

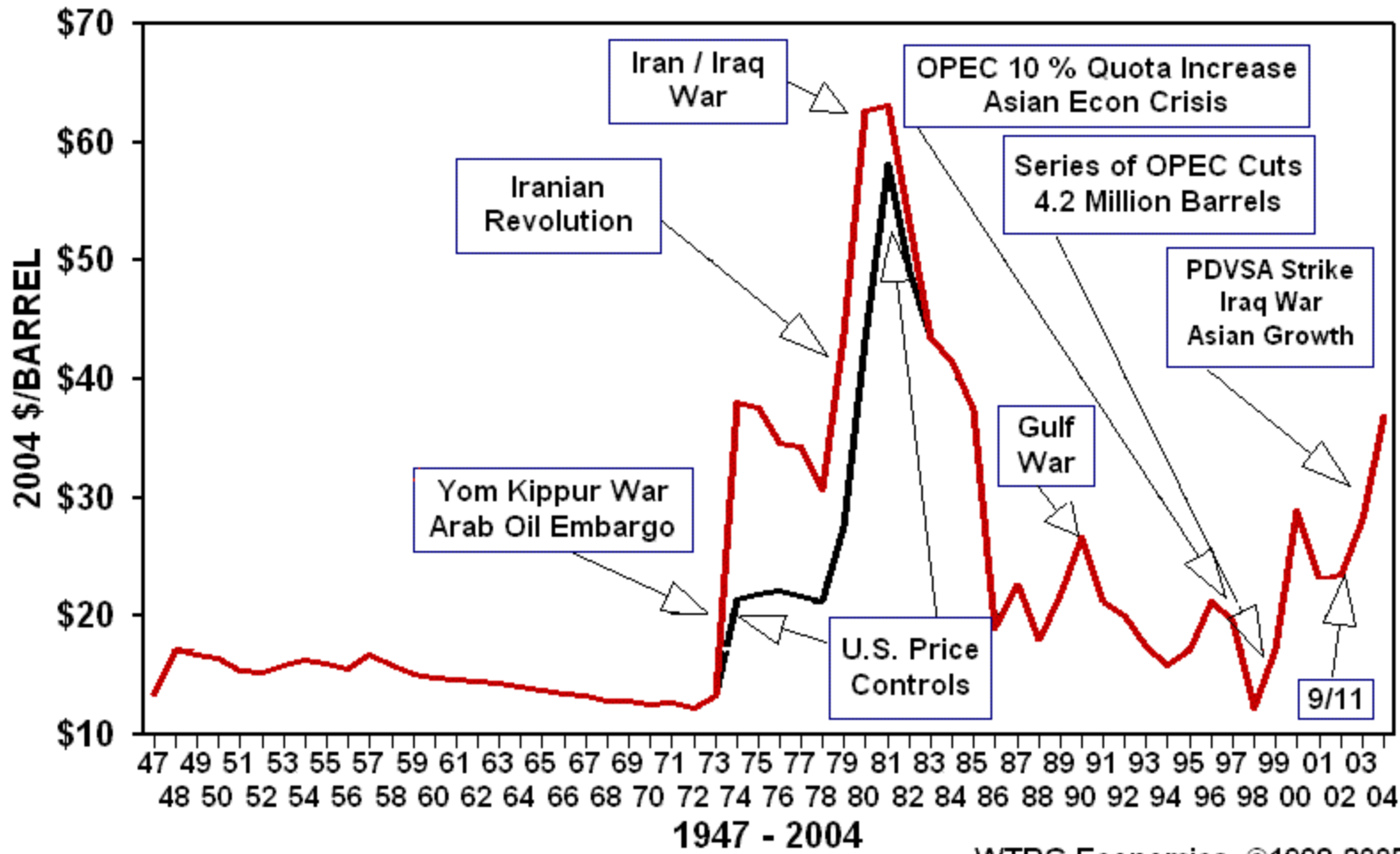
# New Venture Experiments in Renewable Fuels

Noubar Afeyan, PhD

CEO, Flagship Ventures  
Senior Lecturer, MIT

February 2012

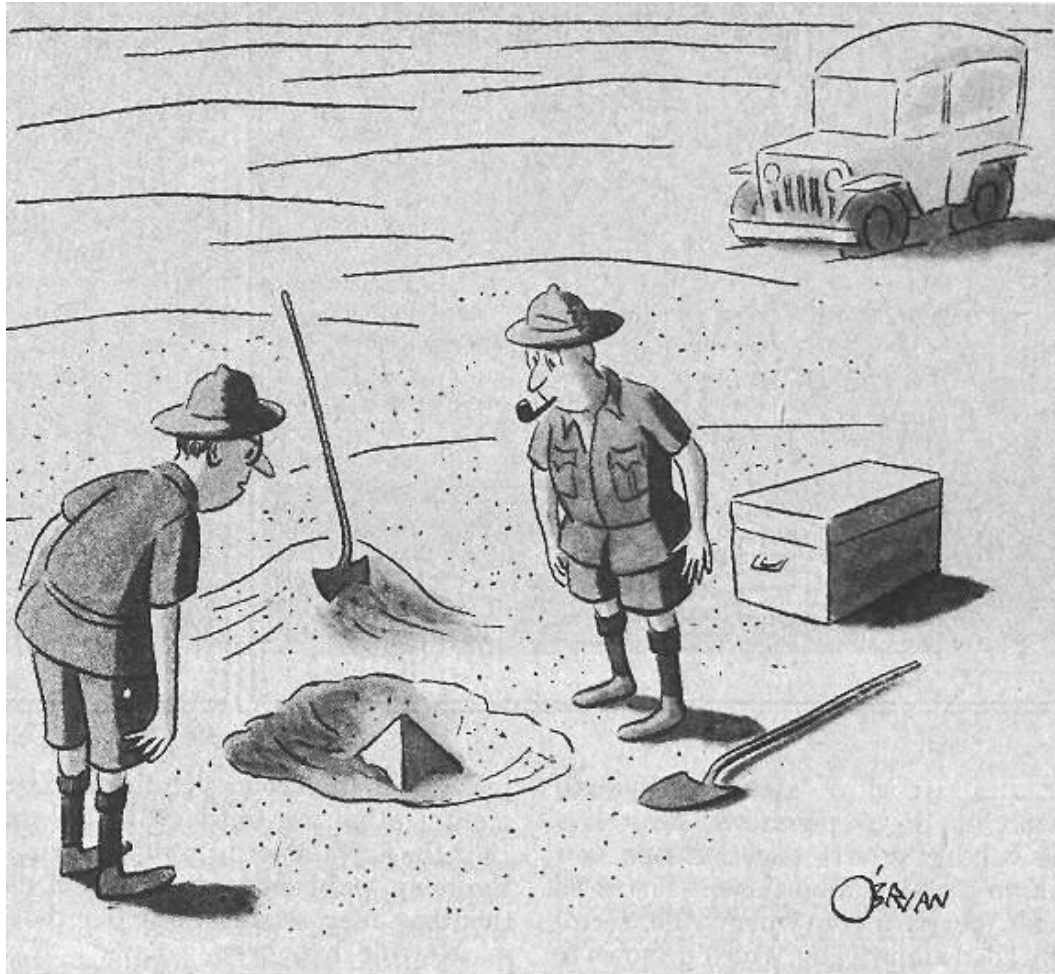
# Historical Price of Oil



— U.S. 1st Purchase Price ( Wellhead ) — "World Price" \*

WTRG Economics ©1998-2005  
[www.wtrg.com](http://www.wtrg.com)  
 (479) 293-4081

# Discovering “Big Idea” Ventures



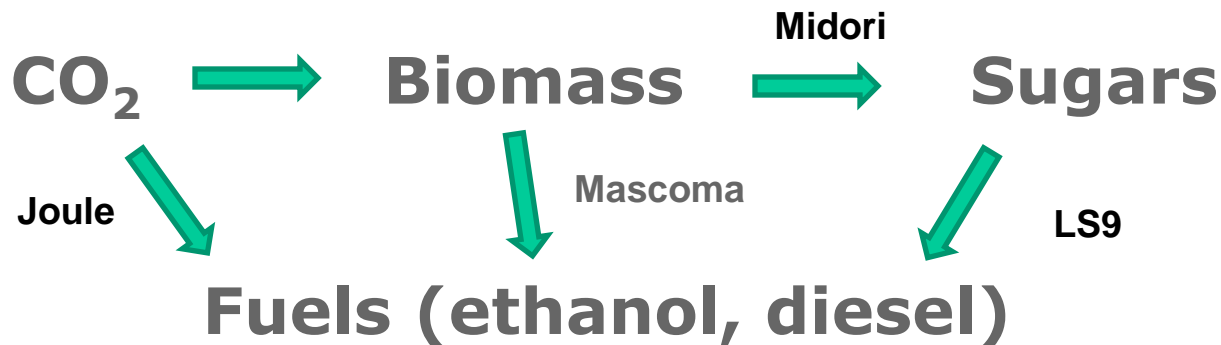
*“This could be the discovery of the century. Depending, of course, on how far down it goes.”*

# 1<sup>st</sup> Generation Biofuels



# Exploring the Adjacent Possible

- **Venturing towards more Renewable Energy**
  - *Mascoma* - Biomass to Ethanol
  - *LS9* - Sugars to Biodiesel
  - *Midori* - Biomass to Sugars
  - *Joule* - CO<sub>2</sub> to Liquid Fuels



# Mascoma: Stepwise Improvements to Biomass Processing

**Biologically-Mediated Event**

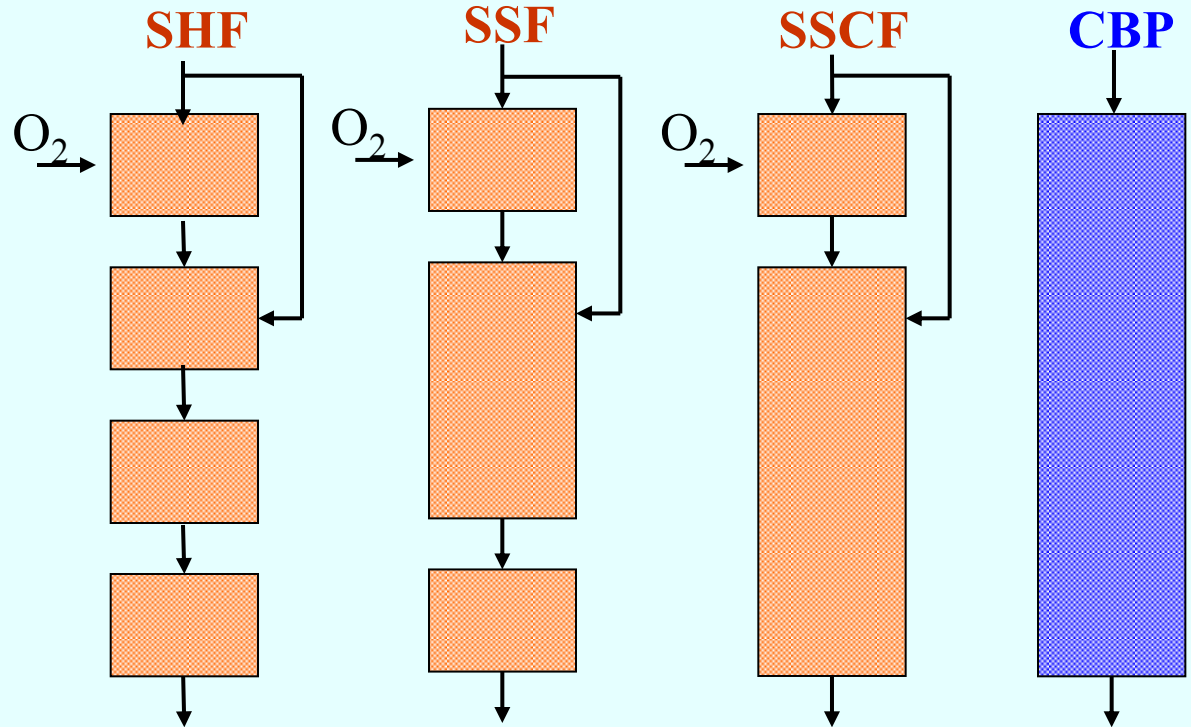
**Processing Strategy**  
(each box represents a bioreactor - not to scale)

**Cellulase production**

**Cellulose hydrolysis**

**Hexose fermentation**

**Pentose fermentation**



**SHF: Separate hydrolysis & fermentation**

**SSF: Simultaneous saccharification & fermentation**

**SSCF: Simultaneous saccharification & co-fermentation**

**CBP: Consolidated bioprocessing**

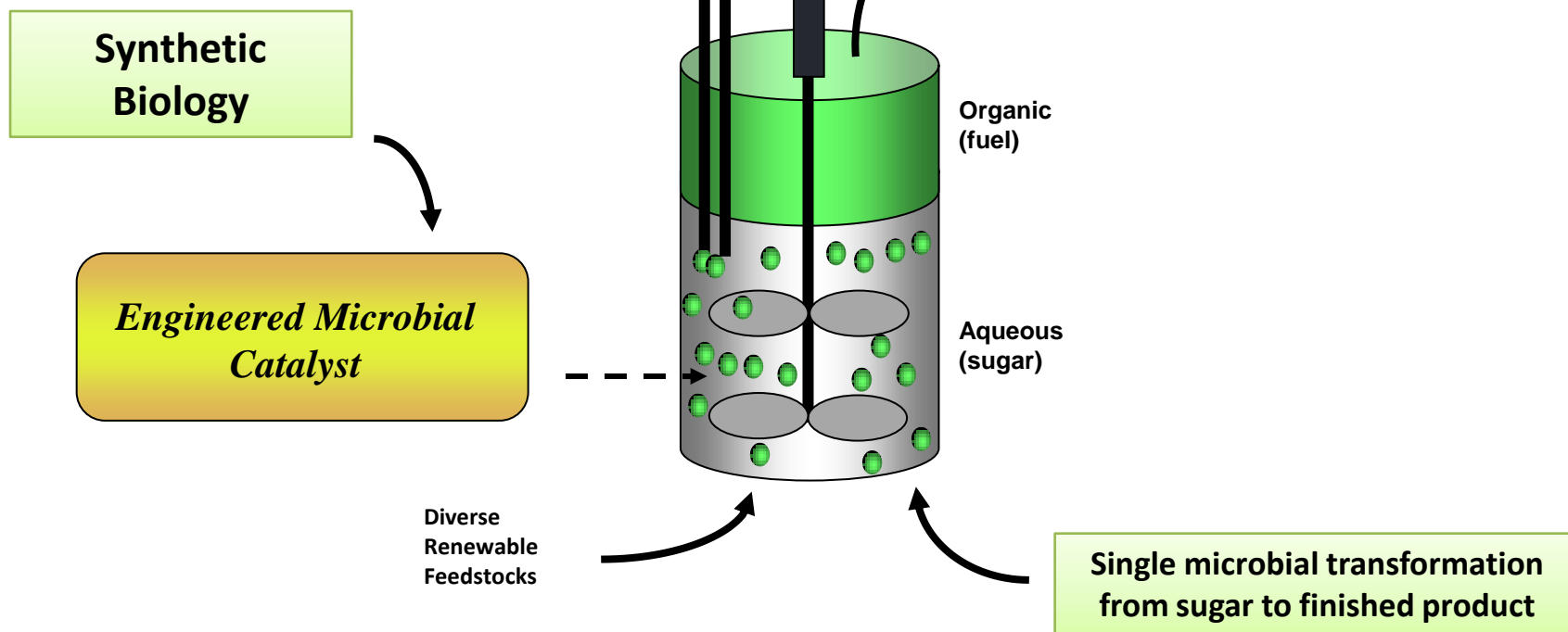


# Simple Efficient Processes

- Platform
- High yield
- Simple

## Drop in:

- Fuels
- Chemicals



# Engineered Microbial Catalyst - Industrial Synthetic Biology

1. Select target product
2. Validate product & process economics and feasibility
3. Design synthetic pathway
4. Collect and evaluate genes
5. Compile components into organism
6. Optimize organism



Feedstock  $\rightarrow$  A  $\rightarrow$  B  $\rightarrow$  Product  
Gene 1      Gene 2      Gene 3







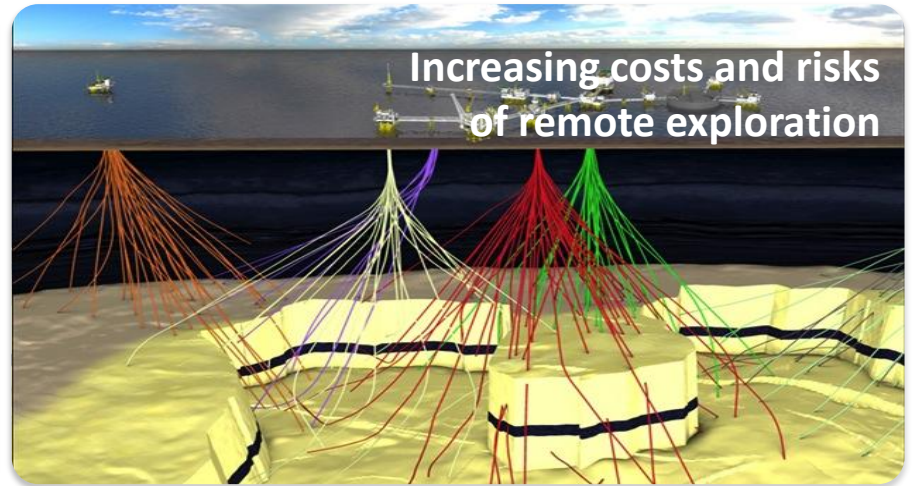
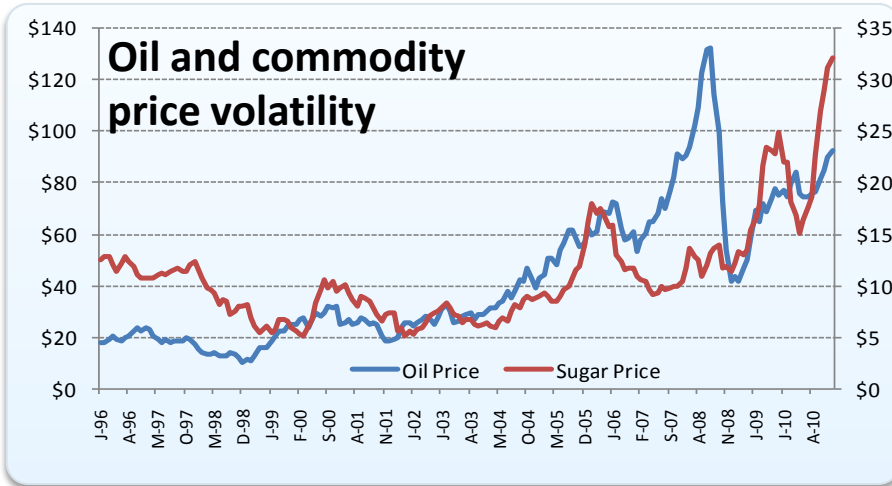
# Midori Process Overview

---



- Biomass and water are converted to sugars and boiler fuel in a simple, scalable process
- Midori's patented chemical catalyst is 100% recovered and reused internally

# The Challenge: Meeting Global Chemicals/Fuels Demands in Spite of ...

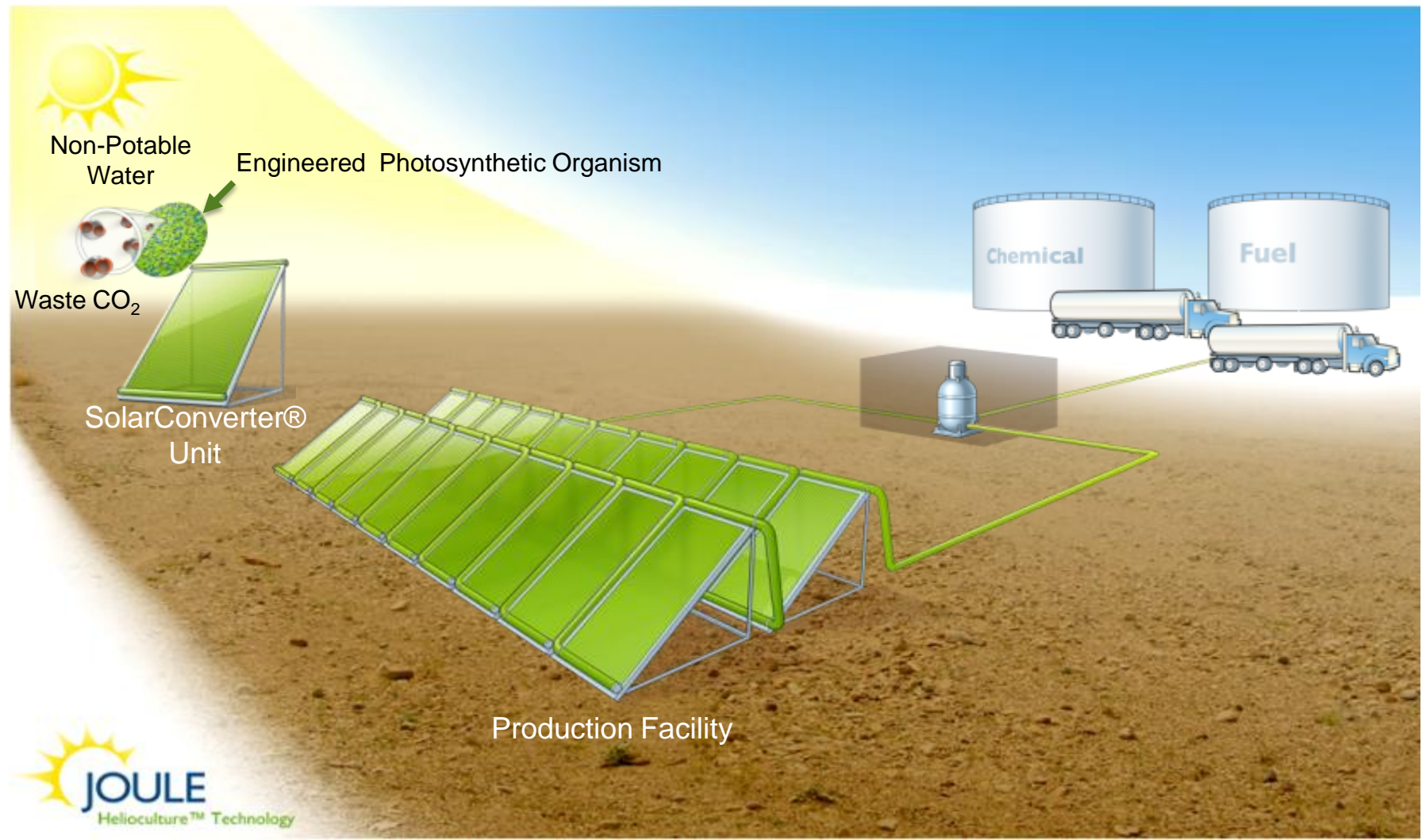


# Opportunity

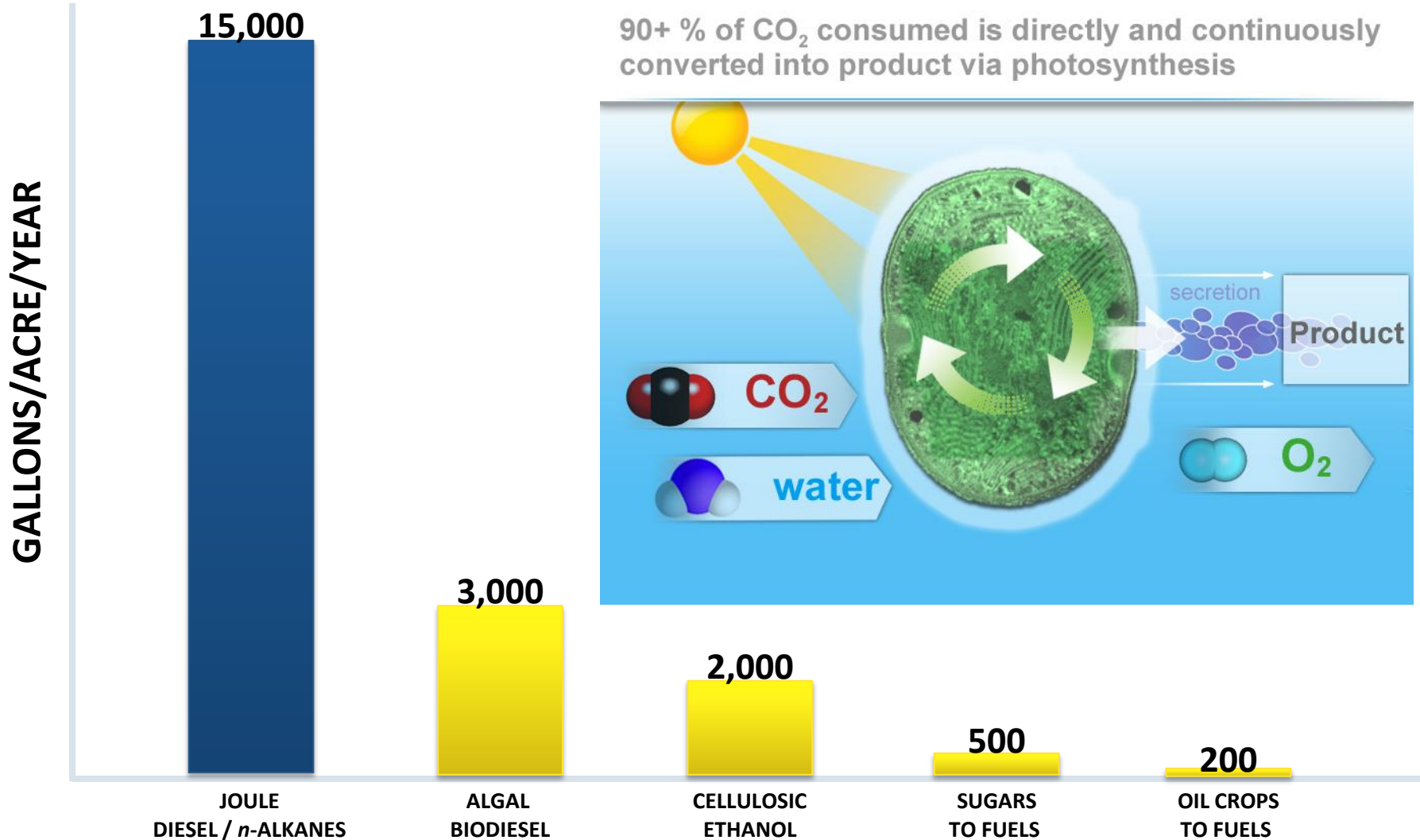




# Joule's Helioculture™ Platform Allows Modular Scale-up to 1,000s of Acres



# Higher Land Productivities Possible Compared to Biomass-Dependent Processes - **~1bbl/acre/day**



# Photon Utilization Efficiency Translates to Areal Productivity



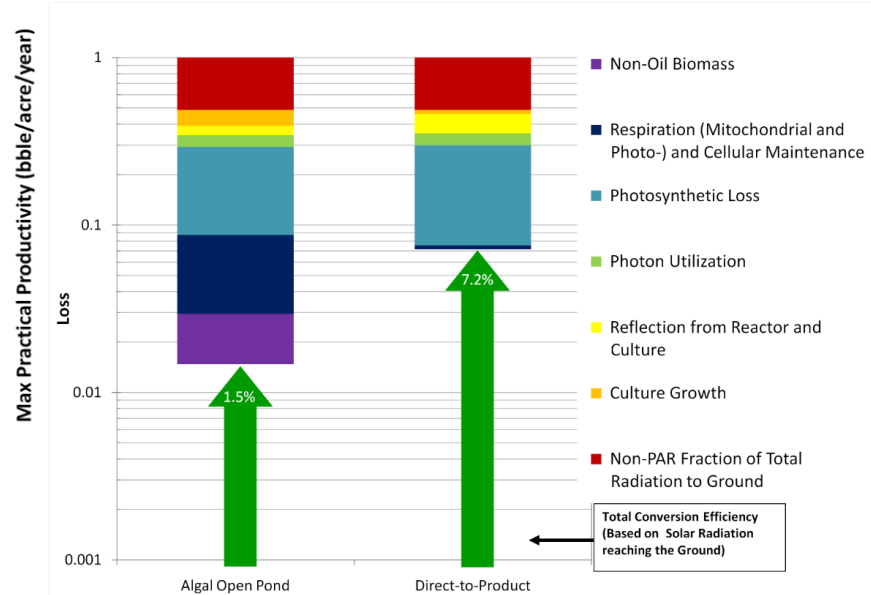
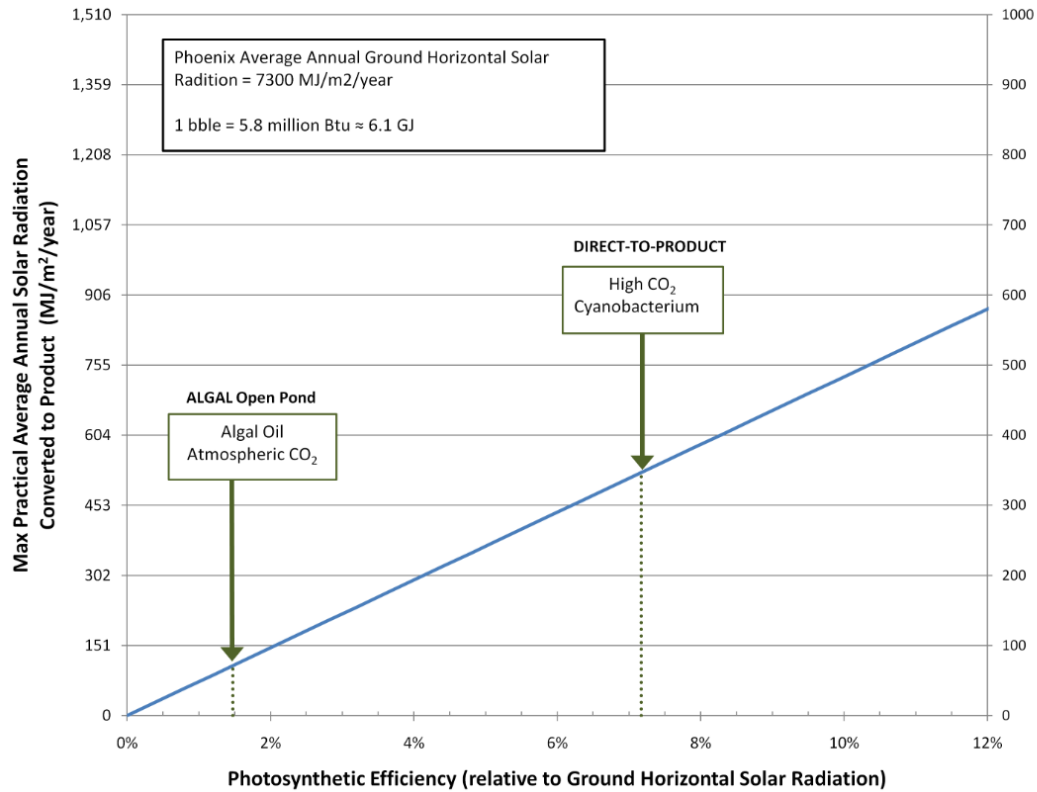
Direct, continuous process enables high productivities

Photosynth Res  
DOI 10.1007/s11120-011-9631-7

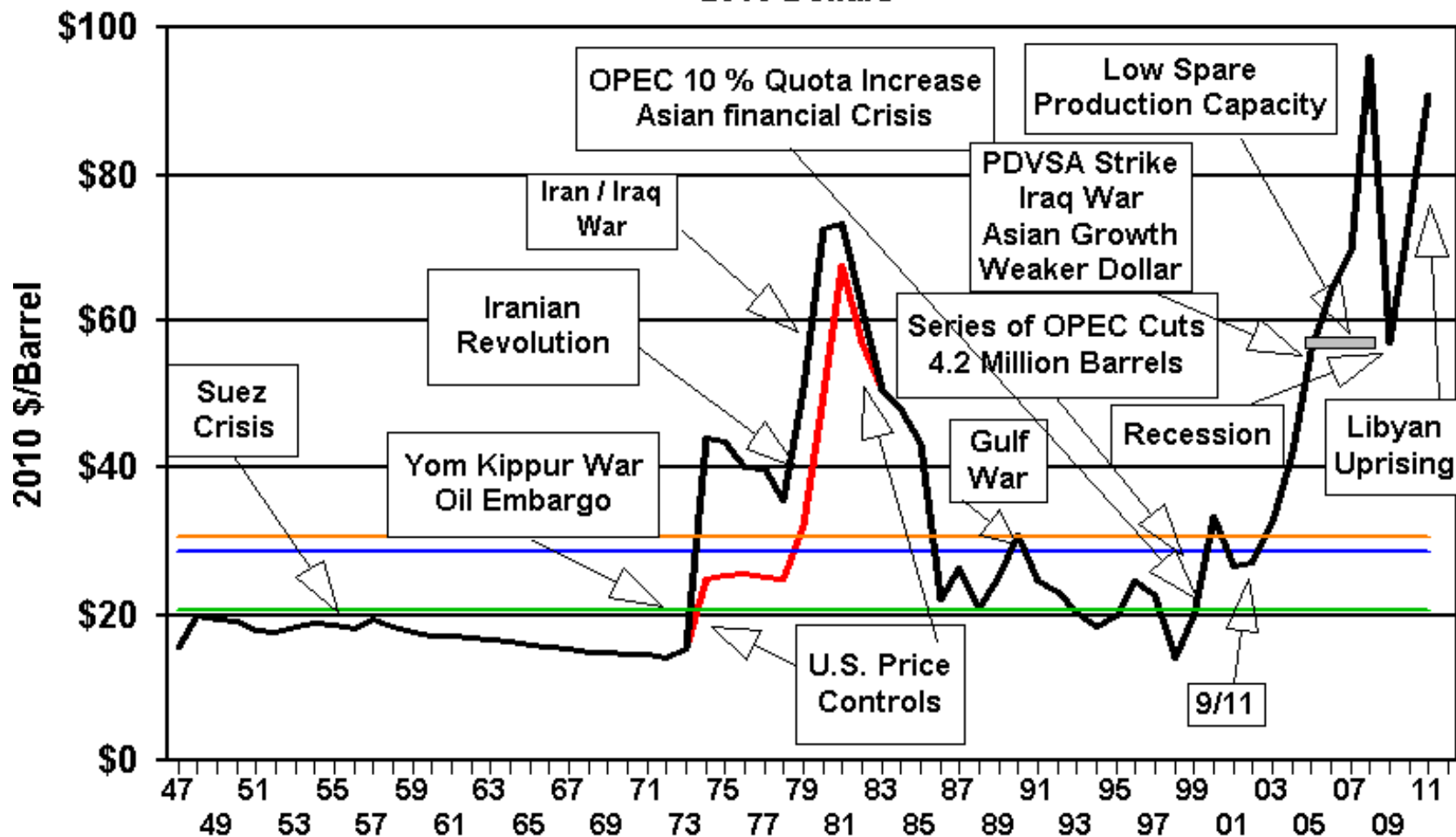
REGULAR PAPER

## A new dawn for industrial photosynthesis

Dan E. Robertson · Stuart A. Jacobson ·  
Frederick Morgan · David Berry · George M. Church ·  
Noubar B. Afeyan



## Crude Oil Prices 2010 Dollars



1947 - October 2011 WTRG Economics ©1998-2011

— U.S. 1st Purchase Price ( Wellhead )   
 — "World Price" \*   
 [www.wtrg.com](http://www.wtrg.com)  
— Avg U.S. \$28.52   
 — Avg World \$30.54   
 — Median U.S. & World \$20.53   
 (479) 293-4081