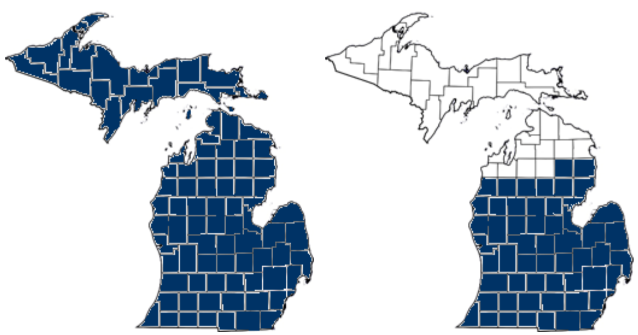
Global LLDPE Capacity



0.43 X Michigan

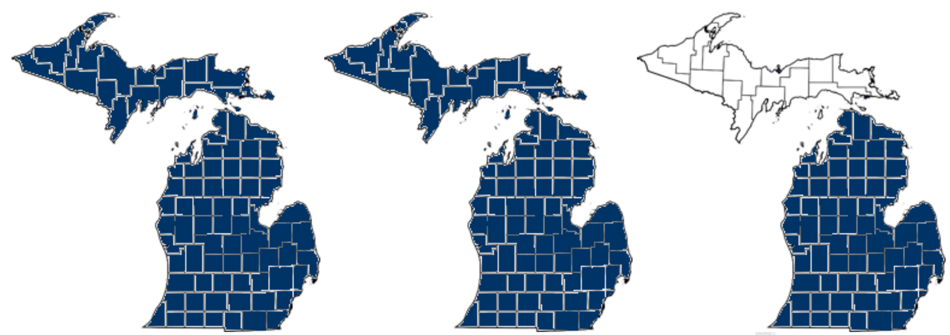
Assumes Brazil Cane Yields

Global Polyethylene



1.6 X Michigan

Global Ethylene

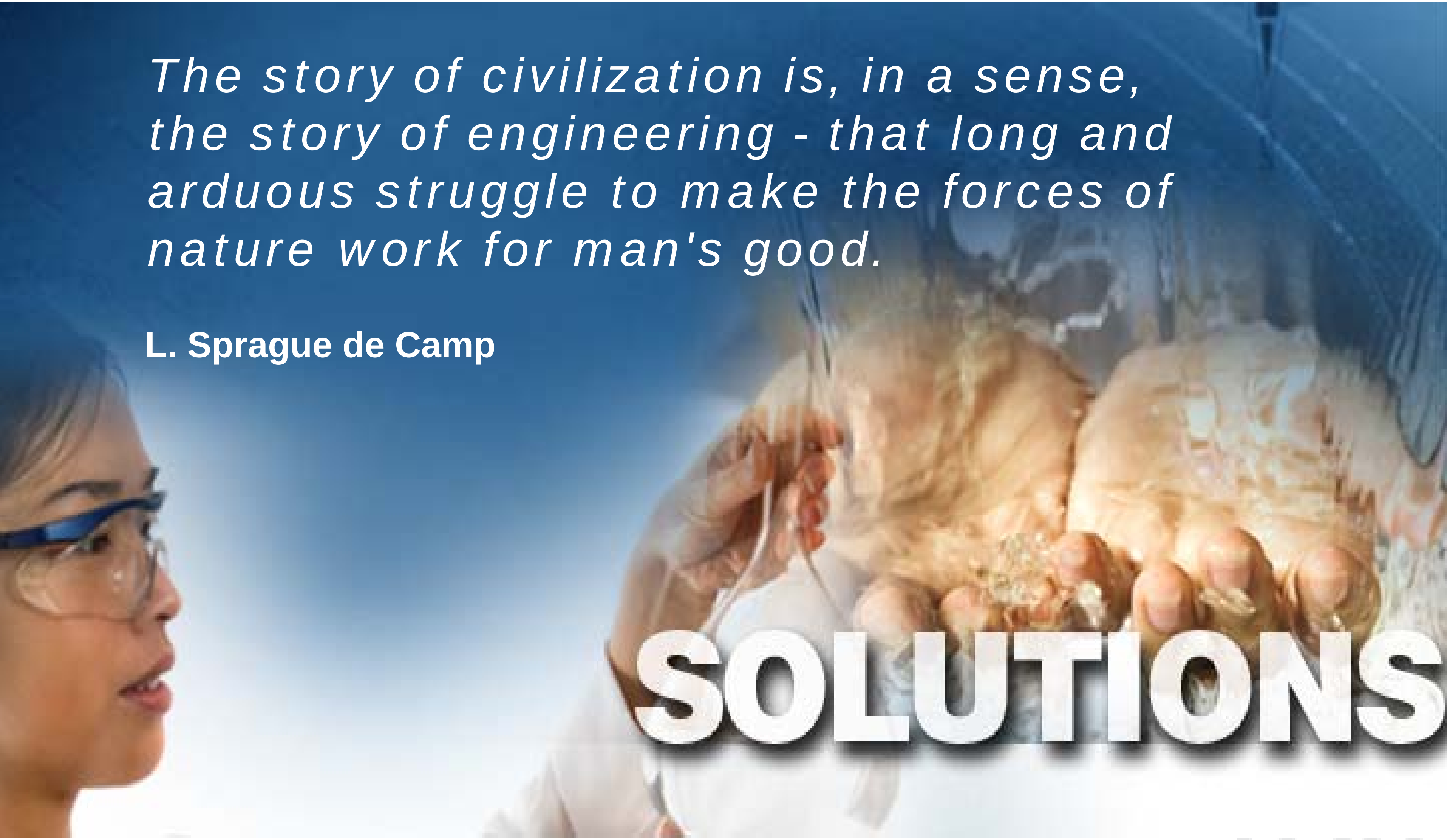


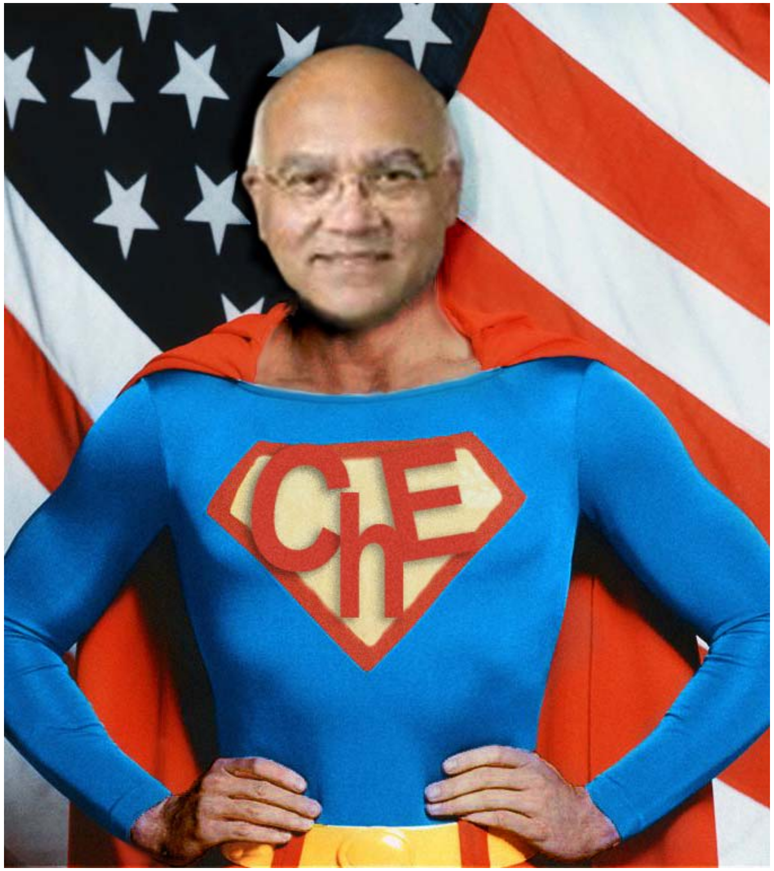
2.7 X Michigan

The Challenge for the Chemical Engineer

The story of civilization is, in a sense, the story of engineering - that long and arduous struggle to make the forces of nature work for man's good.

L. Sprague de Camp





Thank You

Question 1

Question 2

Question 3

Question 4

Question 5