completing the energy sustainability puzzle

AAAS/SWARM

April 11, 2008

Albuquerque, NM

ENERGY and WATER

Biofuels and the Energy-Water Nexus

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Contents of Presentation

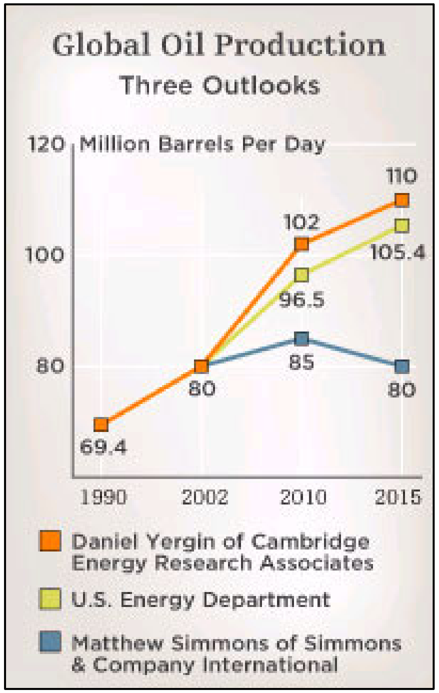
- Biofuels Interest and Motivation for Sandia
- Energy-Water Nexus Context for Biofuels
- Water Issues for Alternative Transportation Fuels
- The Promise & Challenge of Algal Biofuels
- Conclusions

Biofuel Interest & Motivation

- **Energy Security … Heavy U.S. dependence on petroleum imports**

  - Oil imports of ~10-M bbl/day (150+ B-gal/yr)
    … two thirds for transportation fuels
  - Subject to supply disruption from volatile regions
  - Represents $300+ B/yr burden on U.S. economy
    … supports interests hostile to US
  - Increasing competition (China, India, etc.)
    & price volatility for limited global supplies
  - "Peak Oil" concerns
    … decades away?
    ... In 10-years?
    … happening now?

  → <u>Place your bets !</u> →



- **Assessing paths for build-up & integration with existing production, energy/fuels, and transportation infrastructure**
  - Sustainable Approaches and Associated Costs/Benefits/Impacts Tradeoffs
  - Technology, Processes, and Systems R&D Needs and Priorities
  - Insight for Technical and Non-Technical (e.g. Policy) Decision-Support
- **Energy-Water Nexus and Climate Change Concerns**
  - Mitigate adverse impacts on land use, water, GHG footprint, etc.

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Biofuel Interest & Motivation

- **Energy-Water Nexus Investigations for DOE**
  - **Report to Congress released in early-2006**

    http://www.sandia.gov/energy-water/docs/121-RptToCongress-EWwEIAcomments-FINAL.pdf

  - **National Energy-Water Technology Roadmap Effort (2005-2007)**
    - **Three Needs Assessment Workshops: Western, Central, Eastern U.S.**
    - **Gaps Analysis Workshop**
    - **Technology Innovations Workshop**
    - **Energy-Water Roadmap Report expected to be released by DOE in 2008**
    - **More Information available at www.sandia.gov/energy-water**

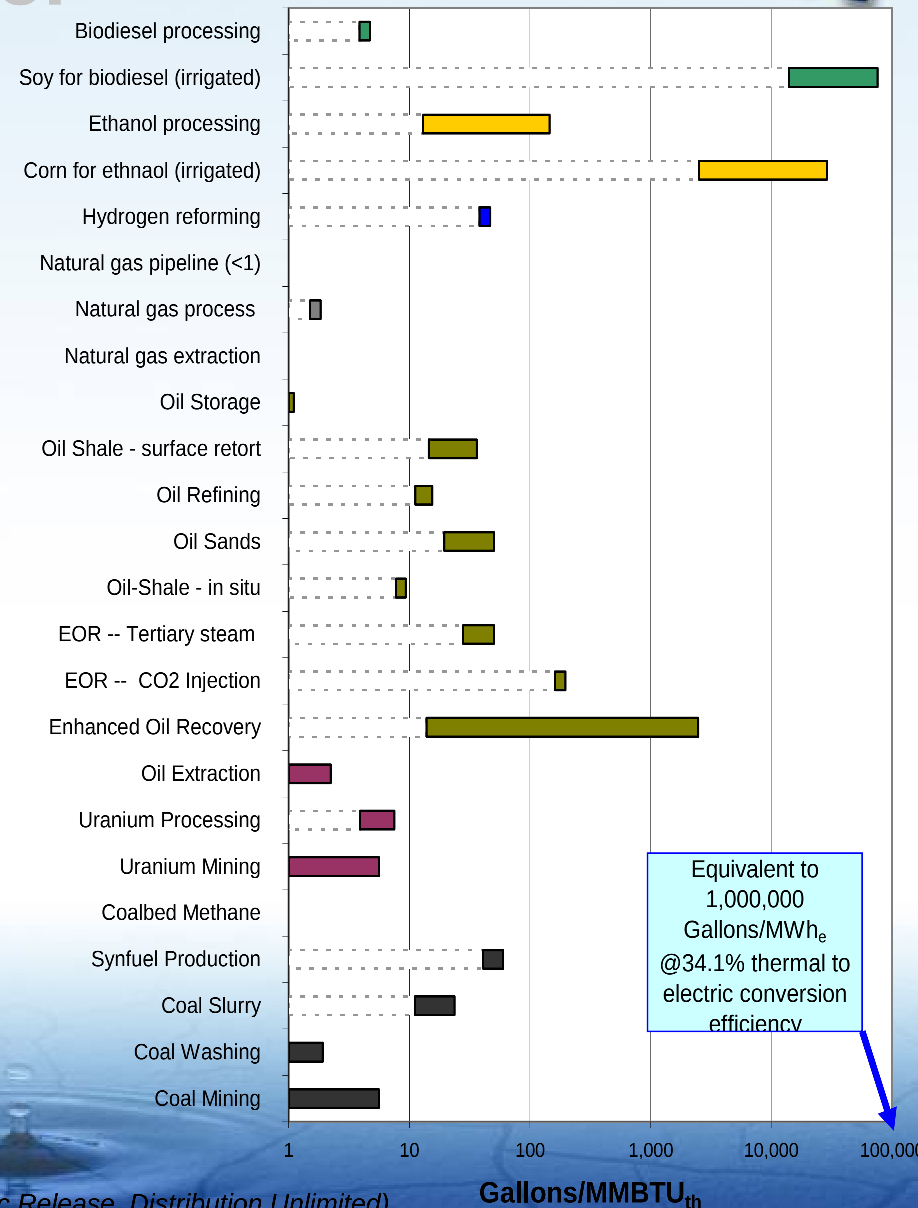
- **Among the major findings:**
  - **Water for Biofuels is an Emerging Issue**
  - **Water Impacts of National Biofuels Scale-up Needs Attention**
  - **Corroborated by recent National Academy Report**

    http://www7.nationalacademies.org/ocga/briefings/Water_Implications_of_Biofuels_Production.asp
    http://www.nap.edu/catalog.php?record_id=12039

Energy-Water Nexus Context for Biofuels

Future energy development will put new demands on water

- Many newer technologies will be more water intensive
- Transition to biofuels and a possible longer-term future hydrogen economy will require significantly more water than current fossil transportation fuels
- Constraints will grow for power plant siting because of water for cooling needs, advanced scrubbing, and CO_2 removal
- Constraints will grow in some areas for siting of biorefineries and other alternative fuel processing plants (oil shale, coal-to-liquids) due to water supply limitations or impacts



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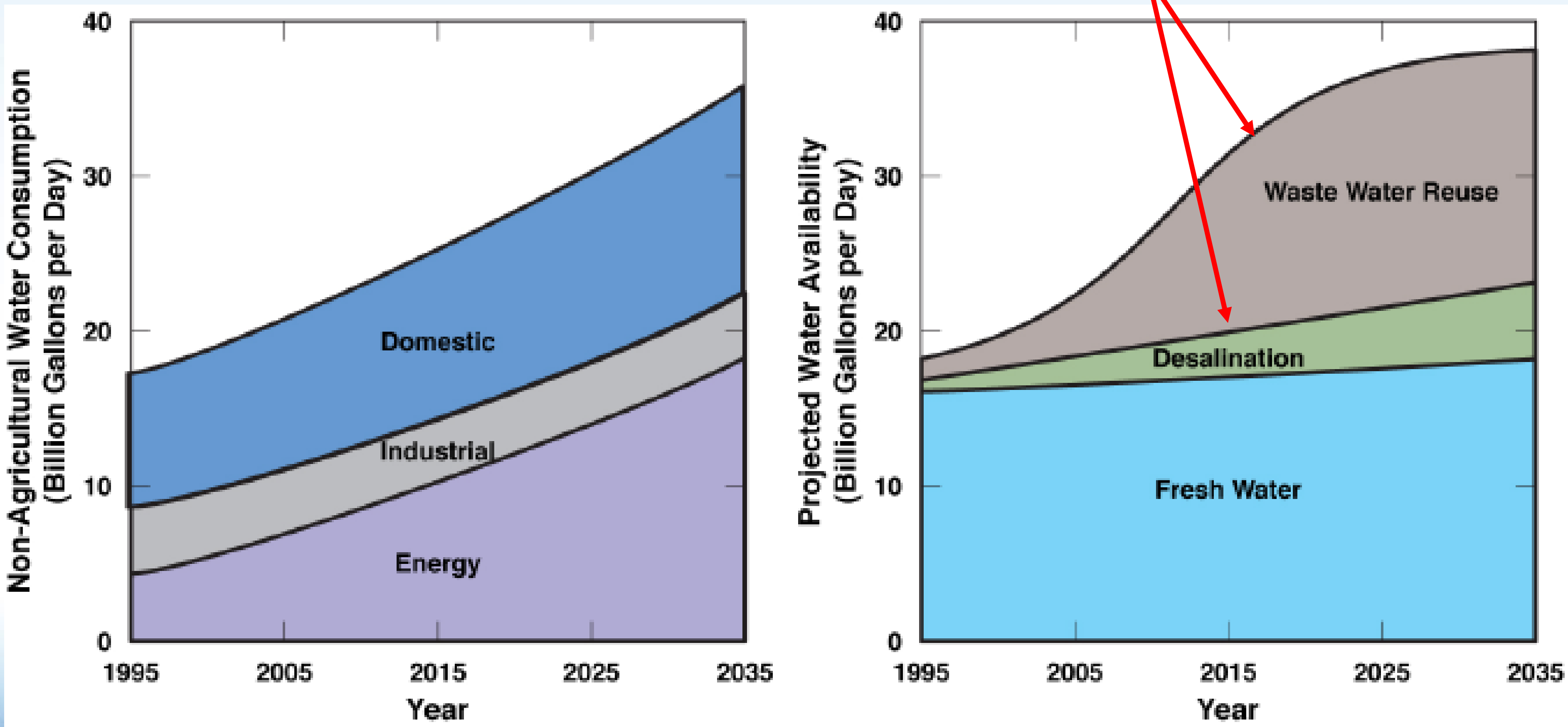
"A" (Approved for Public Release, Distribution Unlimited)

Projected Trends in Non-Agricultural Water Consumption and Available Water Supplies From Fresh and Treated Sources

Take-Away Message: New Water will be Non-Fresh !!



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Water Issues for Alternative Transportation Fuels

Water Demand/Impact of Transportation Fuels

Fuel Type and Process	Relationship to Water Quantity	Relationship to Water Quality	Water Consumption: Water consumed per-unit-energy [gal / MMBTU] †	Water Consumption: Average gal water consumed per gal fuel
Conventional Oil & Gas	Water needed to extract and refine; Water produced from extraction	Produced water generated from extraction; Wastewater generated from processing;		
- Oil Refining			7 – 20	~ 1.5
- NG extraction/Processing			2 – 3	~ 1.5
Biofuels	Water needed for growing feedstock and for fuel processing;	Wastewater generated from processing; Agricultural irrigation runoff and infiltration contaminated with fertilizer, herbicide, and pesticide compounds		
- Grain Ethanol Processing			12 - 160	~ 4
- Corn Irrigation for EtOH			2500 - 31600	~ 980*
- Biodiesel Processing			4 – 5	~ 1
- Soy Irrigation for Biodiesel			13800 – 60000	~ 6500*
- Lignocellulosic Ethanol and other synthesized Biomass to Liquid (BTL) fuels	Water for processing; Energy crop impacts on hydrologic flows	Wastewater generated; Water quality benefits of perennial energy crops	24 – 150 ‡§ (ethanol) 14 – 90 ‡§ (diesel)	~ 2 - 6 ‡§ ~ 2 - 6 ‡§
Oil Shale	Water needed to Extract / Refine	Wastewater generated; In-situ impact uncertain; Surface leachate runoff		
- In situ retort			1 – 9 ‡	~ 2 ‡
- Ex situ retort			15 - 40 ‡	~ 3 ‡
Oil Sands	Water needed to Extract / Refine	Wastewater generated; Leachate runoff	20 - 50	~ 4 - 6
Synthetic Fuels	Water needed for synthesis and/or steam reforming of natural gas (NG)			
- Coal to Liquid (CTL)		Wastewater generated from coal mining and CTL processing	35 - 70	~ 4.5- 9.0
- Hydrogen RE Electrolysis			20 – 24 ‡	~ 3 ‡
- Hydrogen (NG Reforming)			40 – 50 ‡	~ 7 ‡

† Ranges of water use per unit energy largely based on data taken from the Energy-Water Report to Congress (DOE, 2007)
* Conservative estimates of water use intensity for irrigated feedstock production based on per-acre crop water demand and fuel yield
‡ Estimates based on unvalidated projections for commercial processing; § Assuming rain-fed biomass feedstock production

Water Demand for Biofuels Production

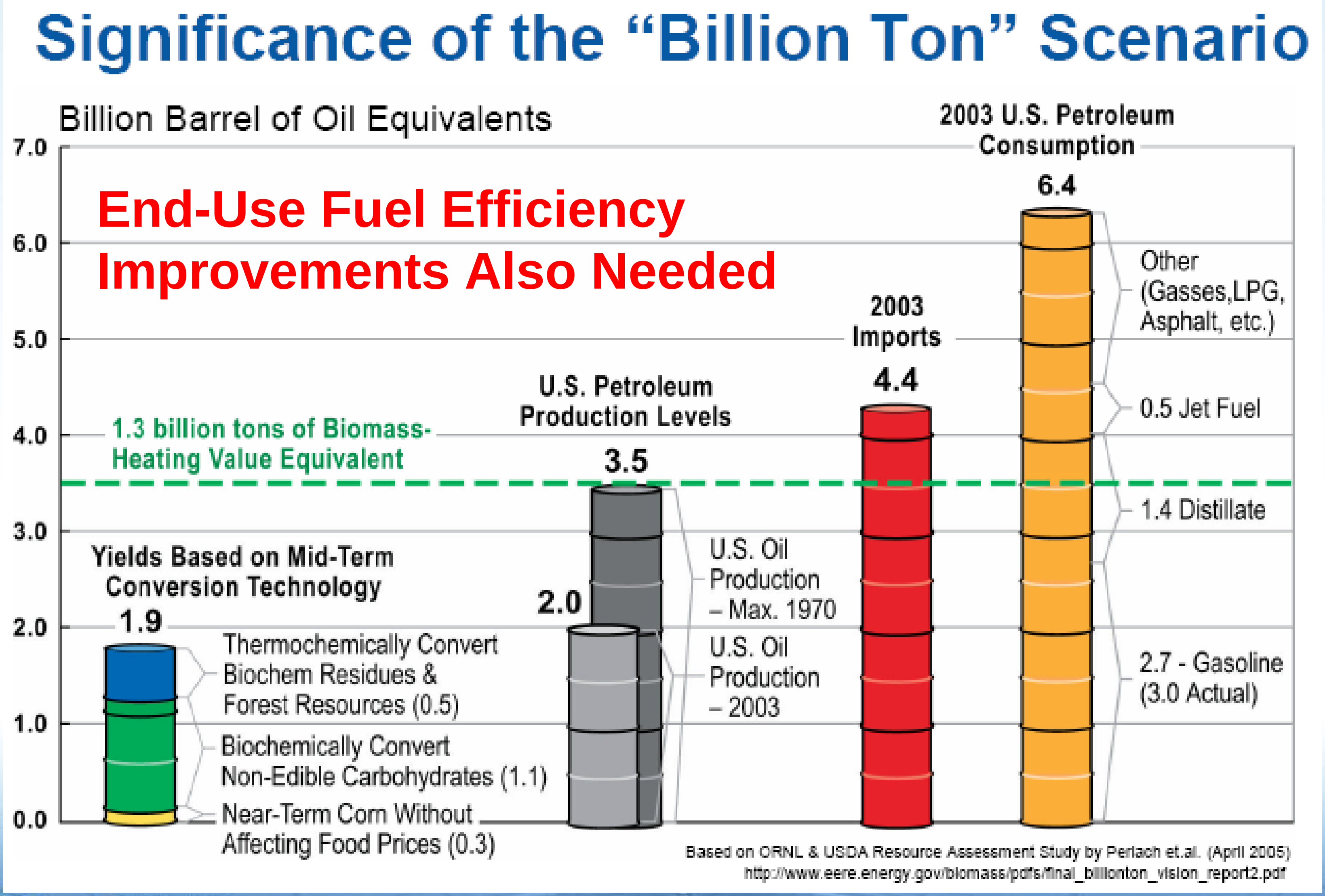
Feedstock Production and Fuel Processing

Fuel Type and Conversion Process	Biomass Feedstock	Processing Water Use Intensity (gal H_2O/gal fuel)		Feedstock Water Use Intensity		
		Process Water Use	Process Water Consumption	Feedstock Water Demand Ac-ft / Acre	Biofuel Yield gal fuel / Acre	Feedstock Water Consumption[d] gal H_2O/gal fuel
Ethanol, Starch or sugar-based Wet mill or Dry mill	Corn	~ 2 - 6	~ 4	~ 1.2	400	980
	Sorghum			~ 1.0	170	1900
	Sugar Cane			~ 2.0	560	1160
	Sugar Beets			~ 2.3	550	1360
Ethanol, Cellulose-based[a] Biochem or Thermochem	Switchgrass	~ 3 – 12 [e] estimate	~ 2 - 6 [e] estimate	~ 2.3	500 - 800 (700 estimated)[b]	Rain-fed
	Woody biomass			~ 2.5	500 – 800	Rain-fed
Biodiesel from Oil Extraction and Trans-Esterification	Soybeans	~ 0.3 - 3	~ 1	~ 0.8	40	6500
	Sunflower			~ 1.5	80	6100
	Oil Palm			≥ 2.5	510	Rain-fed
	Algae	~ 0.3 - 3	~ 1	Not determined [f]	3,000 - 15,000 [c] (5000 estimated)	Not determined [f]

[a] Cellulose-based ethanol yields of 100 gal/dry ton based on laboratory data, processes are still experimental
[b] Switchgrass yields have exceeded 10 dry tons/acre experimentally, but more routinely range from 3 to 7 dry tons/acre
[c] Algal-based biodiesel production estimates based on laboratory and small scale test data; viable high-yield scale-up still uncertain
[d] Water consumption with irrigated feedstock production at per-acre water demand and per-acre biofuel yield levels shown
[e] Estimates based on unvalidated projections for commercial processing; [f] Non-fresh water used; losses mainly from evaporation

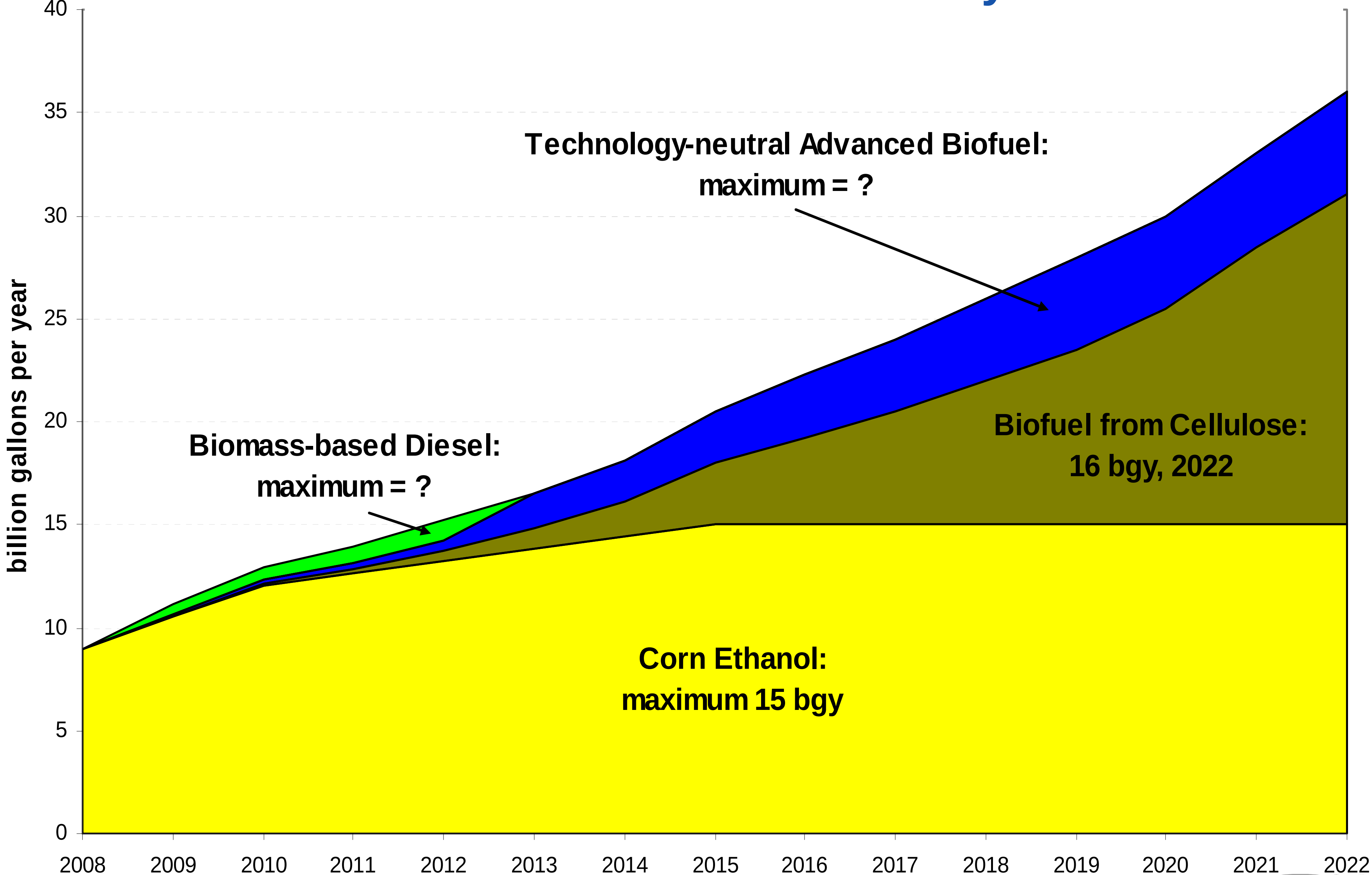
Biofuels Challenge: Sustainable Scale-Up

Replacing Petroleum-based Fuels
… is a Huge Challenge !



EISA 2007 Renewable Fuels Standard

36-Billion Gallons of Biofuel by 2022



Water Impacts Seen with Increase in Biofuels and Bioenergy Production

PERGAMON

Global Environmental Change 12 (2002) 253–281

GLOBAL ENVIRONMENTAL CHANGE

www.elsevier.com/locate/gloenvcha

Bioenergy and water—the implications of large-scale bioenergy production for water use and supply

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Abstract

There are major expectations that bioenergy will supply large amounts of CO_2 neutral energy for the future. A large-scale expansion of energy crop production would lead to a large increase in evapotranspiration appropriation for human uses, potentially as large as the present evapotranspiration from global cropland. In some countries this could lead to further enhancement of an already stressed water situation. But there are also countries where such impacts are less likely to occur. One major conclusion for future research is that assessments of bioenergy potentials need to consider restrictions from competing demand for water resources.

MSNBC StarTribune.com
Minneapolis - St. Paul, Minnesota

Water supply can't meet thirst for new industry

By Greg Gordon / StarTribune

"Nowhere is the growing clash between economic development and water conservation more evident than in the push to build ethanol plants that typically guzzle 3½ to 6 gallons of water for every gallon of fuel produced. Minnesota's 15 ethanol plants together consume about 2 billion gallons of water per year, and plants in Winthrop, Windom, Marshall and Granite Falls are straining available water resources."

Decemeber 26, 2005

- … Emerging as an energy-water nexus issue
- … Need better understanding and management
- … Need innovative approaches & technologies
- … Need options that exploit non-fresh water

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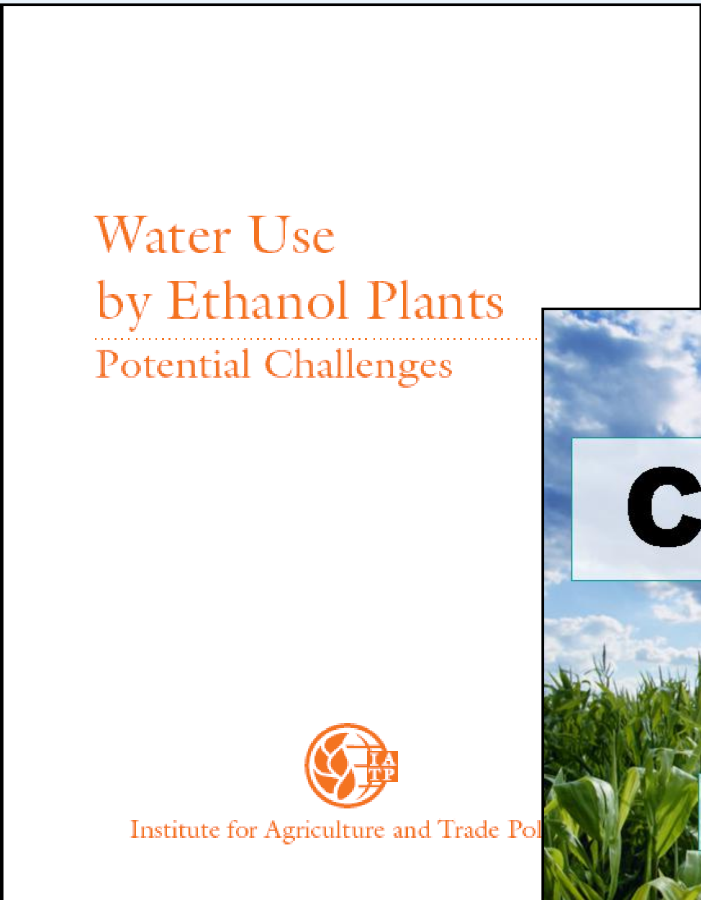
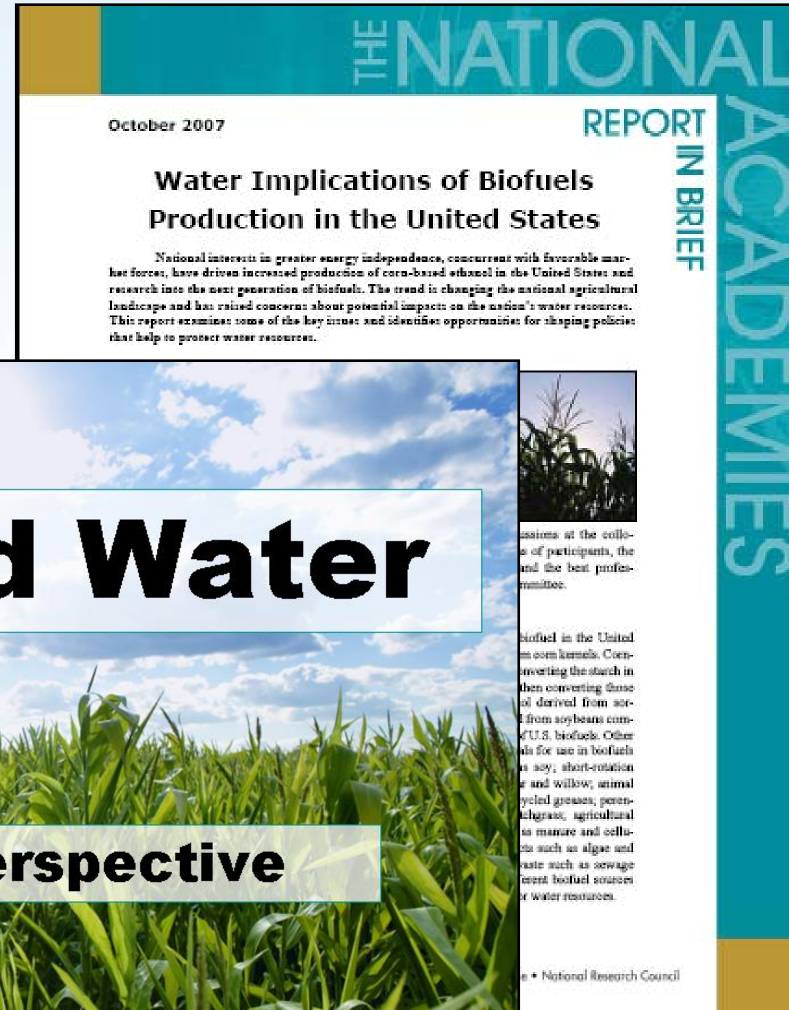
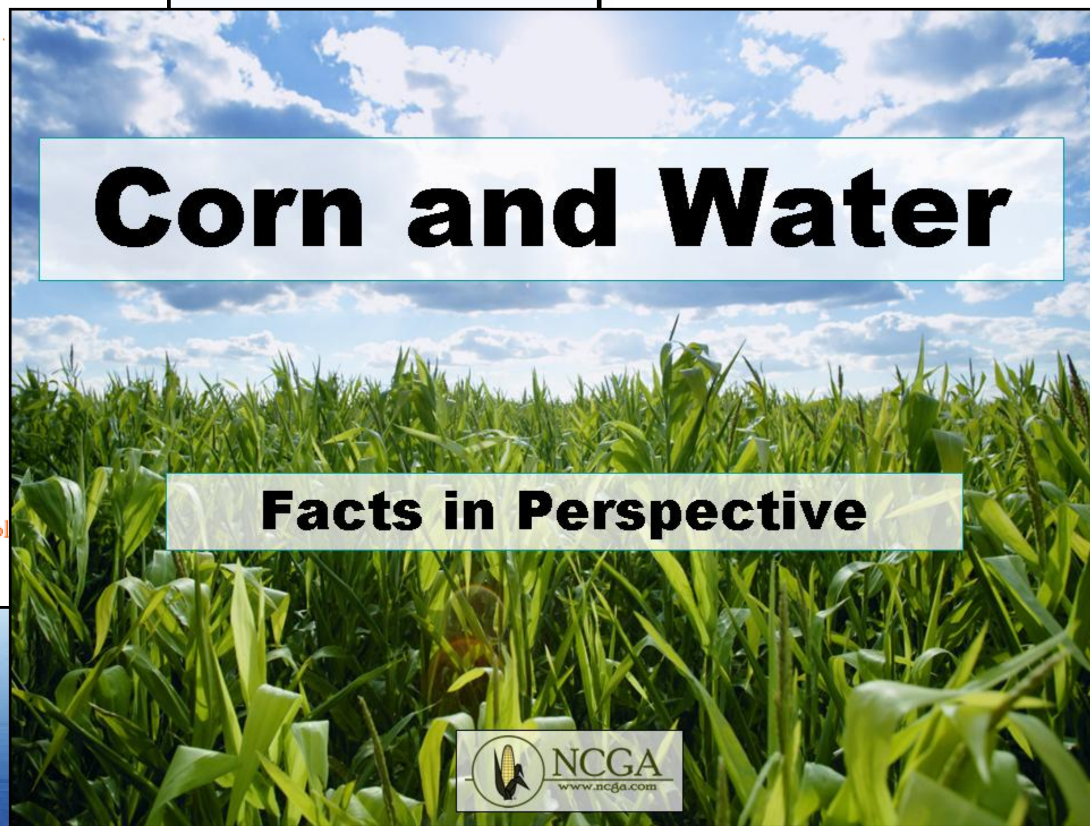
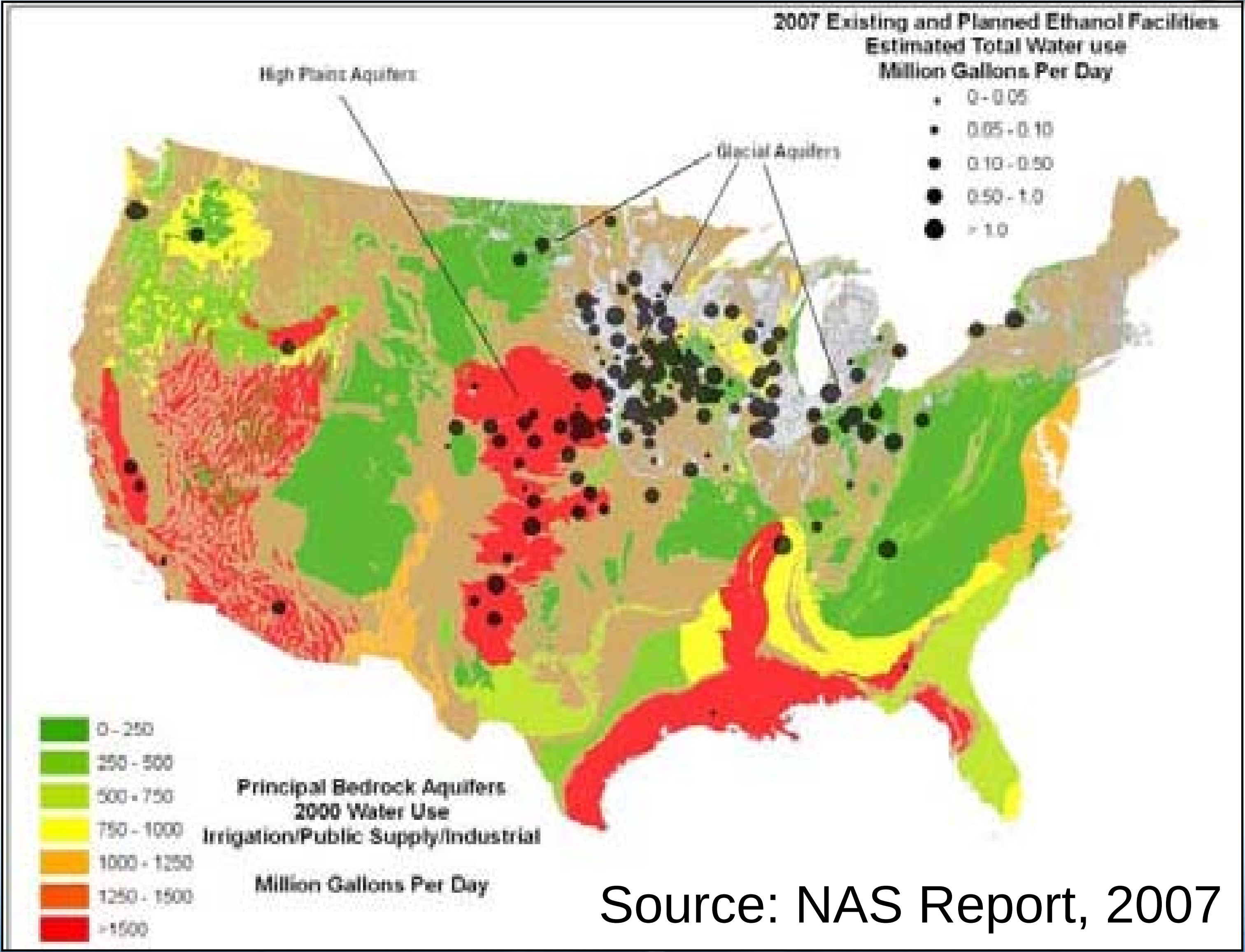
The Biofuel-Water Connection… Subject of Increasing "Discussion"


Water Use
by Ethanol Plants
Potential Challenges
Institute for Agriculture and Trade Pol


THE NATIONAL ACADEMIES
REPORT IN BRIEF
October 2007
Water Implications of Biofuels Production in the United States
National interests in greater energy independence, concurrent with favorable market forces, have driven increased production of corn-based ethanol in the United States and research into the next generation of biofuels. The trend is changing the national agricultural landscape and has raised concerns about potential impacts on the nation's water resources. This report examines some of the key issues and identifies opportunities for shaping policies that help to protect water resources.



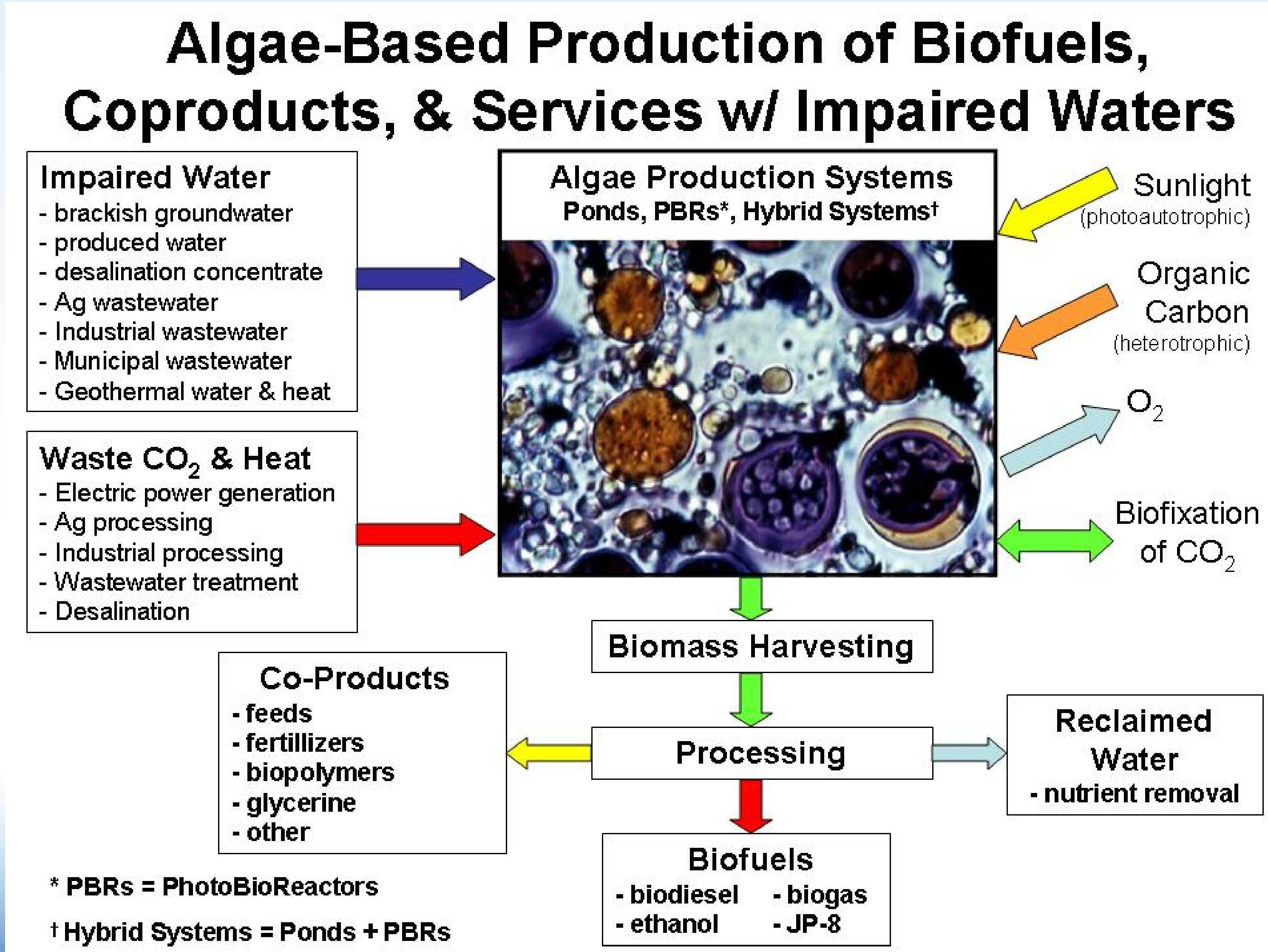
EtOH Production & Groundwater



Source: NAS Report, 2007

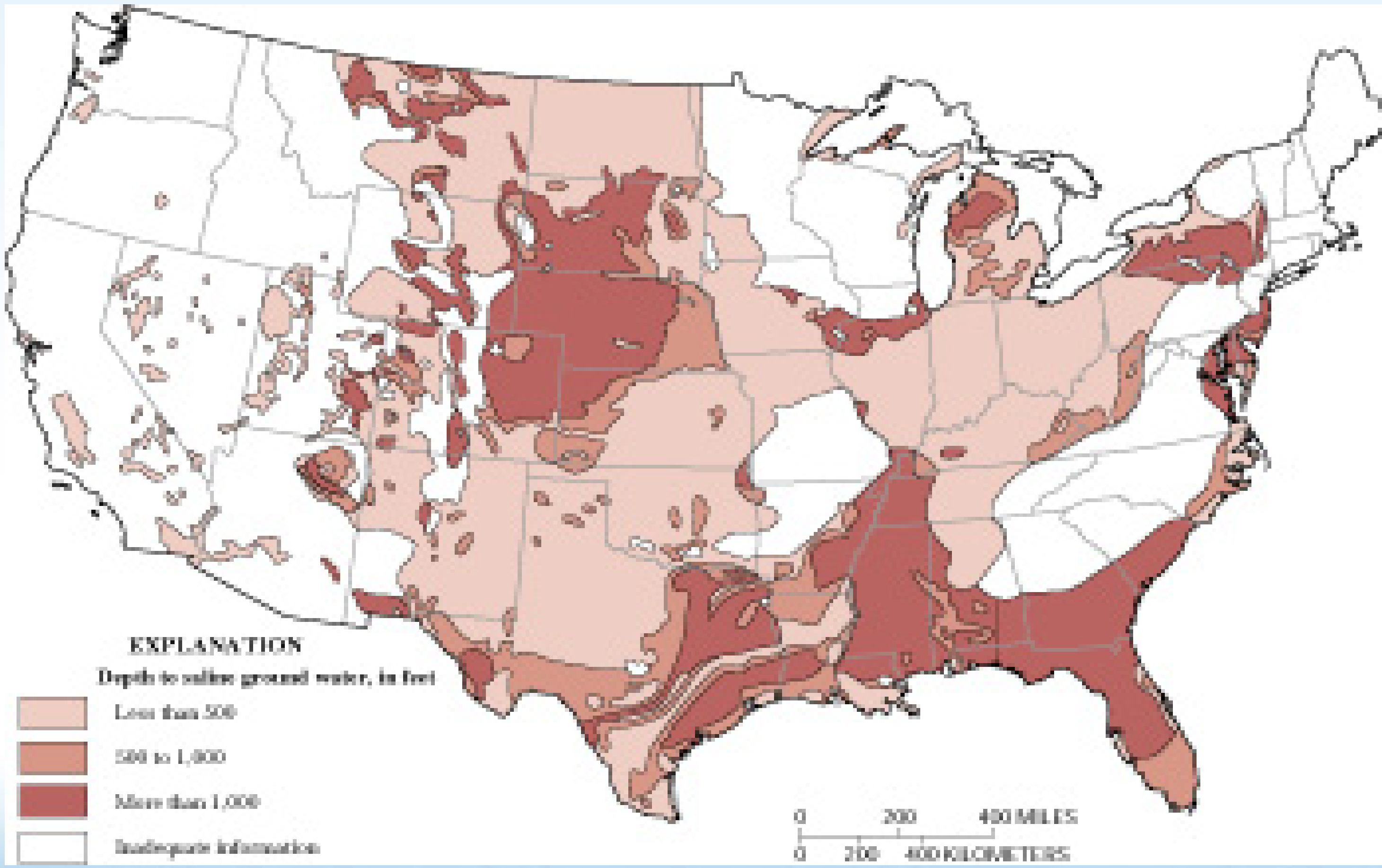
The Promise and Challenge of Algal Biofuels

Opportunity from E-W Perspective:
Biofuel from Algae using Non-Fresh Water Sources



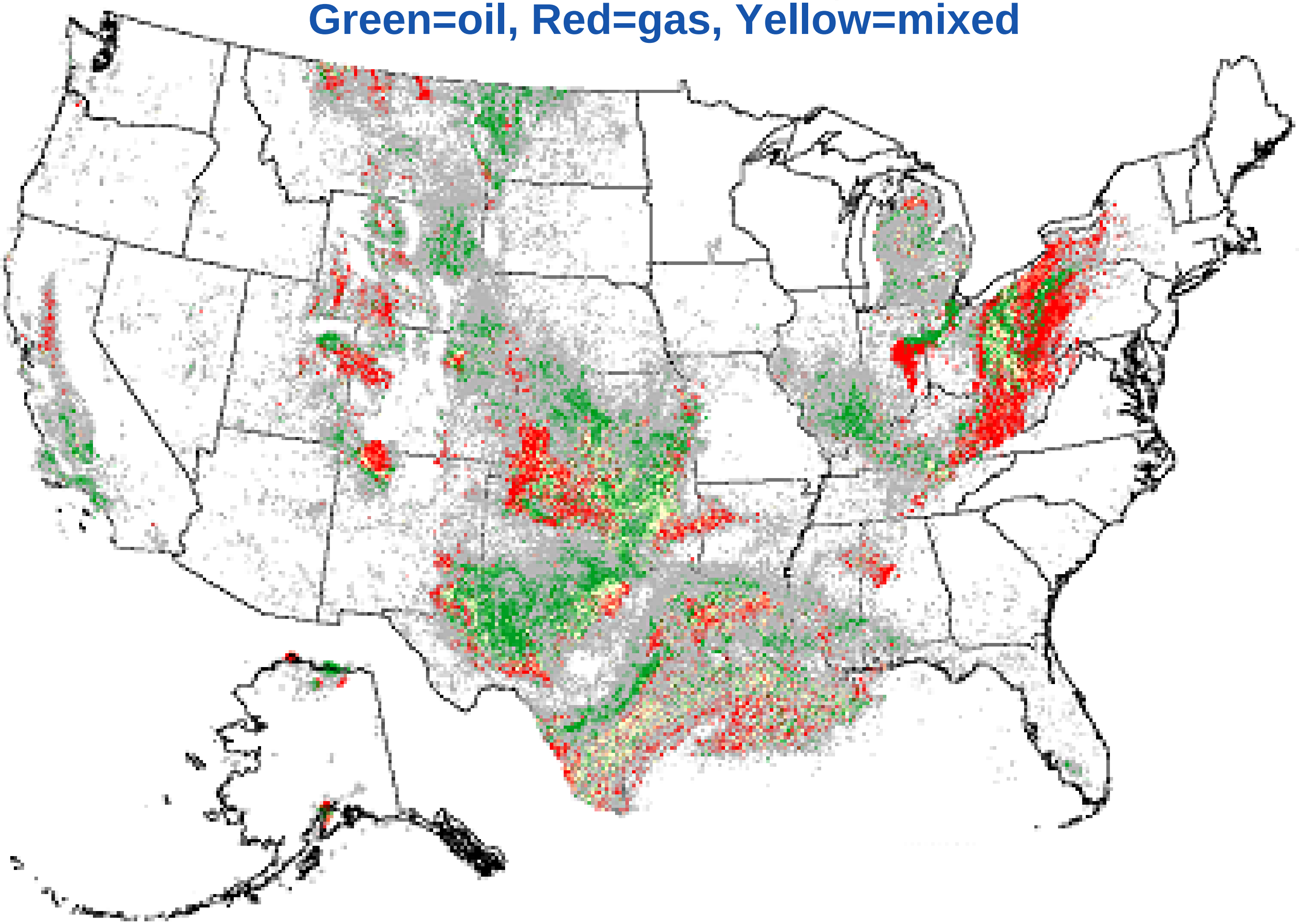
Brackish and Saline Groundwater … Potential Resource for Algae Production

Saline aquifers in the continental U.S. The brown shading refers to the depth of the aquifer. With appropriate treatment, inland brackish water resources could be an important source of water for thermoelectric power plant cooling and biofuel production. (Data from Feth, 1965)

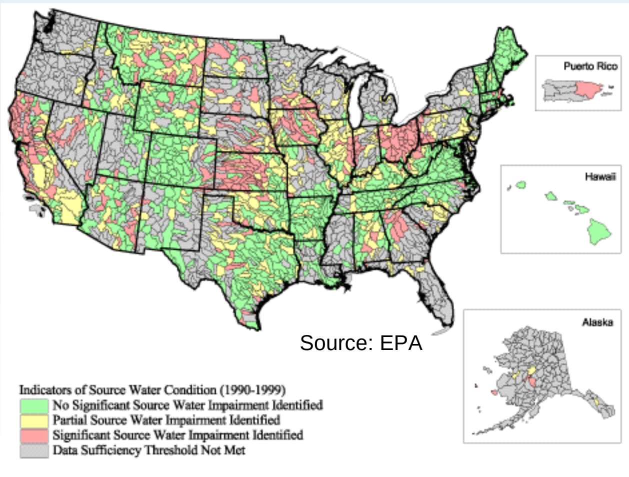


Produced Water from Oil & Gas Wells …
Potential Resource for Algae Production

Green=oil, Red=gas, Yellow=mixed



Pairing Microalgae to Non-Fresh Water to Maximize Algal Oil Production



Water Resources + Microalgae

US Saline Aquifers

Optimal Matches Among Water Properties and Microalgae Growth and Survivability

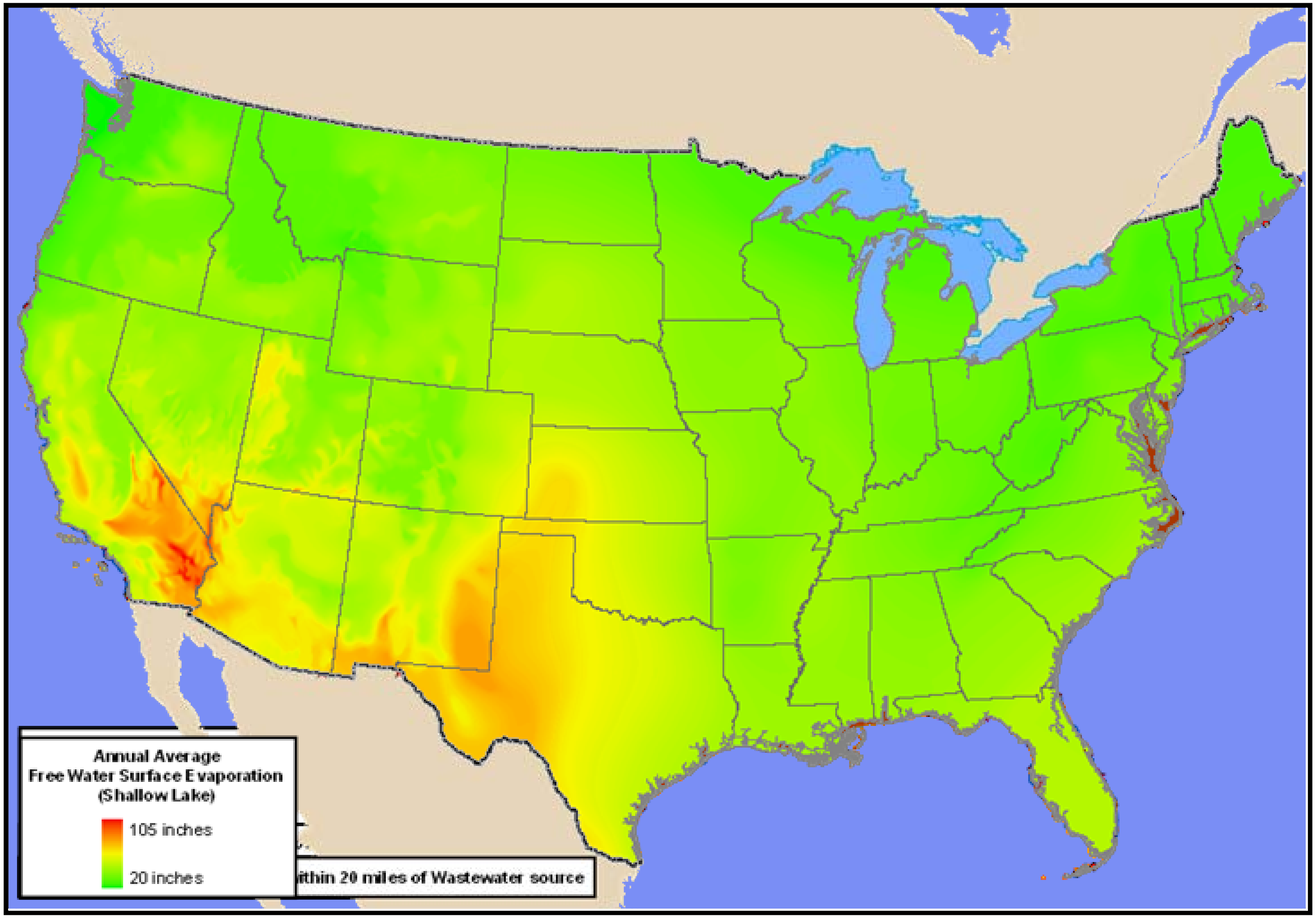
↓

Maximize Triacylglycerol Production

↓

Maximize Microalgal Based Biodiesel and other BioFuels

GIS-based Site Analysis for Algal Biomass Production Facilities



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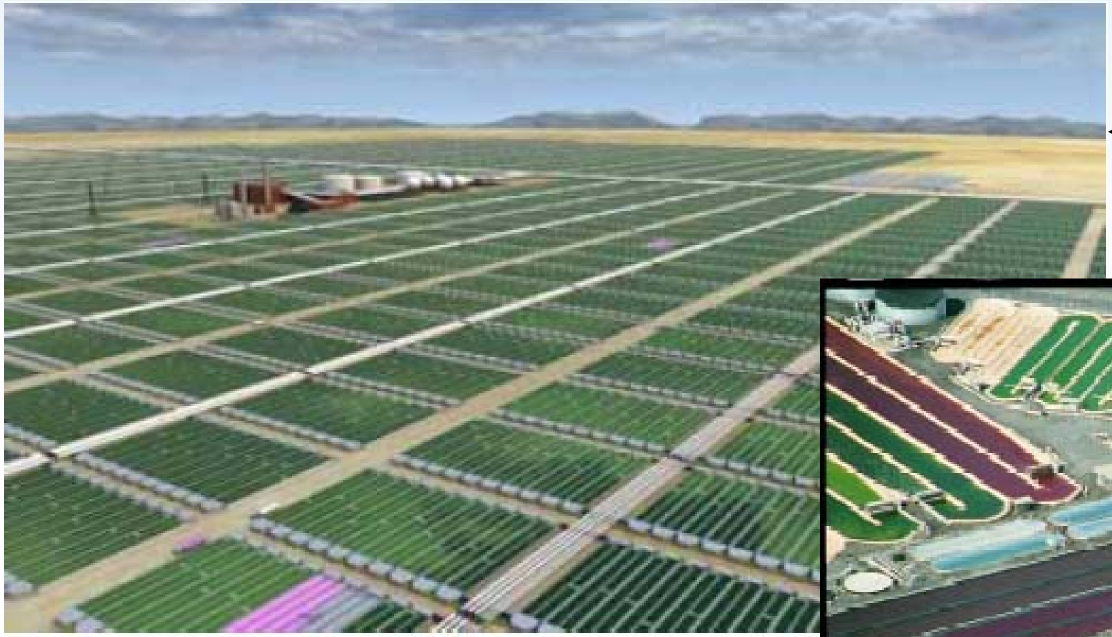
Algal Biomass Production Scale-up Photobioreactor (PBR) vs Pond Systems

… Increased control & performance vs higher infrastructure costs?

… Viability of scale-up for sustainable algal-based biofuel production?

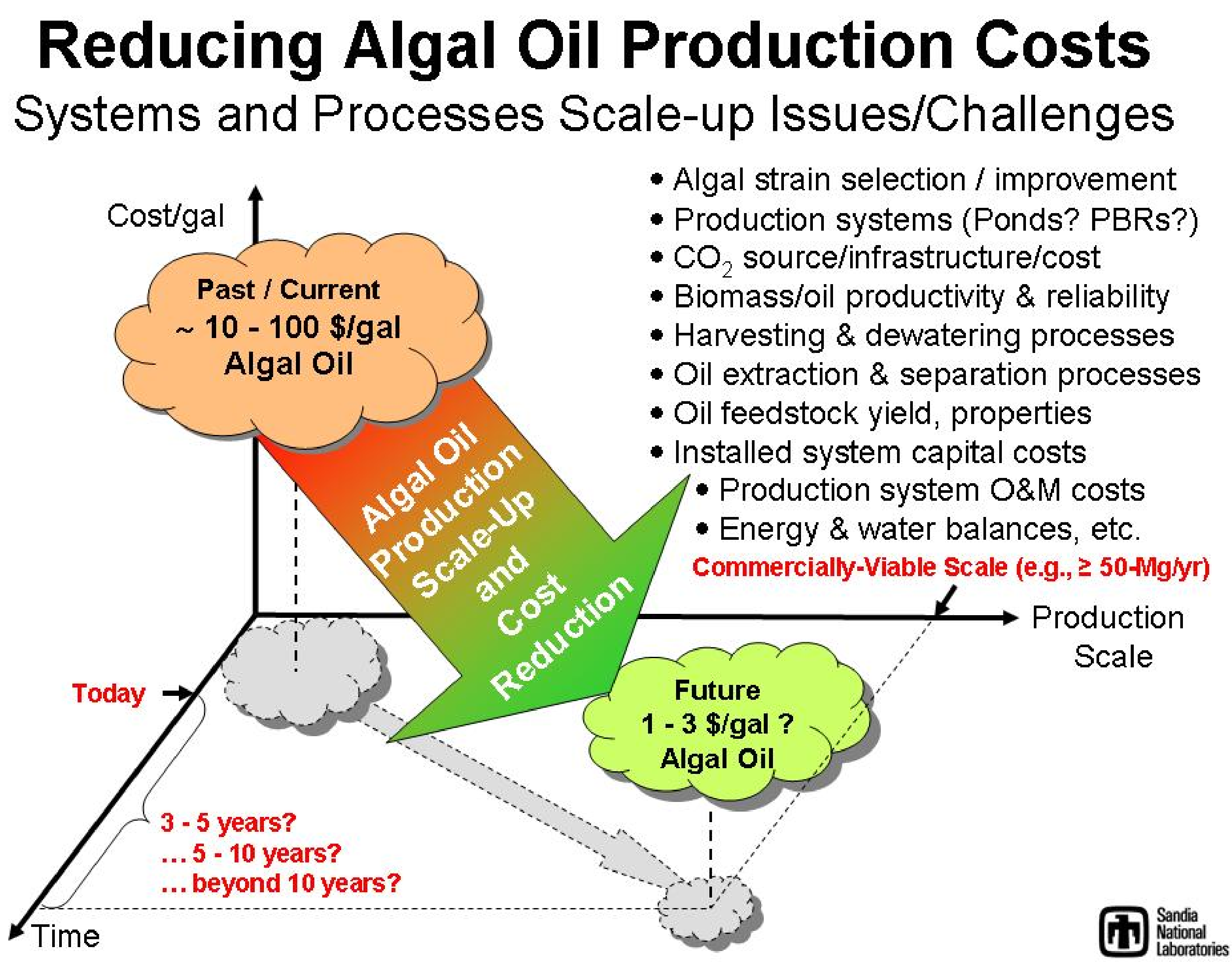


Conceptual Ilustration of Commercial Scale Algal Biomass Production Facility using Photobioreactor systems - Solix

Commercial Microalgae Production Facility using Raceway Pond Systems - Cyanotech Corporation, Kona, Hawaii

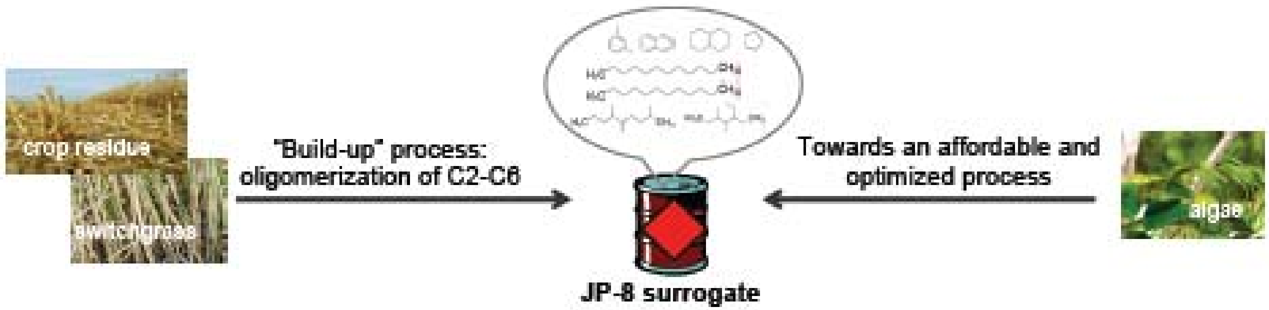
Got Algal Oil?

… not enough and too expensive !



DOD/DARPA is Stepping UP !

BioFuels Program, BAA 08-07



Technical area 1: Cellulosic materials to JP-8

- Cellulosic materials offer the potential as a low-cost feedstock to high-cost oil crops (soy, canola, etc)
- Usage is limited by low processing efficiency
- Leverage and integrate multiple technologies
  - Gasification and liquefaction
  - Biological and catalytic processing
- Key technical challenge is to develop a highly efficient process to JP-8 from cellulosic materials

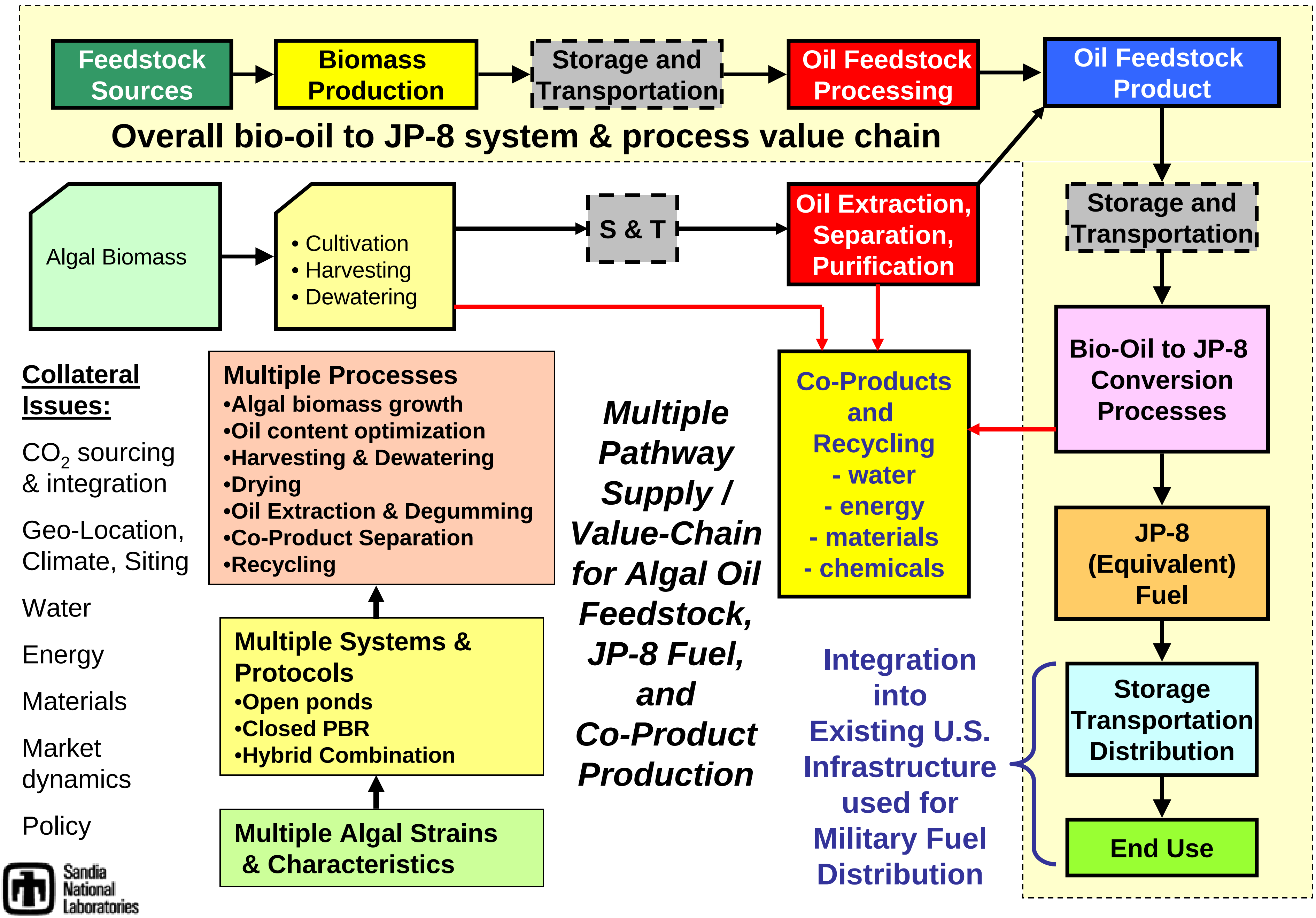
- **Phase 1**: 30% energy conversion efficiency
- **Phase 2**: 50% energy conversion efficiency

Technical area 2: Algal to JP-8

- Algae offers the potential for high-oil yields/acre
- Usage is limited by high-cost processing factors for large-scale production
- Leverage advances already achieved in current BioFuels program through teaming and/or licensing
- Key technical challenge is to develop an integrated algal production system for low-cost oil production

- **Phase 1**: production cost at < $2/gal
- **Phase 2**: production cost at < $1/gal

Bio-Oil-to-JP8 Systems Analysis Framework

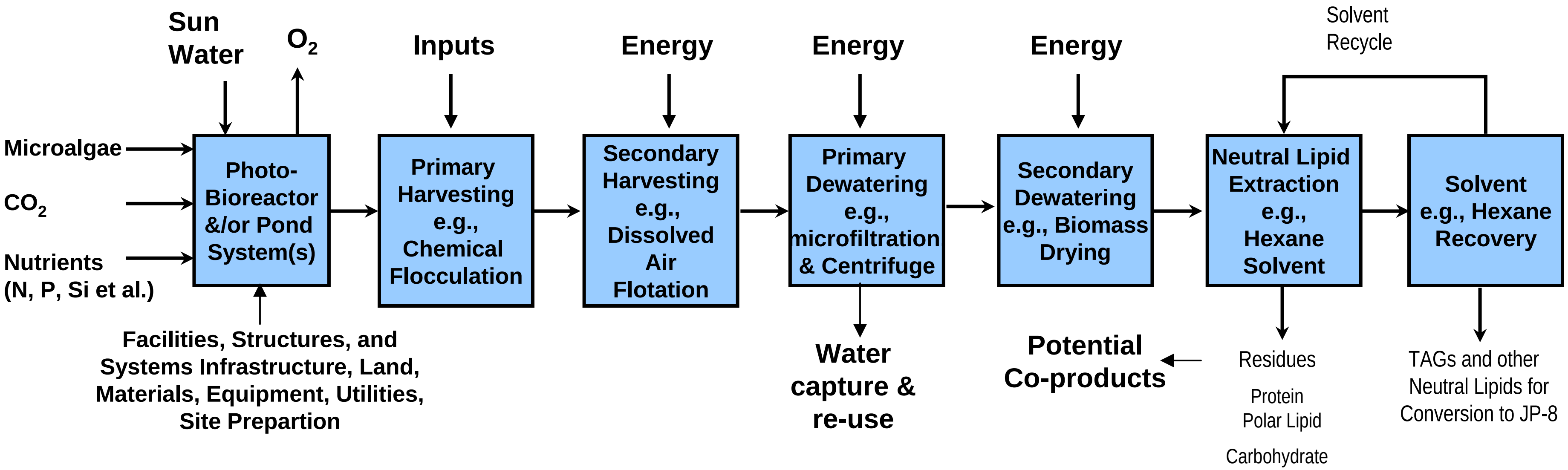


Algal Oil Production Notional “Baseline” Scale-Up Assessment

PBR & Open Pond Systems Approaches

Based on limited available information from open sources applied to two generic algal production system configurations:
1) PBR with cooling to prevent overheating;
2) open raceway pond

Baseline Cost/Performance Analysis Algal Oil Production Systems/Processes



Approach to microalgae oil production cost estimation

- Use Benemann and Oswald's economic analysis in 1996 PETC report (open pond) and more recent pond and PBR technical/economic analyses (e.g., Chisti (2007), Richmond (2004), Molina Grima, et.al. (2003), etc.) for background and comparison
- Develop mod/sim/analysis/LCA of overall system/process chain (diagram shown above)
- Apply unit operations and designs validated by data from outdoor development systems
- Apply scale-up and infrastructure build-up cost/benefit assessments
- Update economic analysis to reflect
  - Inflation
  - New unit operations
- Identify improvement opportunities with systems and processes through sensitivity analysis of multiple pathway options

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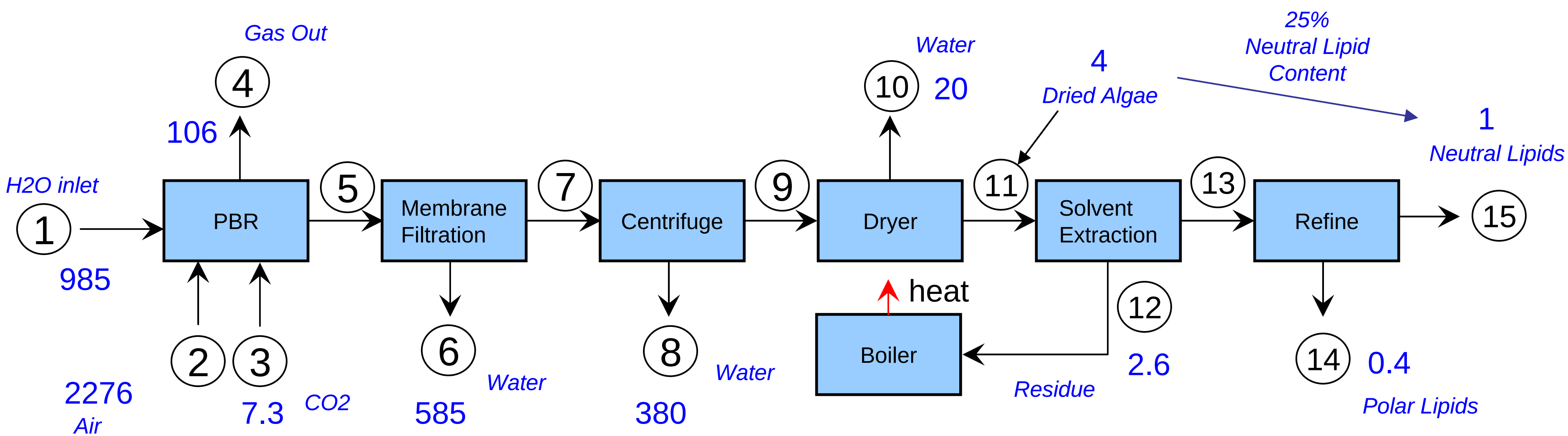
Algal PBR Mass Balance at 50M gal/year

- Capture 75% carbon from 1 GW power plant in daylight
- 68 km^2 (16,796-Ac) to produce 50 million gallons/year of triglyceride
- Productivity ~2977 gal/Ac of Neutral Lipid TAG
- Significant evaporative water loss for cooling PBR ~ 1000:1 (H_2O:oil)



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Description	Water Inlet	Air Inlet	Fertilizer	Air Outlet	PBR out	Mem Water	Slurry	Cent Water	Paste	Exhaust	Dried Algae	Bioresidue	Crude Oil	Polar Lipids	Pure Oils
Biomass (lbs/hr)					186,346		186,346		186,346		186,346	121,125			
Neutral Lipids (lbs/hr)													46,587		46,587
Polar Lipids (lbs/hr)													18,635	18,635	
Water (lbs/hr)	45,917,314				45,871,494	27,236,863	18,634,631	17,702,899	931,732	931,732					
CO2 (lbs/hr)		341,635		-											
O2 (lbs/hr)				227,757											
Air (lbs/hr)		106,017,391		106,017,391											
Fertilizer (lbs/hr)			26,648												
Total	45,917,314	106,359,026	26,648	106,245,148	46,057,840	27,236,863	18,820,977	17,702,899	1,118,078	931,732	186,346	121,125	65,221	18,635	46,587

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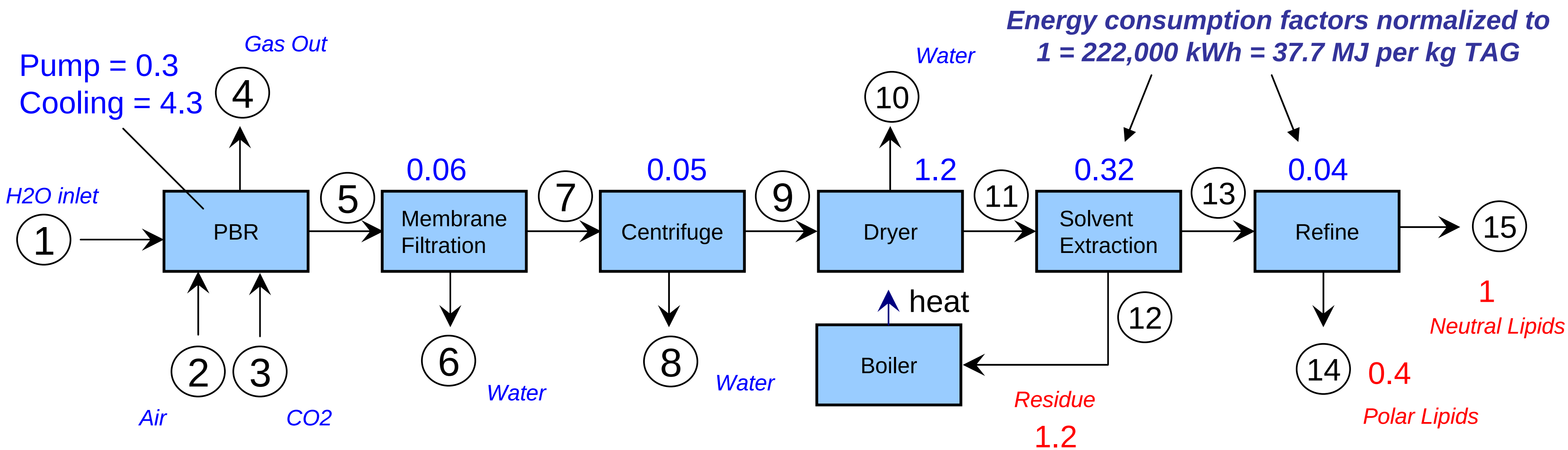
Algal PBR Energy Balance at 50M gal/year

- Direct cooling with chilled water is too energy intensive
- Indirect cooling requires less energy but requires more water
- Drying of biomass is too energy intensive and must be significantly reduced or eliminated



Unit Operation	Energy (kW)
PBR - Aeration	68,512
Cooling Requirement	954,693
Membrane Filtration	12,360
Centrifuge	11,562
Dryer	264,805
Solvent Extraction	69,924
Degumming	7,790

Algal Oil Production Order-of-Magnitude (OOM) Cost Estimate

Basis

- Costs taken from Benemann and Oswald report (1996) and adjusted to 2008 dollars
- Balance of plant costs[1] estimated from Peters et al. (2002)[2] based on historical data from petrochemical industry
- No credit for co-products

Caveat

- Estimates based on limited data so should only be used with great caution

Reactor Type	Oil Cost ($/gal)
Open Pond	9 - 17
PBR ($10/m^2)[3]	20 - 38

[1] Costs are (1) equipment costs - purchased off-the-shelf from vendors, and (2) balance of plant, or everything else - installation, infrastructure, utilities, controls, et al.

[2] Plant Design and Economics for Chemical Engineers by Max S Peters, Klaus D Timmerhaus, Ronald E. West, (2002).

[3] Aggressive cost estimate based on thin plastic material PBR approaches that may be scaleable.

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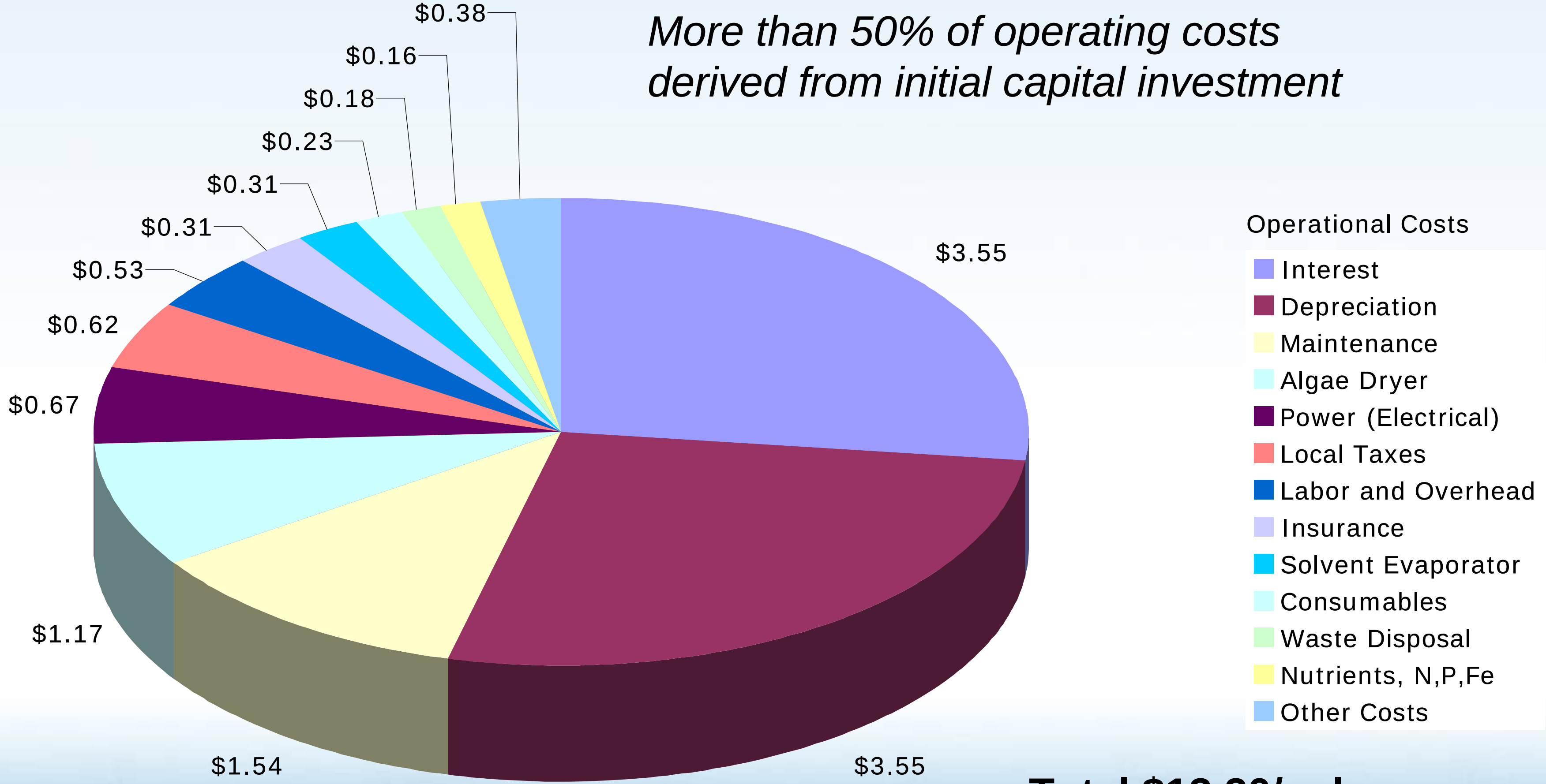
OOM Cost Breakdown for Open Pond System

More than 50% of operating costs derived from initial capital investment



Total $13.20/gal

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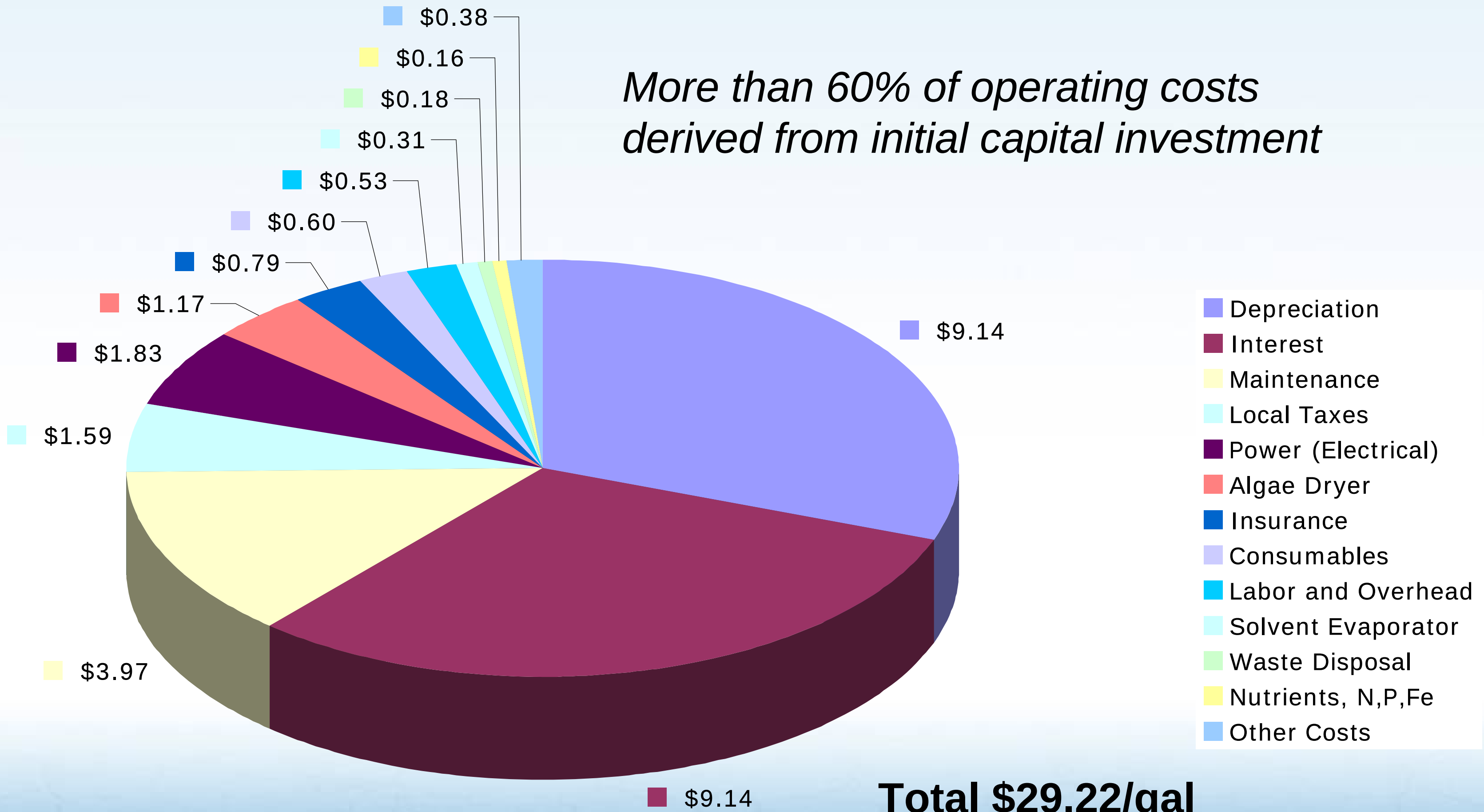
OOM Cost Breakdown for Closed PBR System

More than 60% of operating costs derived from initial capital investment

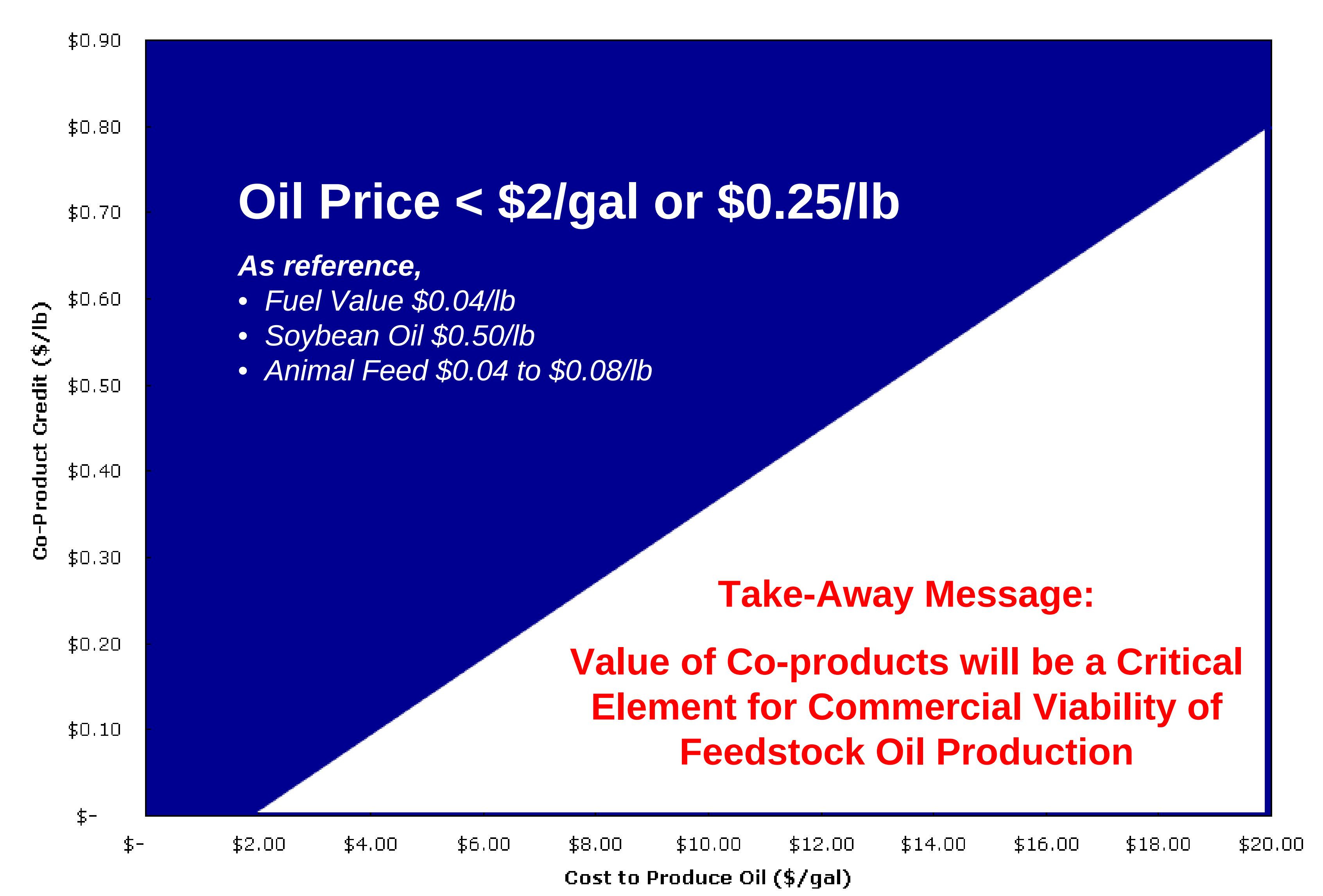


Total $29.22/gal

Algal Oil Production Cost Reduction Opportunities and Areas Needing R&D

- Improved species and growth/lipid production protocols
- Reduce capital costs of systems and equipment with systems innovation (materials, etc.) and by simplifying processes, e.g. - eliminate centrifuge (also big energy user)
- Develop and find market for non-oil co-products
- Alternate oil extraction methods that avoid need for drying
- Utilize waste streams and infrastructure & recycle nutrients/water
  - Ag wastes
  - Wastewater treatment facilities
- Systems integration with CO_2 waste stream sources

Oil Price Reduction from Co-Product Credit



Conclusions

- Algal Biofuels of Significant Interest from E-W Perspective
- Potential for Very High Oil Feedstock Productivity with Non-Fresh Waters, Reduced Land Footprint, and CO_2 recycling
- Could Lead to Biofuel Scale-Up w/ Reduced Impacts on:
  - **Fresh Water Supplies**
  - **Higher Productivity Agricultural Lands**
  - **Food/Feed/Fiber Markets**
- Challenges with Algal Biology, Systems, Processes
  - **Cost-effective, commercially-viable production scale-up**
  - **Sustainable resource utilization (Energy-balance, water-balance, net GHG emissions, productive use of waste streams)**
  - **Thermal management & salt management are issues/concerns**

Thank you !

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