Sandia National Laboratories

Exceptional Service In the National Interest

Promise and Challenges for Algae Biofuels in the Southwest

SAND2009-6931C

Southwest Hydrology Workshop:
Water and Land for Renewable Energy in the Southwest

Tucson, AZ
October 22-23, 2009

Mike Hightower: *Energy Systems Analysis*

Ron Pate: *Energy, Resources & Systems Analysis*

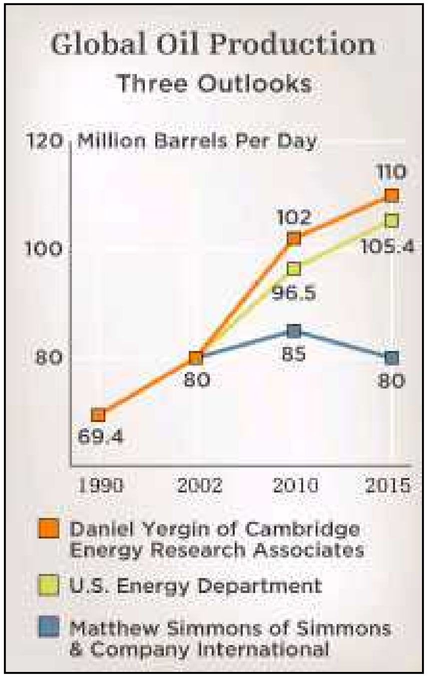
Sandia National Laboratories
Albuquerque, NM
mmhight@sandia.gov, (505) 844-5499
rcpate@sandia.gov, (505) 844-3043

NNSA National Nuclear Security Administration

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000

Recap of Biofuels 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 $400(+/-) B/yr burden on U.S. economy
    … supports interests hostile to US
  - Increasing competition (China, India, etc.)
    & price volatility for limited global supplies
  - Inevitability of "Peak Oil"
    … timing is uncertain, but long-term eventuality is not



- **Desire/Demand for Reduced GHG Footprint**
  - Climate Change concerns make renewable biomass-based fuels attractive
  - Potential for displacing fossil carbon fuels with more carbon-neutral fuels
  - Energy balance depends on systems and processes… not all good !

- **Energy-Water-Environment-Economy Interdependencies**
  - Need solutions to affordable & *sustainable* scale-up
  - Need to ID best paths to avoid or minimize adverse impacts

Sandia National Laboratories

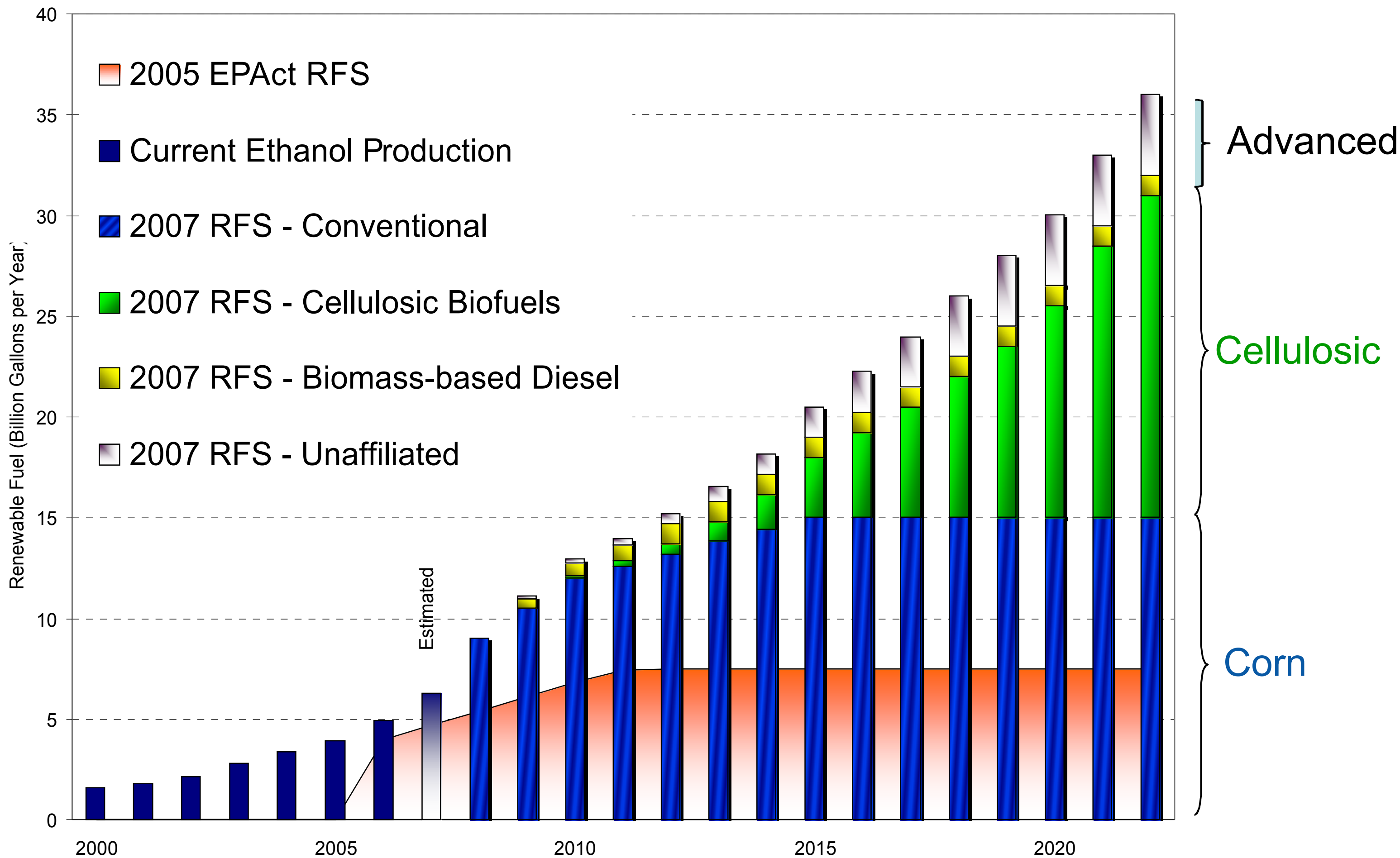
Snap-Shot of U.S. Transportation Fuel Use and CO_2 Emissions

- Breakdown of Annual U.S. Fuel Use for Transportation:
  - Gasoline blends: ~140-B gal/yr
  - Diesel: ~ 45-B gal/yr
  - Aviation: ~ 25-B gal/yr
  - Total: ~ 210-B gal/yr
- Burning each of these fuels produces ~ 20 pounds of CO_2 per gallon
- 210-B gal/yr x 20-lbs CO_2/gal ~ 2.1 Billion tons of CO_2 emitted per year
- Compared with ~ 4-Billion tons CO_2 from stationary sources (power plants, cements plants, ethanol plants, etc.)
- Capture and sequestration of CO_2 and/or re-use of emitted carbon from transportation vehicles is impractical

Sandia National Laboratories

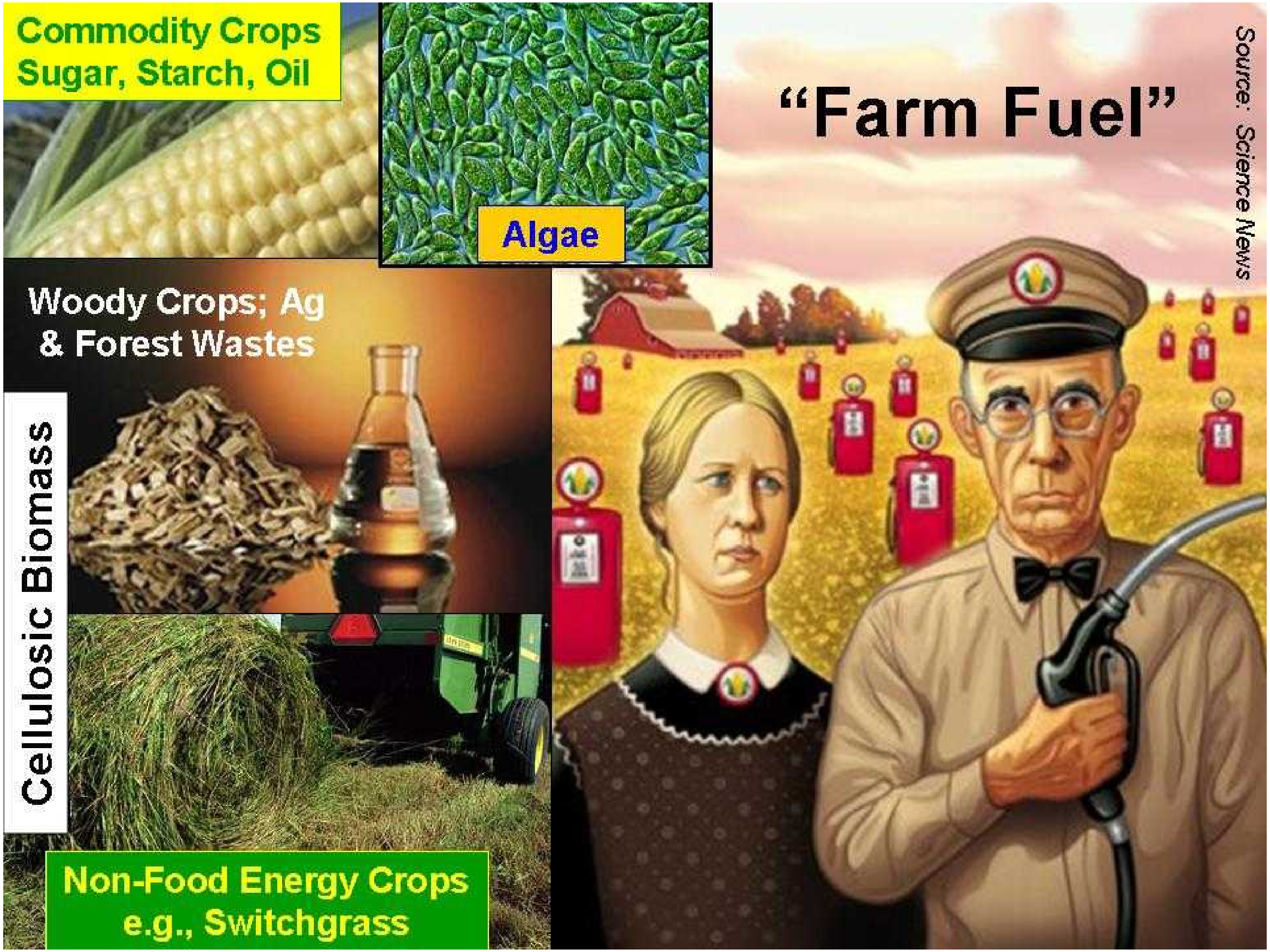
Policy Driver: Advanced Biofuels in 2007 EISA Renewable Fuel Standard

36 billion gallons of renewable fuels by 2022



Source: EISA 2007, Sec. 202, p. 121 Stat 1522-1523

Biofuels Challenge: Sustainable Scale-Up



Sandia National Laboratories

Water: Key Factor for Sustainable Biofuels

A Growing Awareness of Energy-Water Interdependencies

Water Use
by Ethanol Plants
Potential Challenges

IATP
Institute for Agriculture and Trade Policy

THE NATIONAL ACADEMIES

REPORT IN BRIEF

October 2007

Water Implications of Biofuels Production in the United States

production based on discussions at the colloquium, written submissions of participants, the peer-reviewed literature, and the best professional judgments of the committee.

Types of Biofuels

Currently, the main biofuel in the United States is ethanol derived from corn kernels. Corn-based ethanol is made by converting the starch in corn kernels to sugars and then converting those sugars into ethanol. Ethanol derived from sorghum and biodiesel derived from soybeans comprises a very small fraction of U.S. biofuels. Other potential sources of materials for use in biofuels include field crops such as soy; short-rotation woody crops such as poplar and willow; animal fats, vegetable oils, and recycled greases; perennial grasses, such as switchgrass; agricultural ...

The New York Times
nytimes.com

October 11, 2007

Panel Sees Problems in Ethanol Production

By CORNELIA DEAN

Greater cultivation of crops to produce ethanol could harm water quality and leave some regions of the country with water shortages, a panel of experts is reporting. And corn, the most widely grown fuel crop in the United States, might cause more damage per unit of energy than other plants, especially switchgrass and native grasses, the panel said.

BusinessWeek

About Our New Look

THE ASSOCIATED PRESS October 11, 2007, 11:58AM ET

India, China biofuels may sap water

By MICHAEL CASEY

BANGKOK, THAILAND

China's and India's plans to produce more biofuels could cause shortages of water, which is needed for crops to feed their growing populations, according to a water study released Thursday.

The International Water Management Institute or IWMI study said both countries are counting on maize and sugarcane, which need large amounts of water, for much of their biofuels.

Sandia National Laboratories

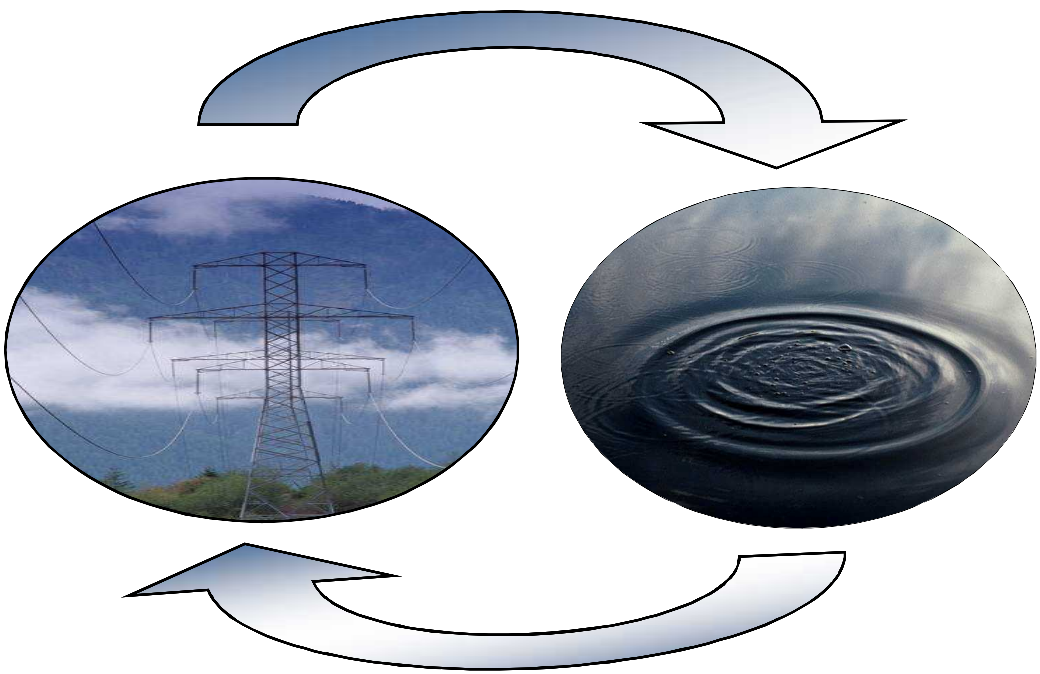
The *Energy-Water Nexus*

Energy and Water are Inextricably linked

<u>Water for Energy</u> and ***<u>Energy for Water</u>***

Energy and power production requires water:

- Thermoelectric cooling
- Hydropower
- Energy minerals extraction / mining
- Fuel Production (fossil fuels, H_2, **biofuels**, other non-conventional fuels)
- Emission controls

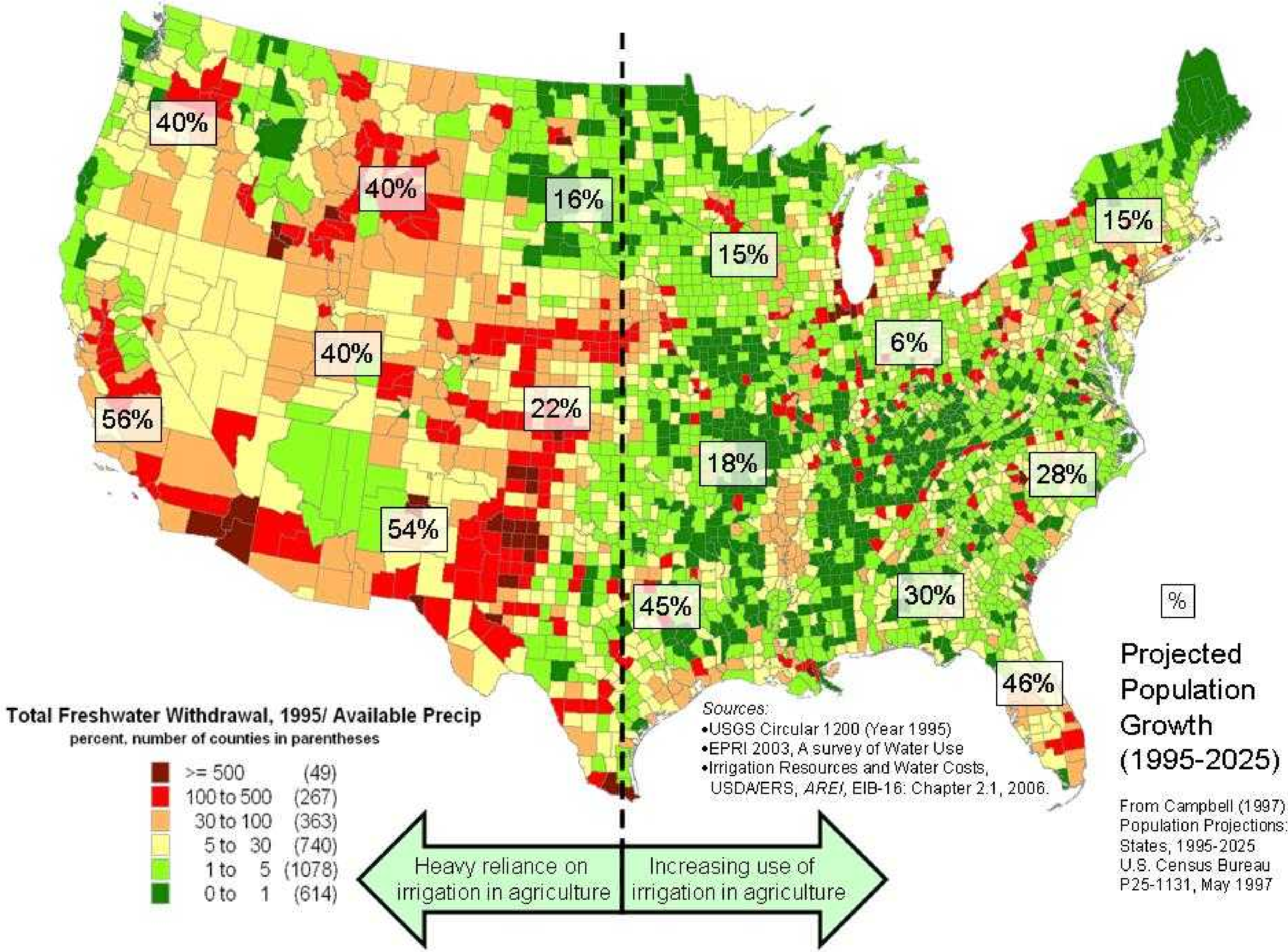


Water production, processing, distribution, and end-use requires energy:

- Pumping
- Conveyance and Transport
- Treatment
- Use conditioning
- Surface and Ground water

Sandia National Laboratories

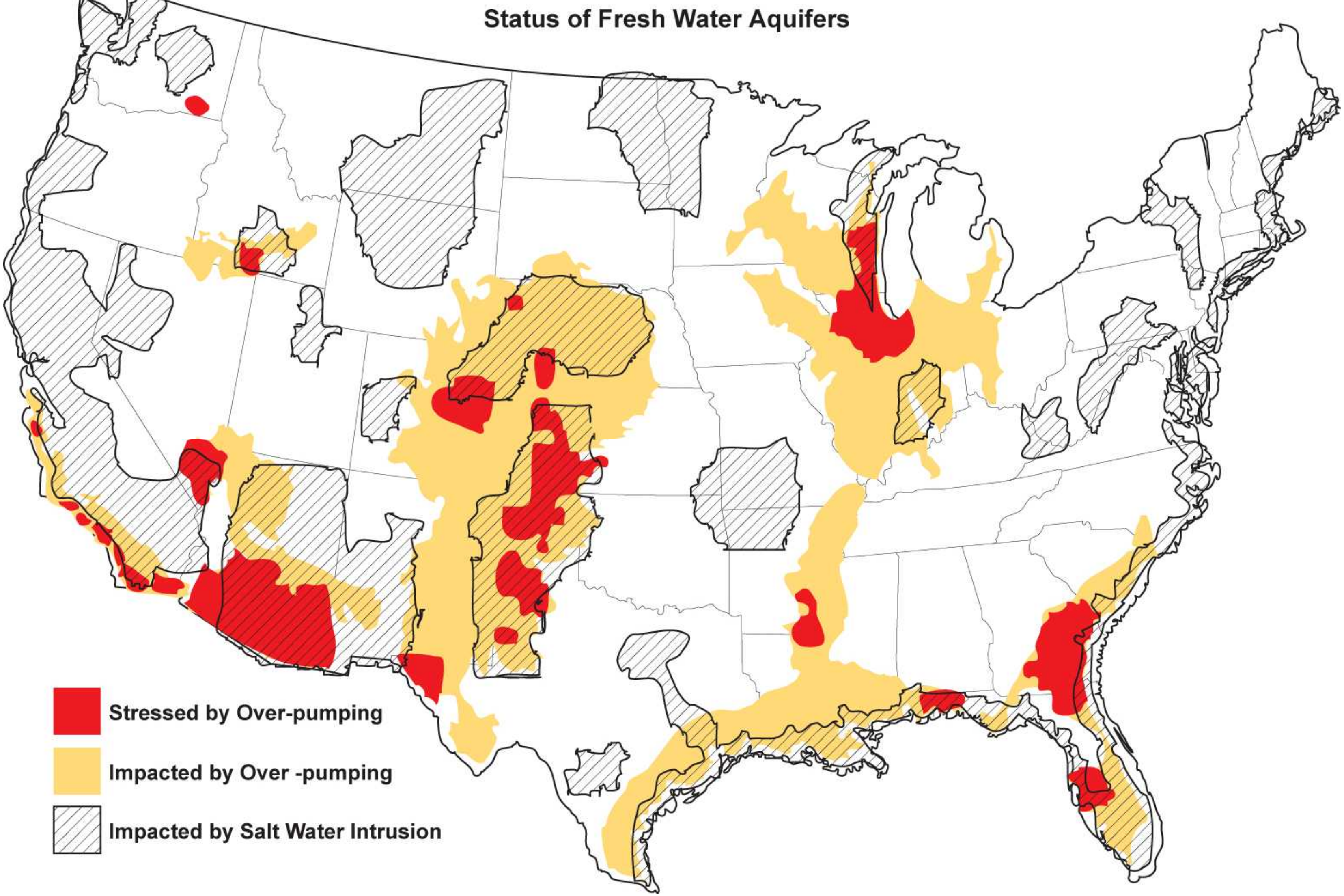
Water Challenges are Nationwide



Sandia National Laboratories

Aquifers Impacted by Over-Pumping

(Shannon, 2006)

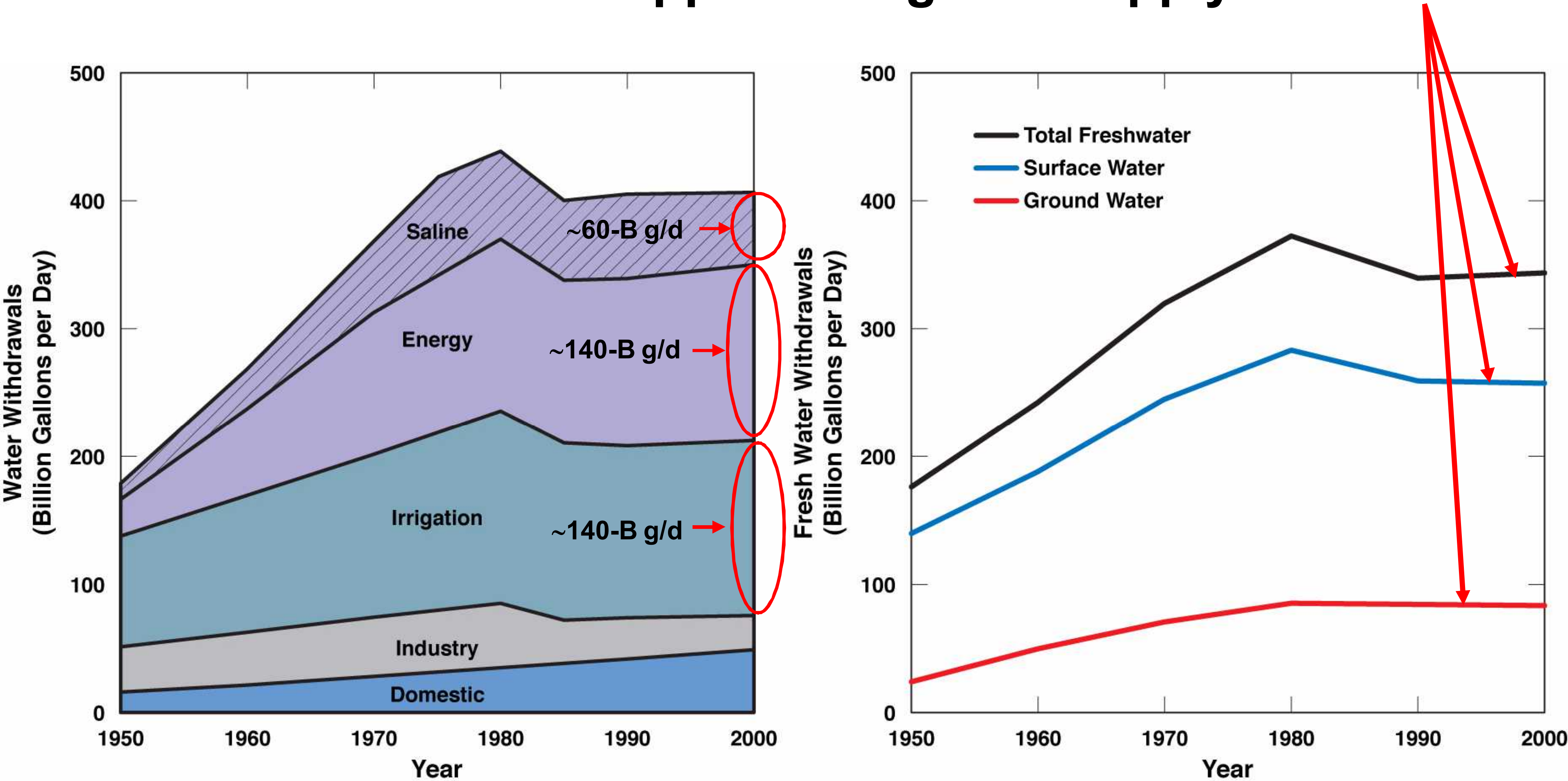


Sandia National Laboratories

Trends in U.S. Water Withdrawals

1950-2000 (Hutson, et.al., 2004)

Recent Trends Flat … Approaching Full Supply Allocation



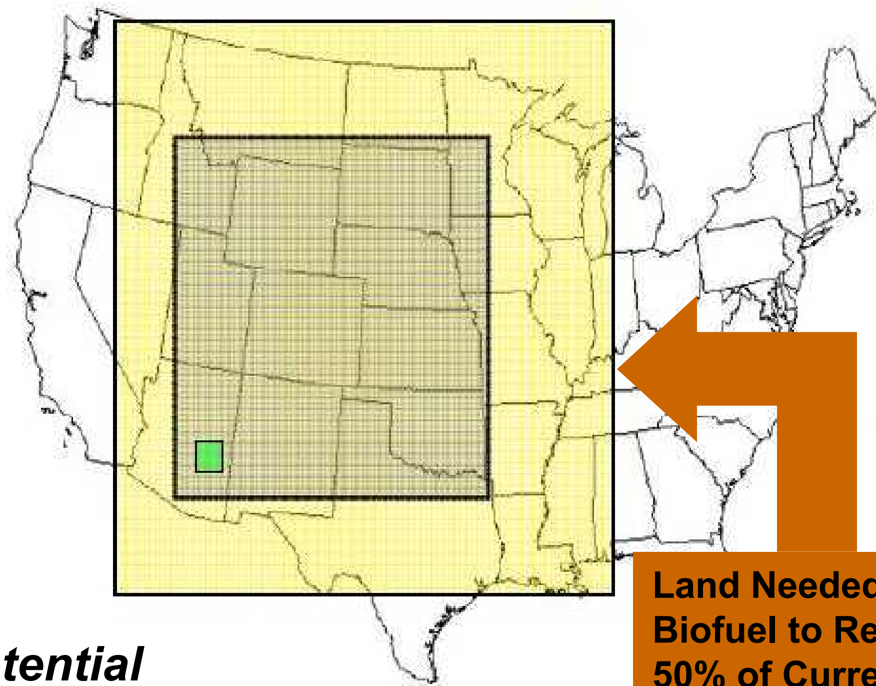
Major Biofuel Production Scale-Up Will Need to Include Exploitation of Non-Fresh Water Sources

Sandia National Laboratories

The Promise of Algae-Based Biofuels

Algae has potential advantages over corn, cellulosic materials, and other crops as an alternative to petroleum-based fuels

Gallons of Oil per Acre per Year	
Corn	18
Soybeans	48
Safflower	83
Sunflower	102
Rapeseed	127
Oil Palm	635
Micro Algae	1000 - 7000



Land Needed for Biofuel to Replace 50% of Current Petroleum Diesel using oil from:

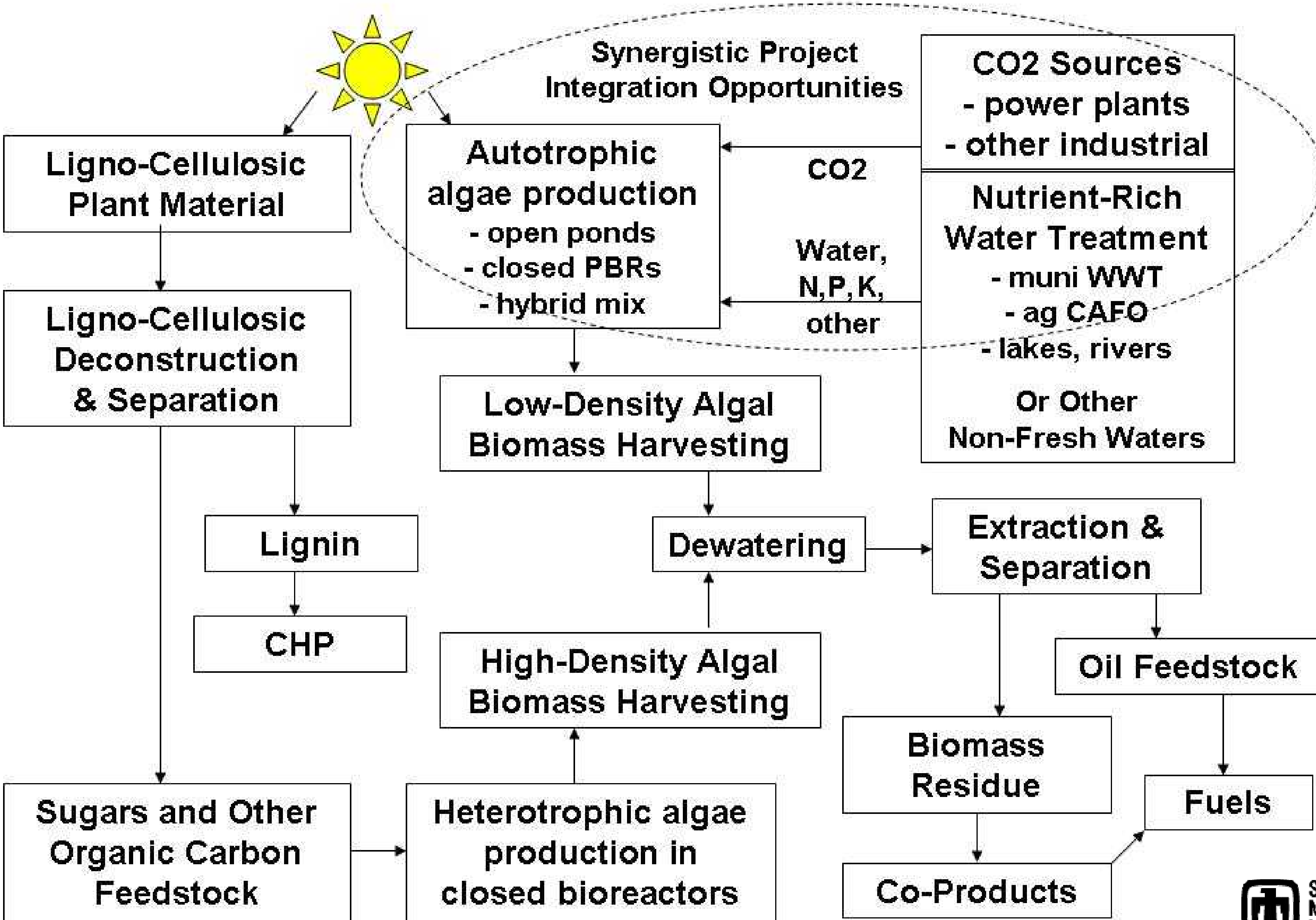
Corn
Soybean
Algae

- ***High biomass productivity potential***
- ***Oil feedstock for higher energy-content fuels***
- ***Can avoid competition with agricultural lands and water for food & feed production***
- ***Can use non-fresh water, resulting in reduced pressure on limited fresh water resources***
- ***Captures CO_2 and recycles carbon for fuels and co-products***

Sandia National Laboratories

Major Paths for Algal Biofuels

Originating with Photosynthesis



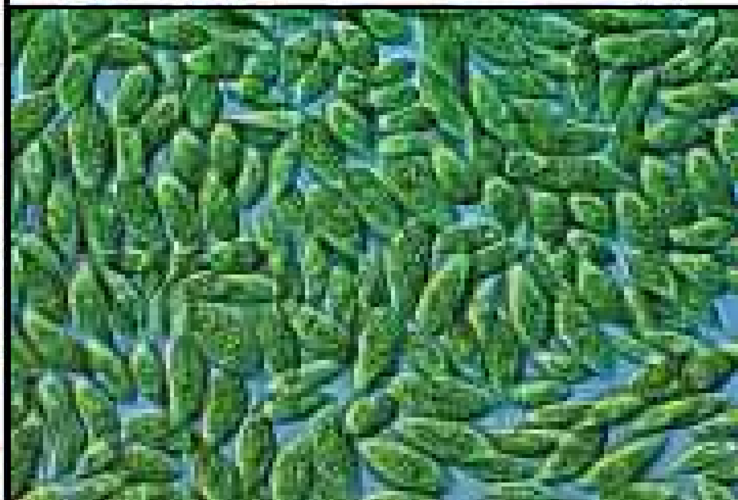
Sandia National Laboratories

Algae-Based Production of Biofuels, Coproducts, & Services w/ Non-Fresh Waters

Impaired Water
- brackish groundwater
- produced water
- desalination concentrate
- Ag wastewater
- Industrial wastewater
- Municipal wastewater
- Geothermal water & heat

Waste CO_2 & Heat
- Electric power generation
- Ag processing
- Industrial processing
- Wastewater treatment
- Desalination

Algae Production Systems
Ponds, PBRs*, Hybrid Systems†



Sunlight (photoautotrophic)

Organic Carbon (heterotrophic)

O_2

Biofixation of CO_2

Biomass Harvesting

Processing

Co-Products
- feeds
- fertillizers
- biopolymers
- glycerine
- other

Reclaimed Water
- nutrient removal

Biofuels
- biodiesel
- ethanol
- biogas
- JP-8

* PBRs = PhotoBioReactors

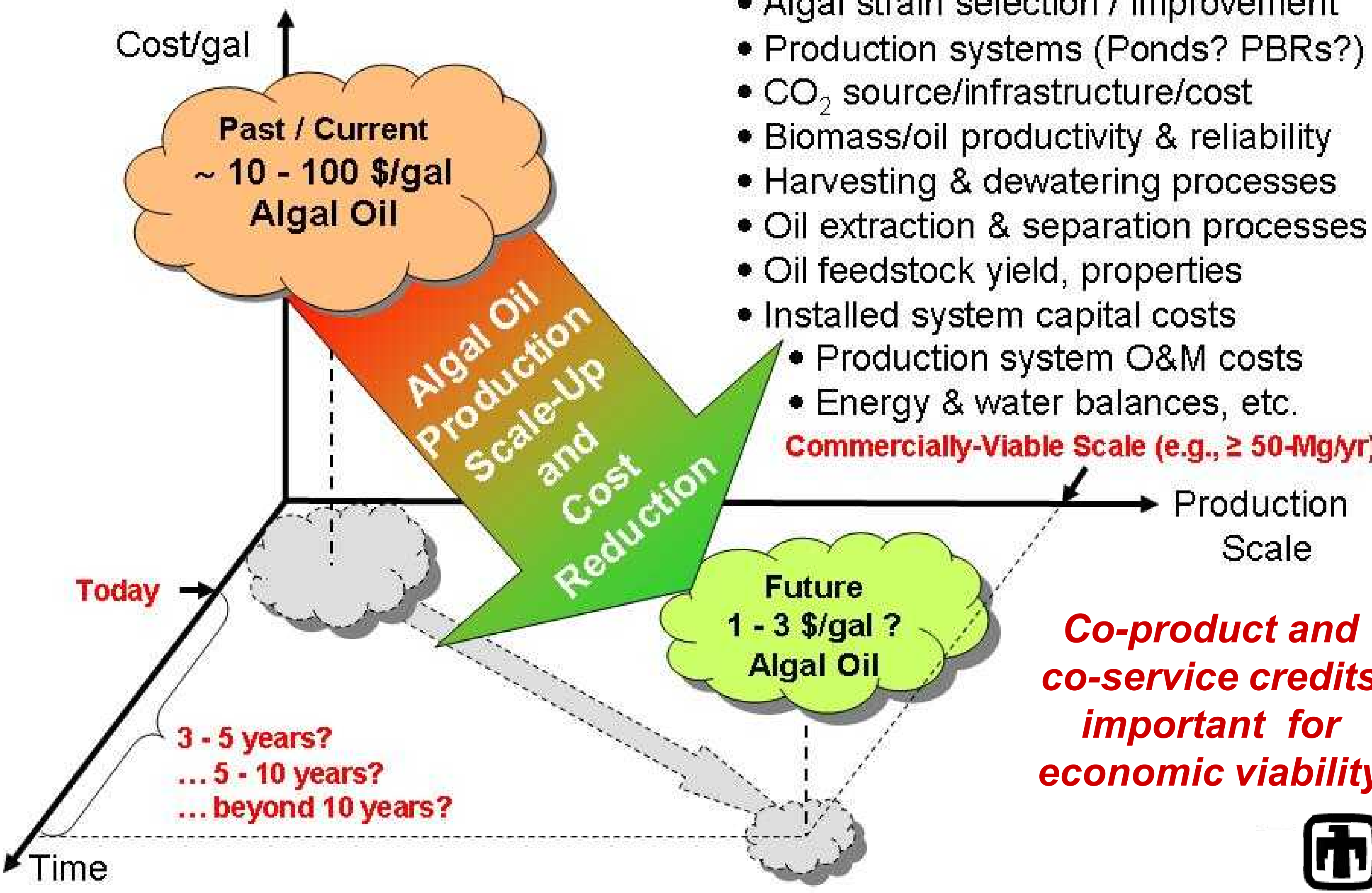
† Hybrid Systems = Ponds + PBRs

Sandia National Laboratories

Cost & Scale-up Challenges for Algal Biofuels

Examples of Systems and Processes Issues

- Algal strain selection / improvement
- Production systems (Ponds? PBRs?)
- CO_2 source/infrastructure/cost
- Biomass/oil productivity & reliability
- Harvesting & dewatering processes
- Oil extraction & separation processes
- Oil feedstock yield, properties
- Installed system capital costs
  - Production system O&M costs
  - Energy & water balances, etc.



Co-product and co-service credits important for economic viability

Sandia National Laboratories

Preliminary Look at Siting & Input Resource Issues for Algal Biofuel Industry Build-Up of Algal Oil Feedstock Production

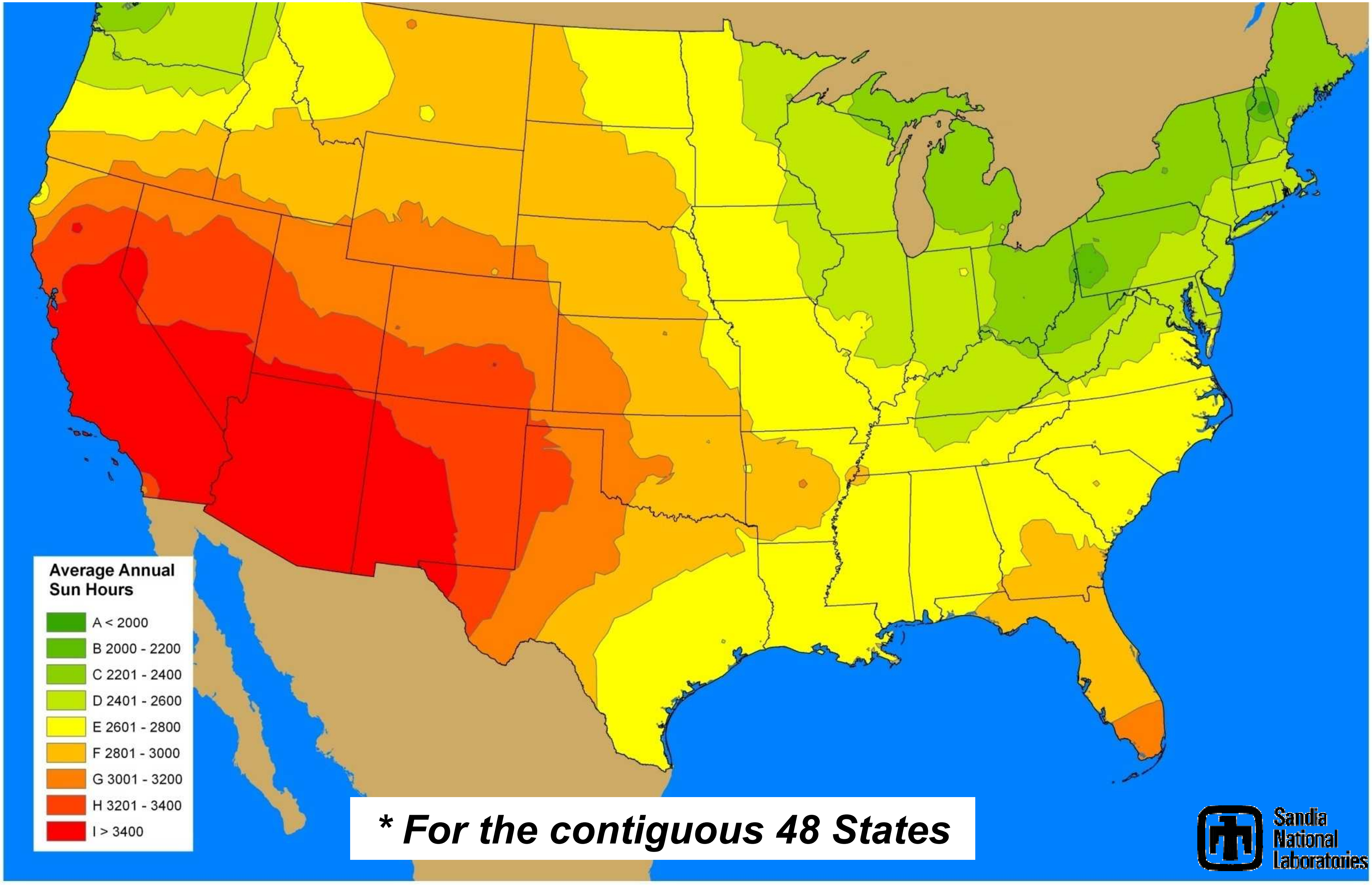
Emphasis here on Southwest Region

Hypothetical National Scale-Up to Three Target Levels

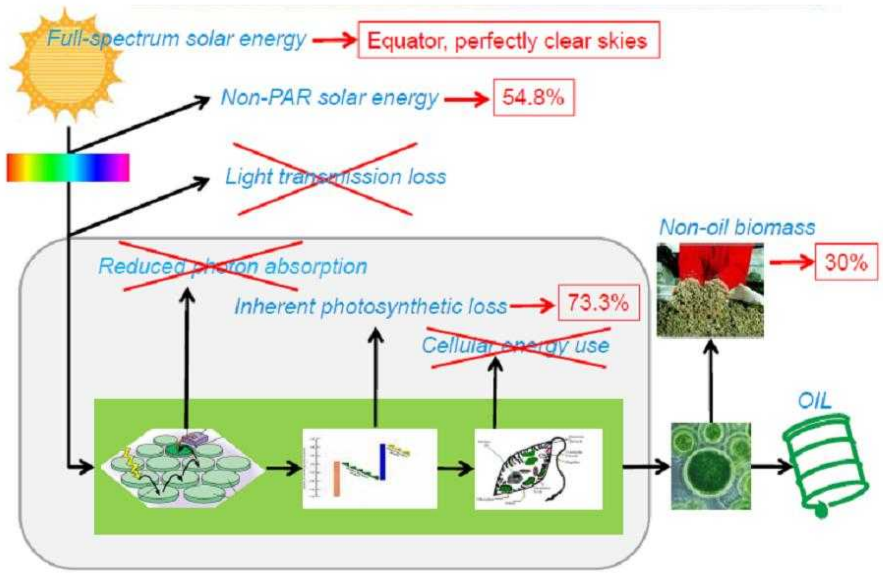
- *20-billion gallons per year*
- *50-billion gallons per year*
- *100-billion gallons per year*

Sandia National Laboratories

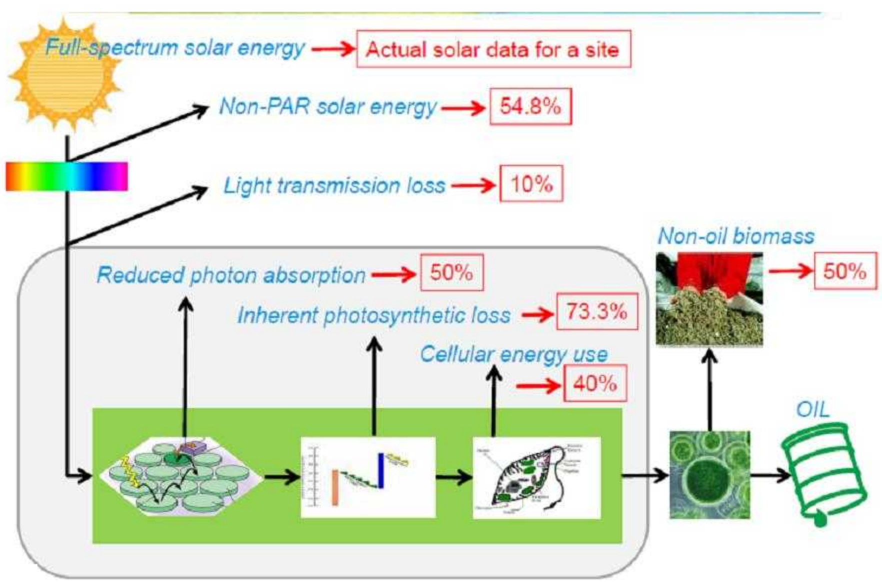
Consider Key Input to be Average Annual US* Solar Resource



Theoretical Case



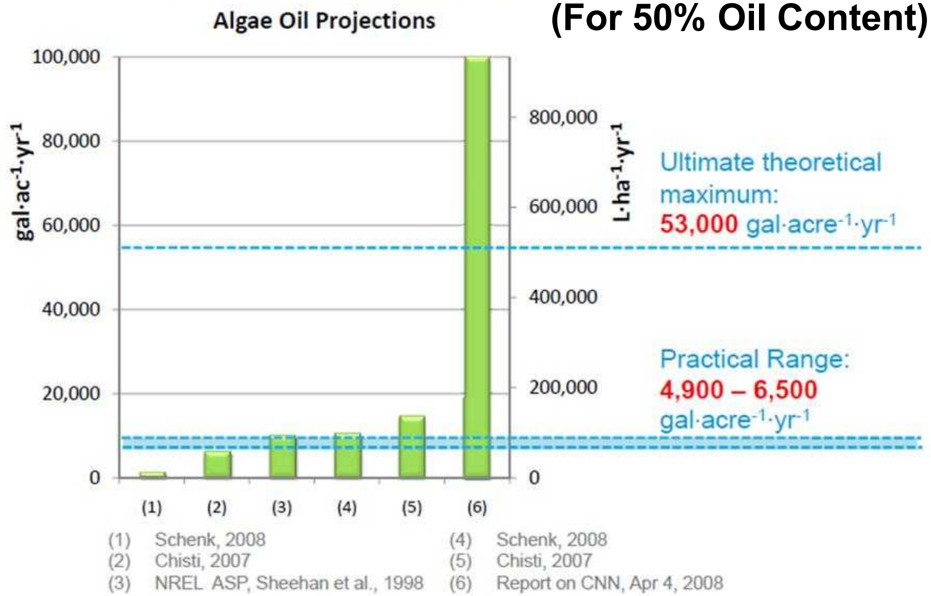
Practical Case



Apply Reality-Check on Algal Oil Production

Conclusions

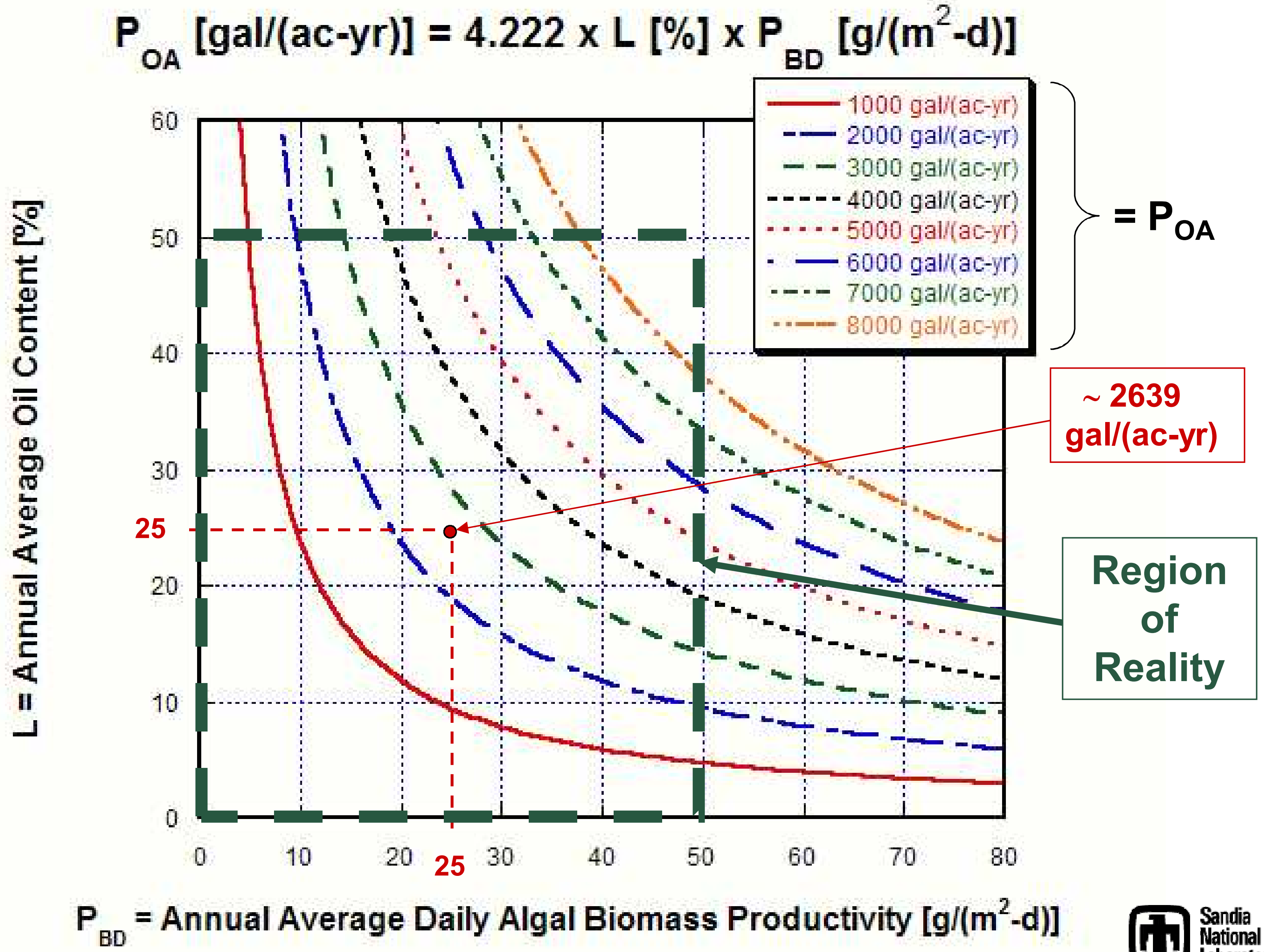
(For 50% Oil Content)



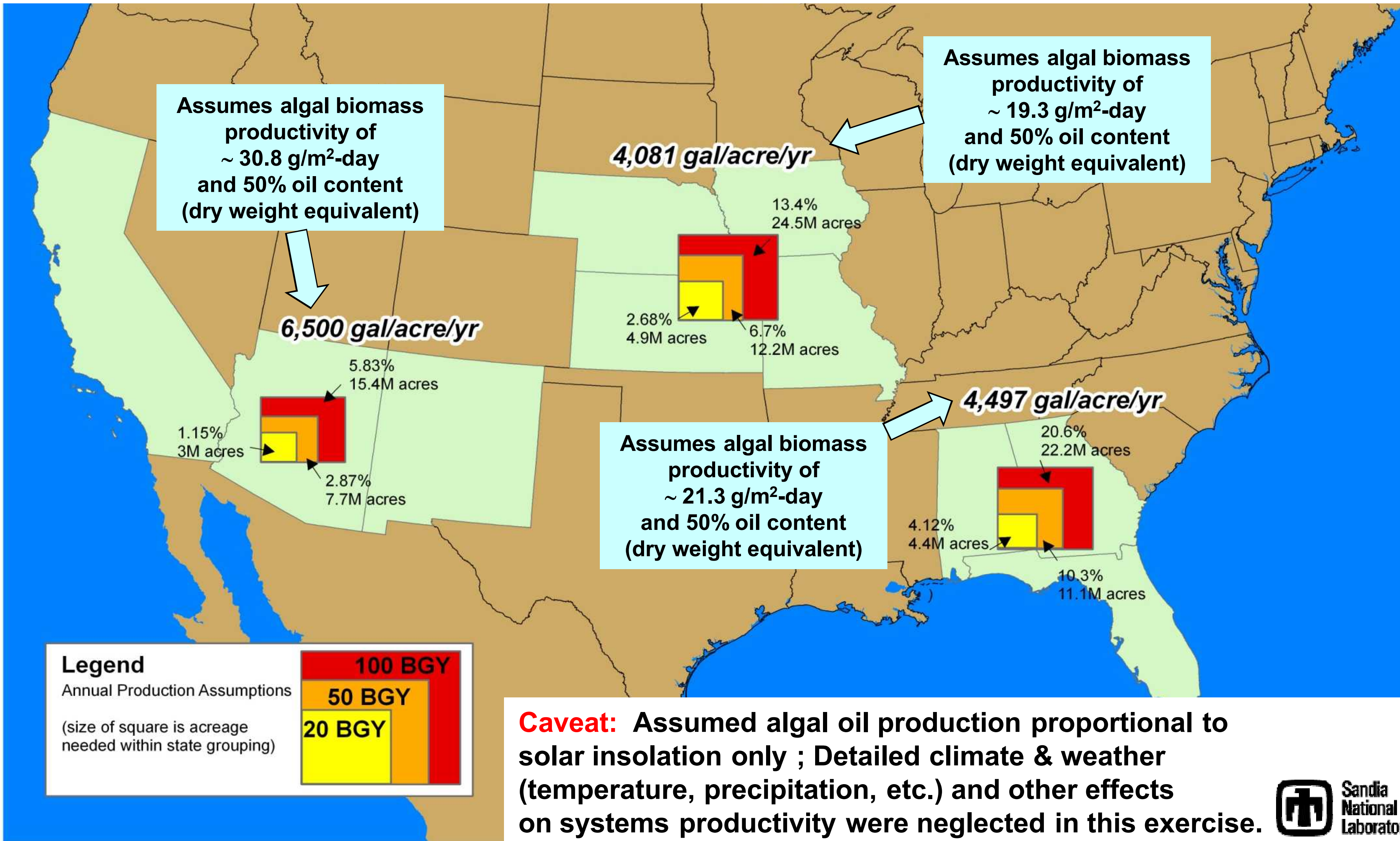
Analysis and illustrations courtesy of **Kristina Weyer***
Solix Biofuels, Inc.
kristina.weyer@solixbiofuels.com
* *"Theoretical Maximum Algal Oil Production"*
2008 Algae Biomass Summit, Seattle, WA

Sandia National Laboratories

Algal Oil Productivity Parametric Curves



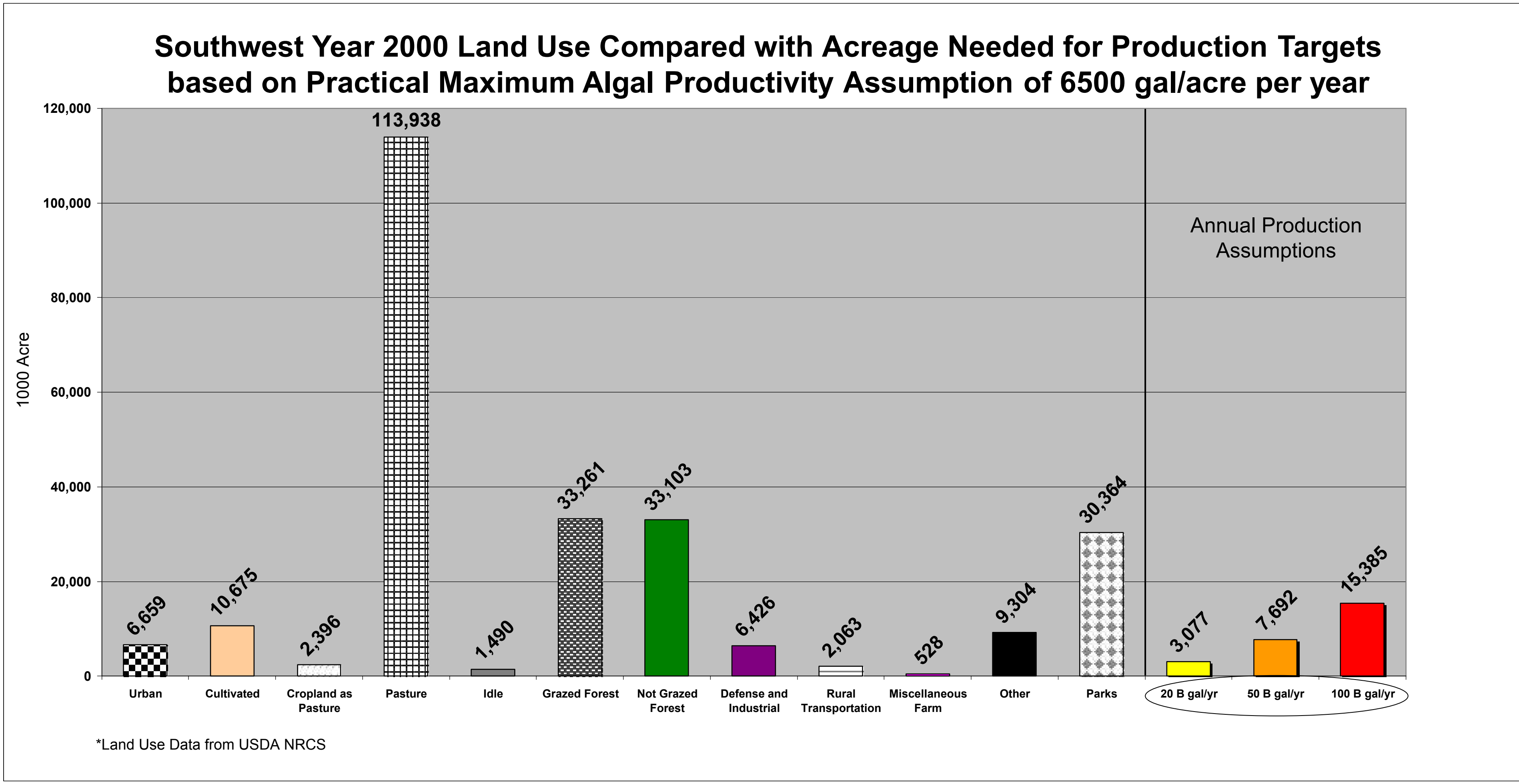
Three "Notional" Scale-Up Scenarios Considered for Initial Look at Algal Biofuel Production Resource Requirements and Implications



Caveat: Assumed algal oil production proportional to solar insolation only ; Detailed climate & weather (temperature, precipitation, etc.) and other effects on systems productivity were neglected in this exercise.

Sandia National Laboratories

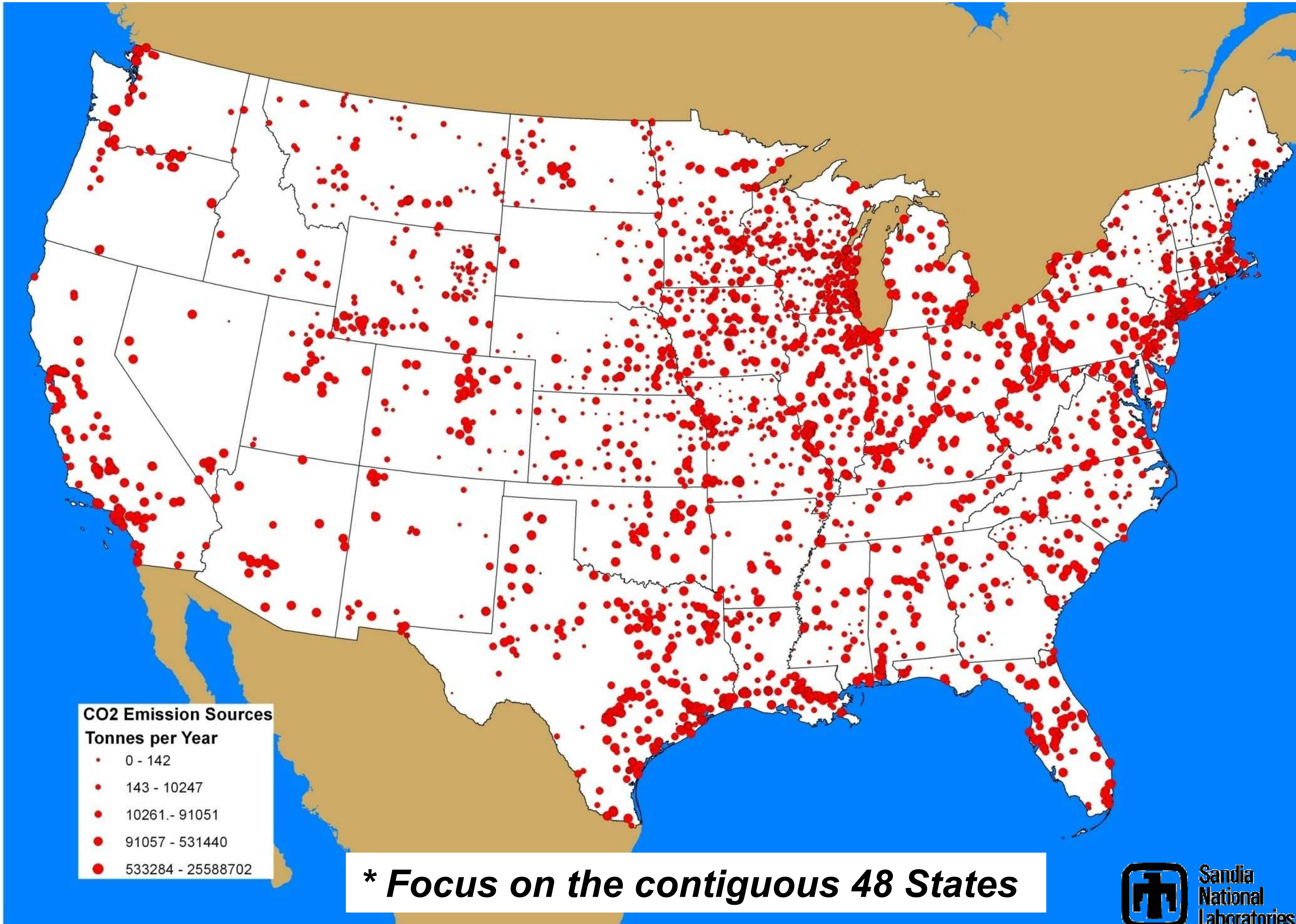
Southwest Region Scenario Land Footprint Consequences Compared with Land Usage*



**** Total Combined Land by Category in CA, AZ, and NM***

Sandia National Laboratories

Factor in US* Distribution of CO_2 Sources



**** Focus on the contiguous 48 States***

Sandia National Laboratories

Identified Stationary CO_2 Sources from *NATCARB 2008 Stationary CO_2 Source Atlas*

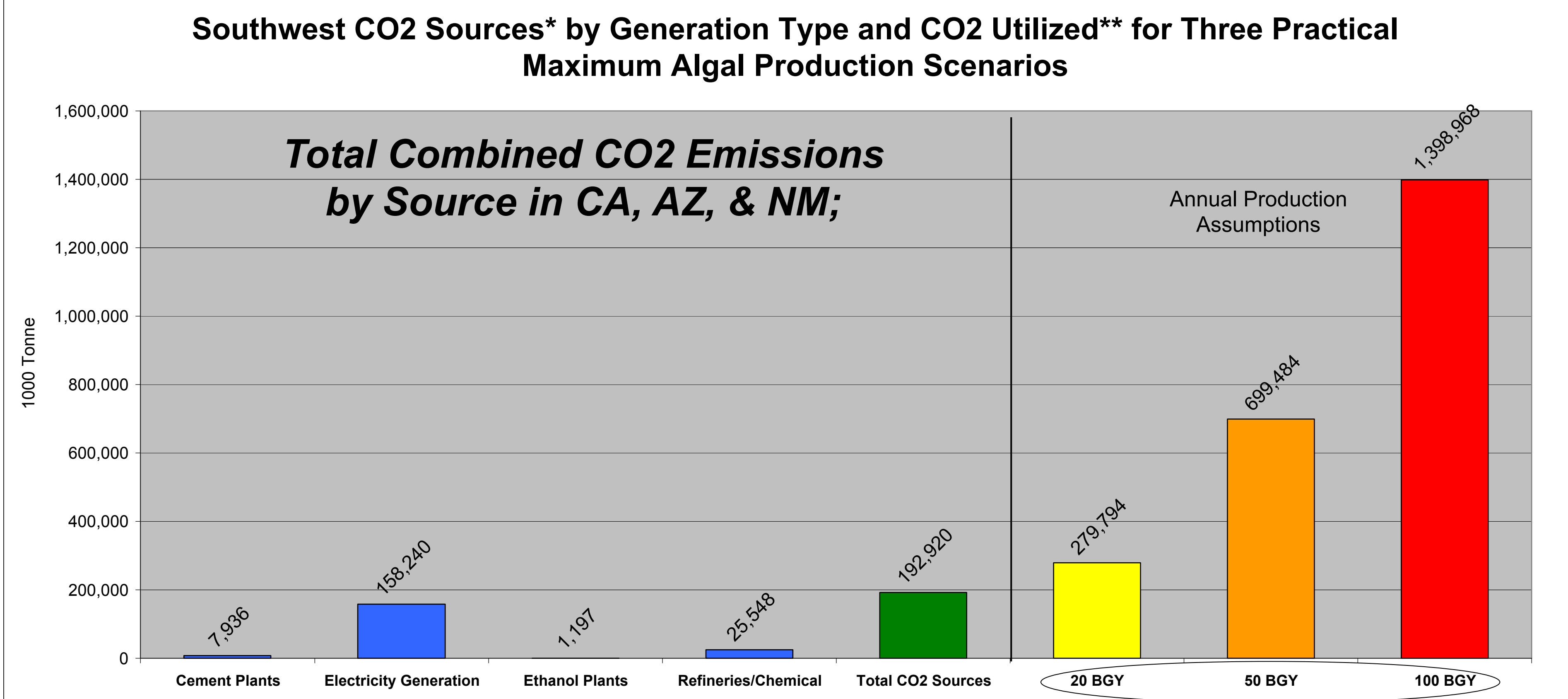
http://www.natcarb.org/

CATEGORY	**CO_2 EMISSIONS Million Metric Ton/Year**	**Number of Sources**
Ag Processing	6.3	140
Cement Plants	86.3	112
Electricity Generation	2,702.5	3,002
Ethanol Plants	41.3	163
Fertilizer	7.0	13
Industrial	141.9	665
Other	3.6	53
Petroleum and Natural Gas Processing	90.2	475
Refineries/Chemical	196.9	173
Total	**3,276.1**	**4,796**

Sandia National Laboratories

Southwest Region Scenario CO_2 Usage Consequences vs. CO_2 Source Constraints

(*Total US* CO_2 Emissions* ~ 3.28 billion metric tonnes**)



Note: CO2 utilization estimate assumes 4-lbs of CO2 consumed for every 1-lb of algal oil (TAG) produced, based on 50% oil content of algal biomass (dry weight) and 7.7 lbs per gallon of oil

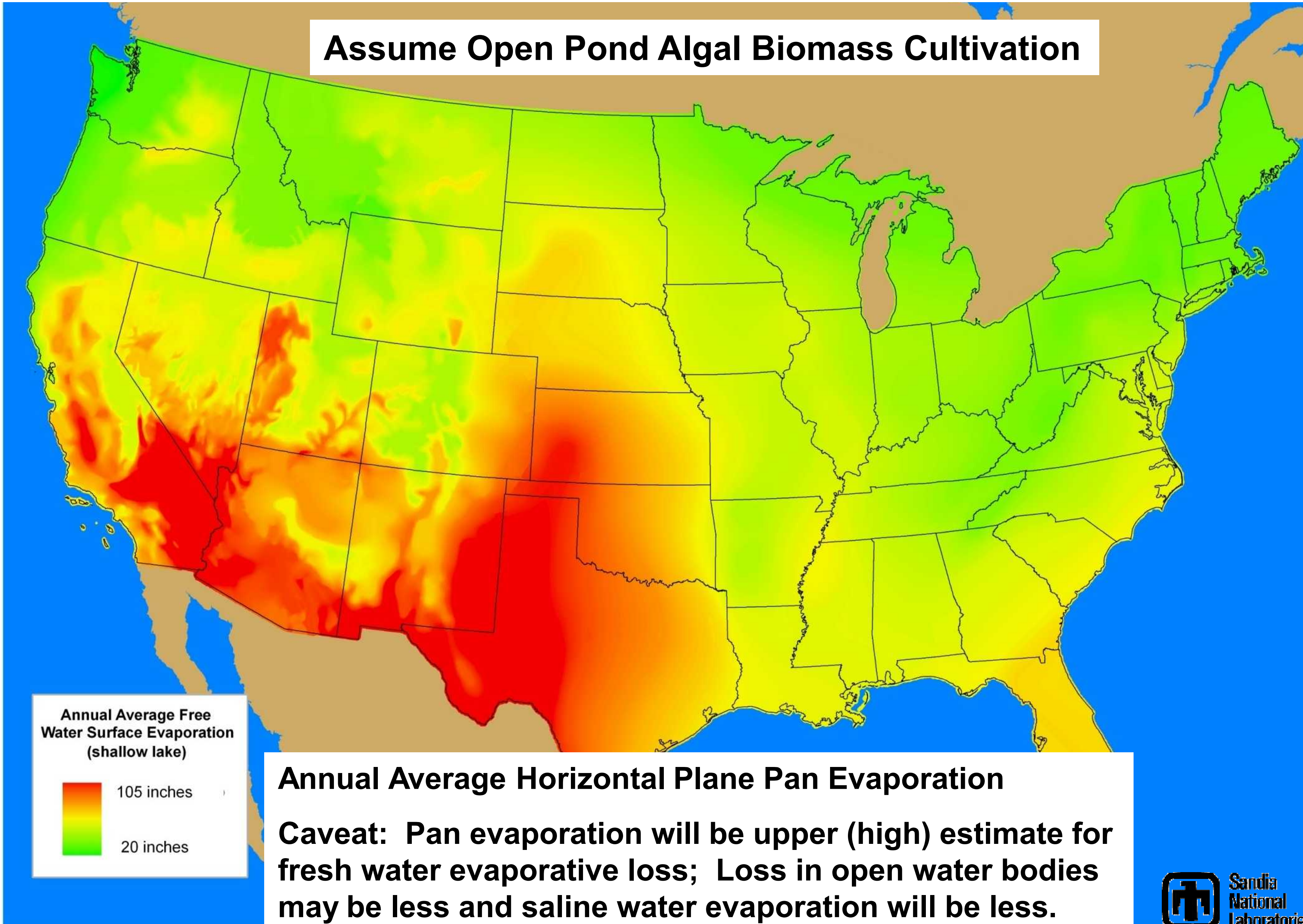
** Focus on the contiguous 48 States*

*** NATCARB 2008 Stationary CO2 Source Atlas*

Sandia National Laboratories

Factor In Evaporative Water Loss

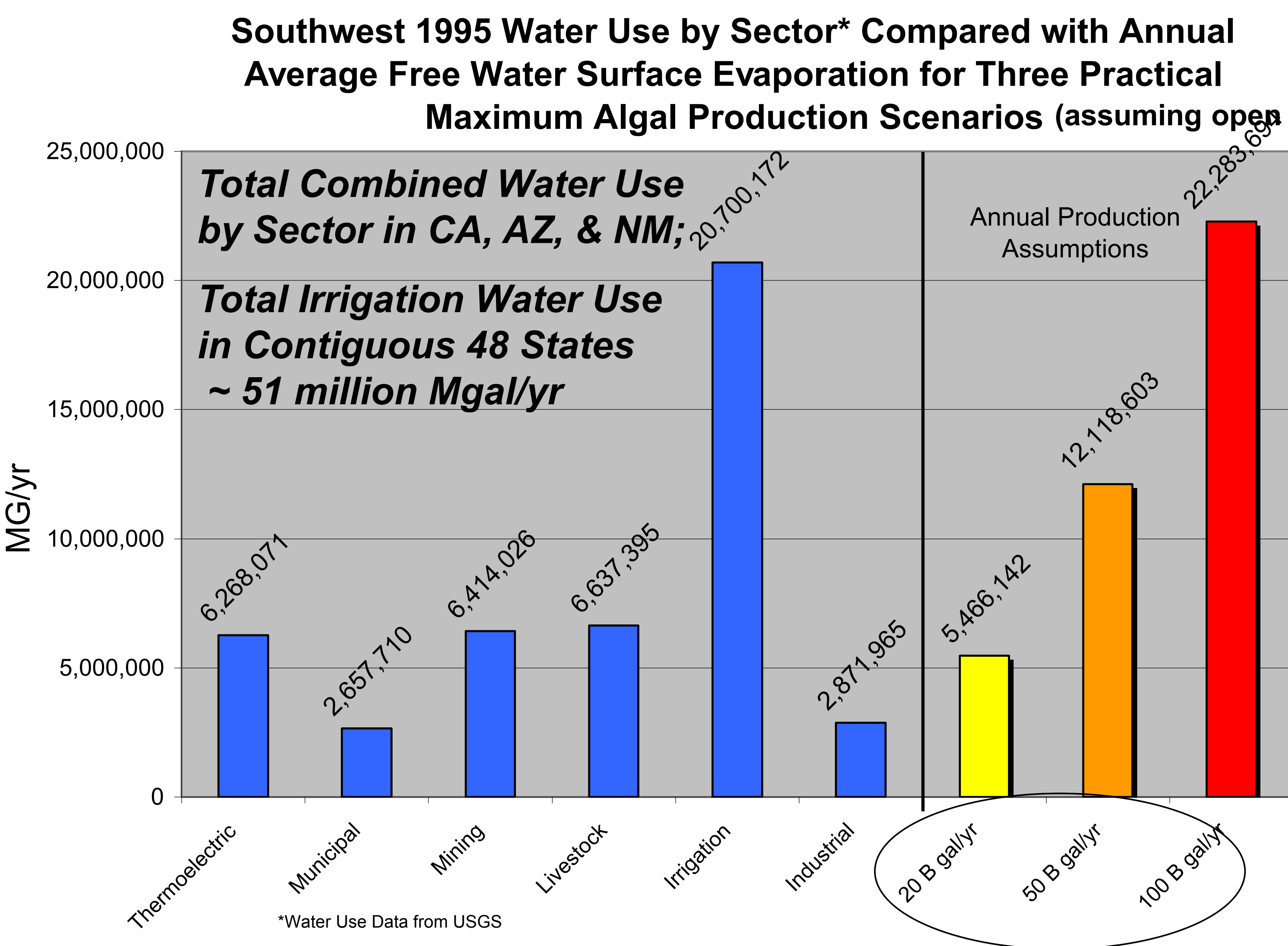
Assume Open Pond Algal Biomass Cultivation



Annual Average Horizontal Plane Pan Evaporation

Caveat: Pan evaporation will be upper (high) estimate for fresh water evaporative loss; Loss in open water bodies may be less and saline water evaporation will be less.

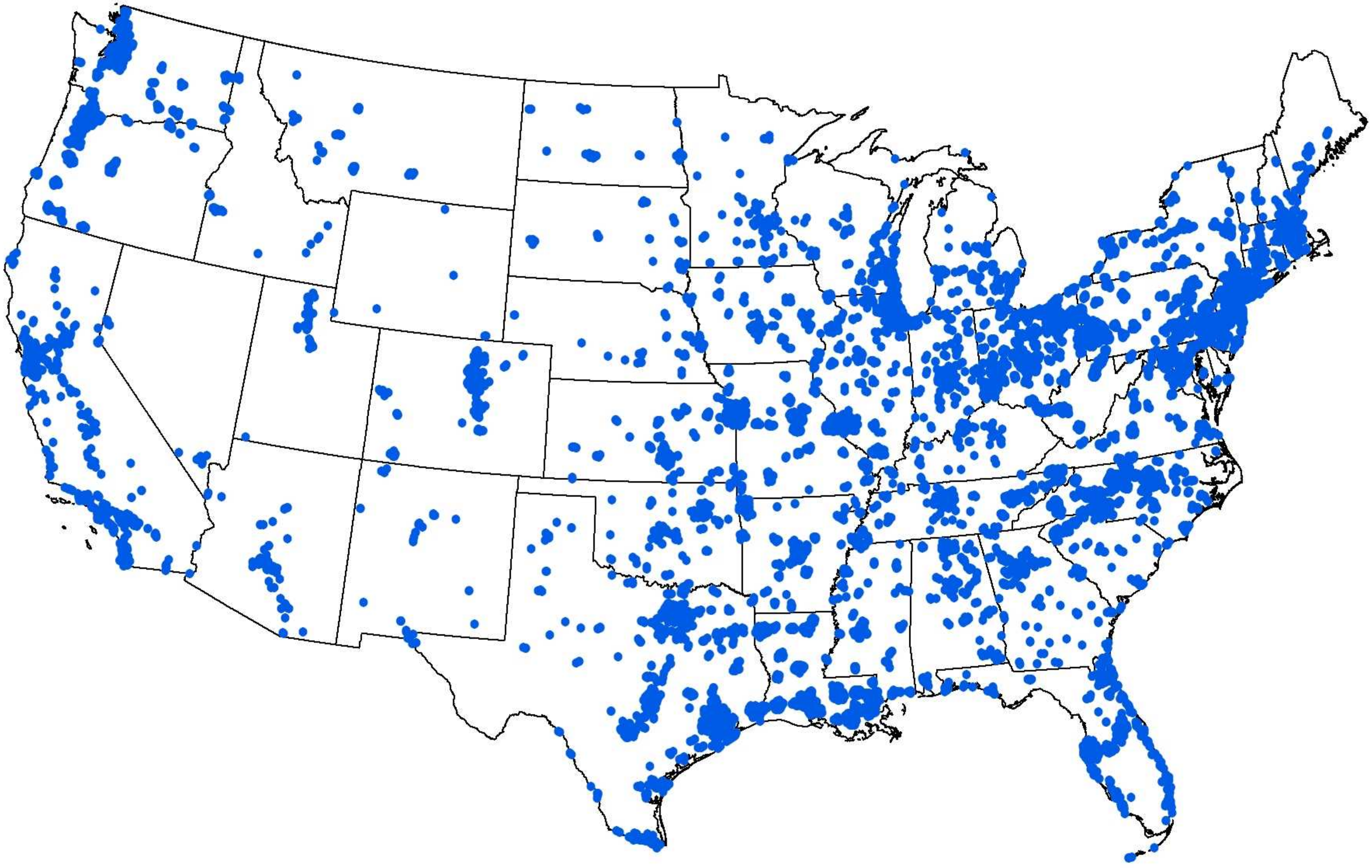
Southwest Region Scenario Water Loss Consequences vs. 1995 Water Use by Sector



Sandia National Laboratories

Co-Location of Algae Production with WWT

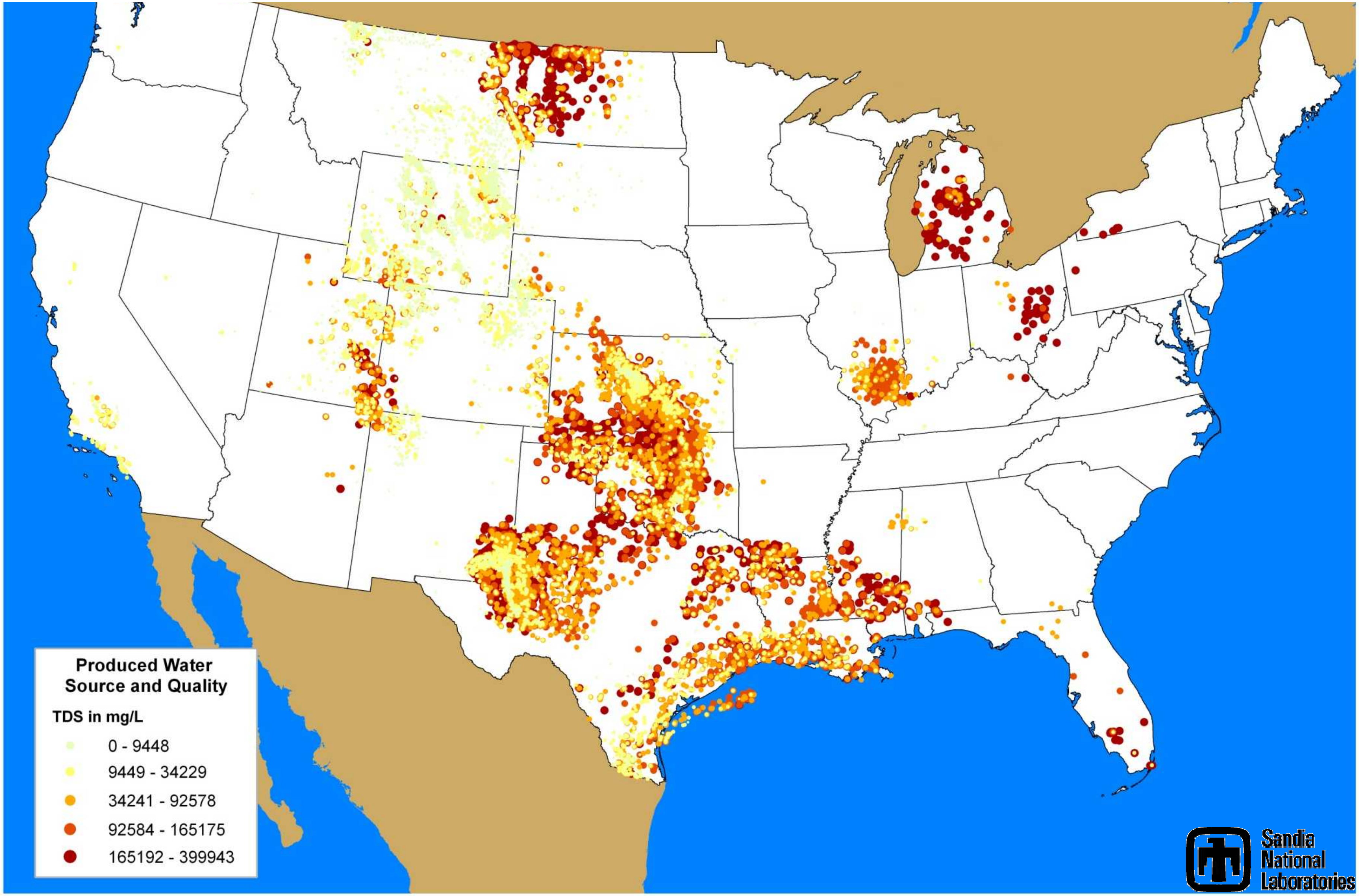
Waste water plants serving populations ≥10,000*



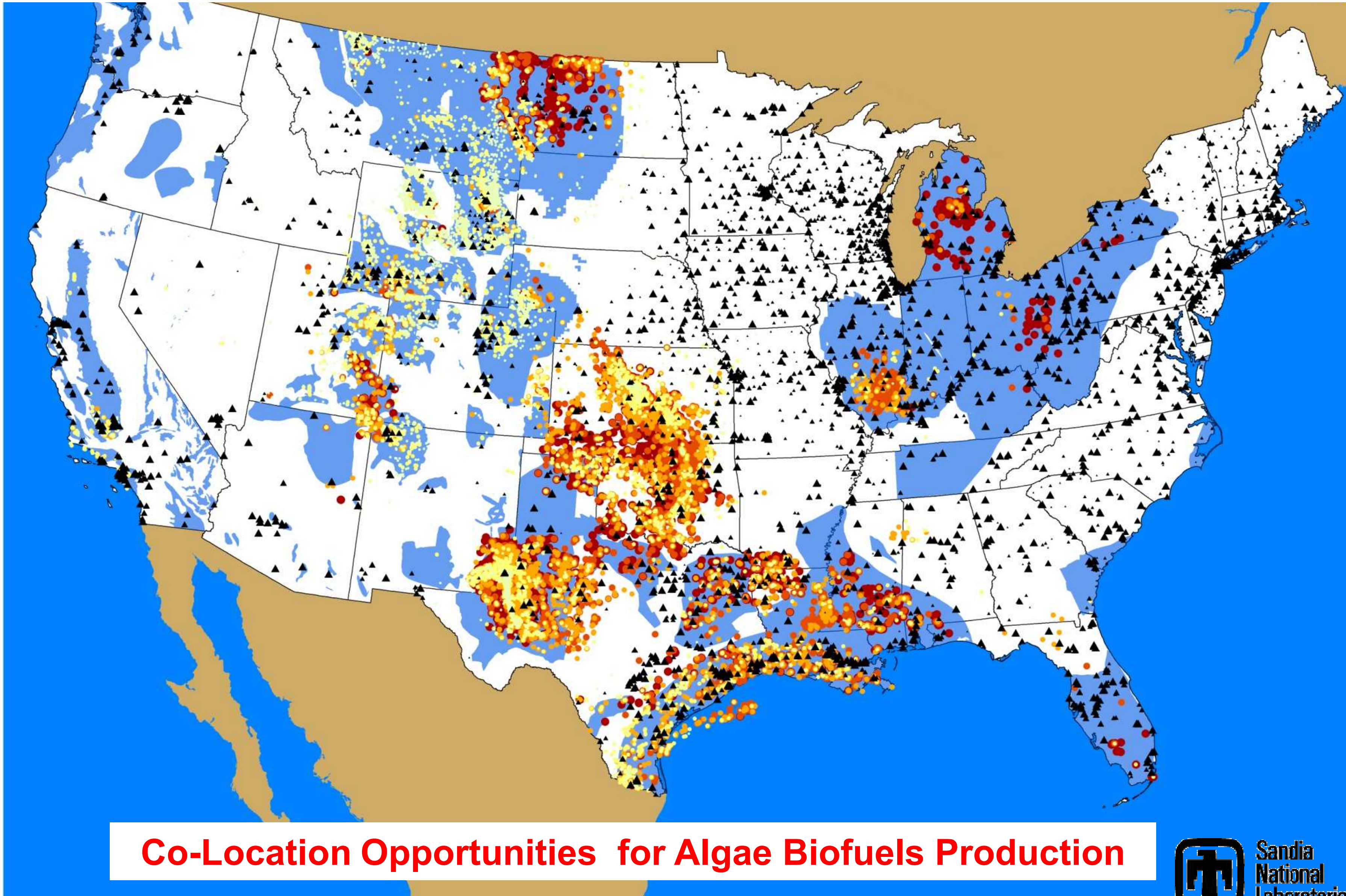
** Extracted from the EPA's Facility Registry System (FRS): Plants within 5 miles of a census place with a population of 10,000 or greater were then selected*

Sandia National Laboratories

Co-location of Algae Production with Non-Fresh Water Produced from Oil, Gas, & CBM



Distribution of Non-Fresh Produced Water, Saline Aquifers, and CO_2 Emitter Sources



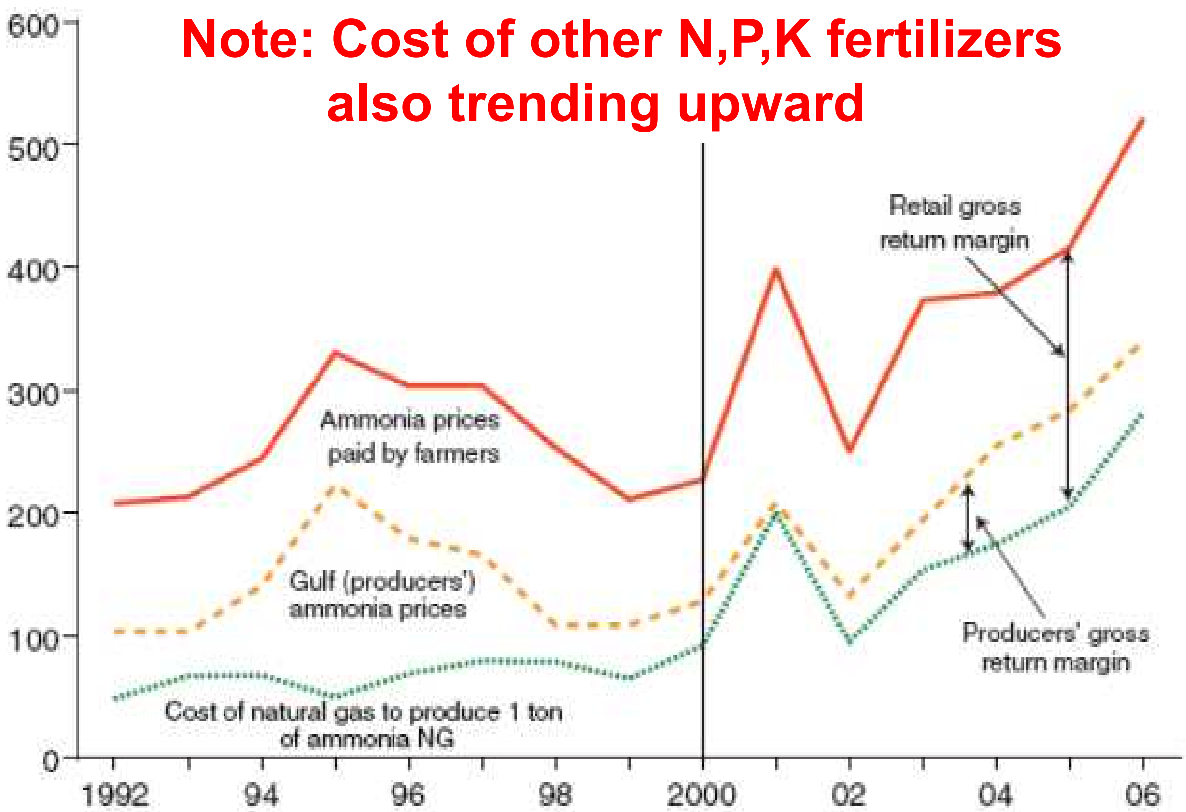
Sandia National Laboratories

Other Nutrients (N, P, K) Critical for Algae Scale-up

- *Subject to increasing costs linked to Energy and Fertilizer*
- *Need to recycle nutrients from waste streams for affordable and sustainable scale-up … to avoid costs and competition for fertilizer*

U.S. ammonia prices and cost of U.S. natural gas to produce ammonia

$ per ton



Note: 32.7 mm Btu per ton of ammonia is used to compute the cost to produce 1 ton of ammonia.

Source: USDA, Economic Research Service using data on ammonia prices paid by farmers from NASS, and data on ammonia Gulf prices and natural gas prices from TFI (b).

Sandia National Laboratories

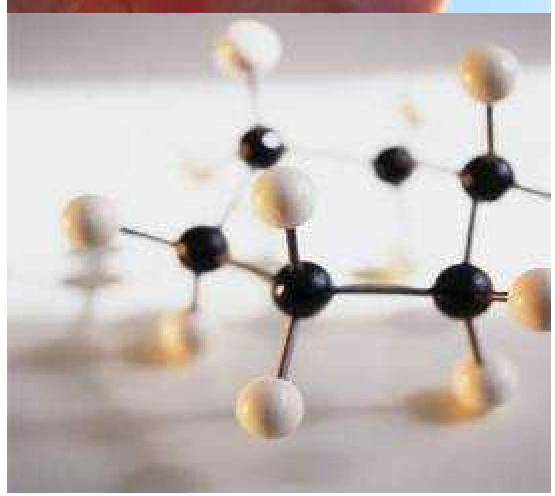
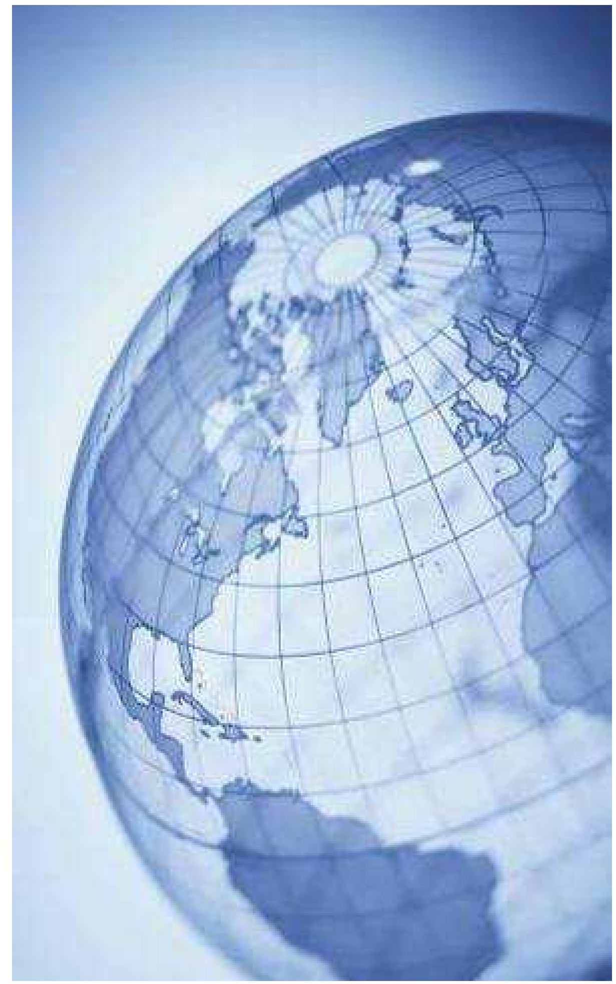
Summary Observations

- Land footprint required for national scale-up of significant algae biofuel production looks manageable.
- Water loss from inland open algae production systems is likely to be an issue for massive scale-up
- Need paths & approaches to mitigate water loss
  - Closed systems and location of open systems in less arid environments
  - Onshore coastal & offshore production options using ocean water
- CO_2 sourcing and distribution for algae is a key issue
- Availability and cost of other nutrients (N,P,K) is an issue
  - Need to exploit capture, recovery & reuse of nutrients from wastewater, etc.
- Salt & thermal management are inland systems issues
- Need to identify and exploit geographically-distributed opportunities for synergistic co-location of algae biofuels production with water treatment, power generation, and other co-product industries and markets
- Innovation needed in biology, systems and processes, and systems integration for commercial viability

DOE/EERE Office of Biomass Program

Recent Algal Biofuels Program Activities and Investments



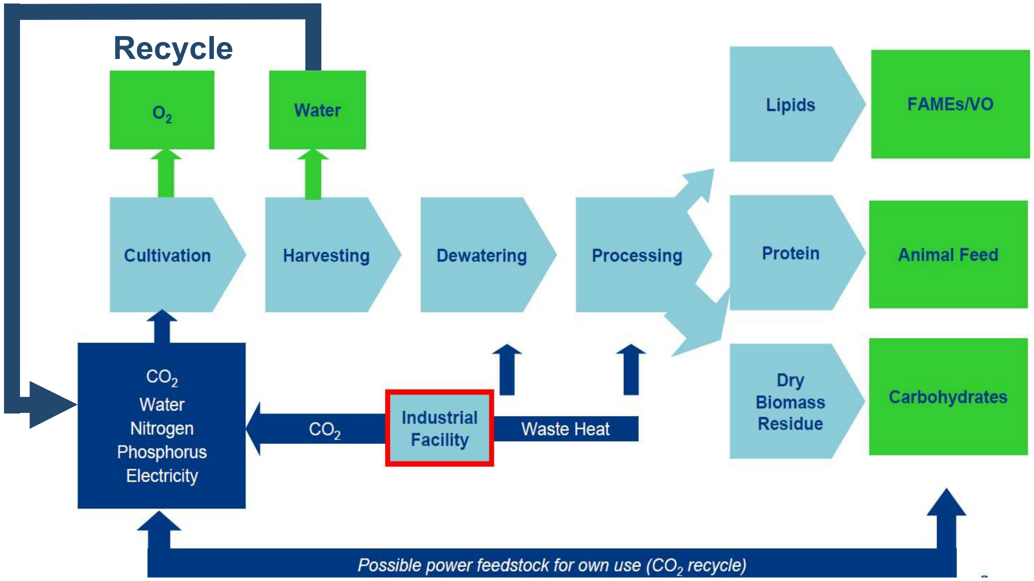



Algal Biofuels Technology Roadmap Workshop

Sponsored by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy (EERE), Office of the Biomass Program

December 9-10, 2008
University of Maryland, Inn and Conference Center

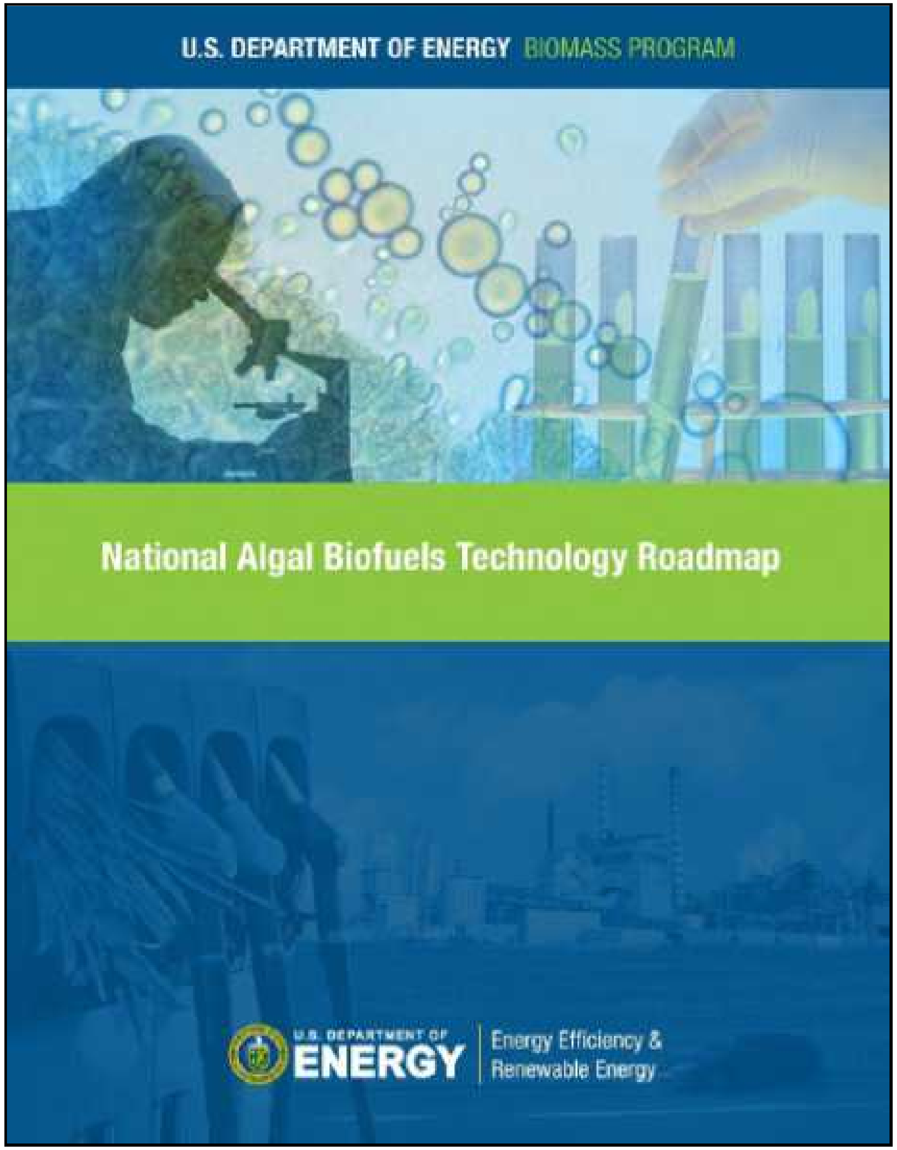
Identify fundamental and applied research needed to resolve uncertainties associated with commercial-scale algal biofuel production:



- Algal Biology
- Cultivation
- Harvest/dewatering
- Extraction/fractionation
- Conversion to fuels
- Co–products
- Systems integration
- Siting & Resources
- Regulation & Policy

Sandia National Laboratories

Draft Algae Roadmap Report Released June 5



- **DOE Solicited Public Review and Comment on Draft Report for 60-days**
- **Comments/Suggestions being Factored into Final Report being Revised and to be Published by DOE in early-FY10**
- **Draft report available at:**

http://e-center.doe.gov/iips/faopor.nsf/8373d2fc6d83b66685256452007963f5/79e3abcacc9ac14a852575ca00799d99?OpenDocument

Sandia National Laboratories

A New DOE/EERE Center– "Algae Consortium"

Team Proposals Were Due to DOE by Sept. 14, 2009

Algal Biofuels Consortium

- Purpose is to "accelerate technology development"
- ARRA-funded competitive solicitation -- **$50M for 3 yrs**

Primary objective – "develop cost effective algae-based biofuels that are competitive with petroleum counterparts"

Other items from DOE Special Notice:

- Focus on barriers from DOE's National Algal Biofuels Roadmap (draft released June 5 for 60-days public comment)
- Not seeking to construct new facilities but leverage existing capabilities and resources.
- Partnerships emphasized, because suite of technologies is required: *Industry, National Labs, Universities*

Congress added $35M more for Algae in FY10

Sandia National Laboratories

Conclusions

- Algal Biofuels of Significant Interest from Several Perspectives:
  - Energy/Fuel Availability & Security … National Security & Economic Benefits
  - Sustainable Scale-up and Resource Use (land, water, energy, nutrients, other)
  - Reduced GHG Emissions
  - Leverage of Existing Hydrocarbon Fuels Distribution & Use Infrastructure
- Potential for High Oil Feedstock Productivity with Non-Fresh Waters, Reduced Land Footprint, and CO_2 Capture and Reuse
- Synergy with Waste Water Treatment and Industrial CO_2 Emitters
- Potential for Biofuel Scale-Up w/ Reduced Impacts on:
  - Fresh Water Supplies
  - Higher Productivity Agricultural Lands
  - Food/Feed/Fiber Markets
- R&D Needed to Meet Challenges with Biology, Systems, & Processes for:
  - Cost-effective, commercially-viable feedstock & fuels production scale-up
    - Technologies, Processes, Systems
    - Systems Integration and commercial scale-up
  - Sustainable resource utilization (Energy-balance, water-balance, nutrients, net GHG emissions, productive use of waste streams, etc.)
  - Dealing with evaporative water loss issues/concerns
  - Dealing with thermal management & salt management issues/concerns
  - Developing commercially viable Co-products & Co-services

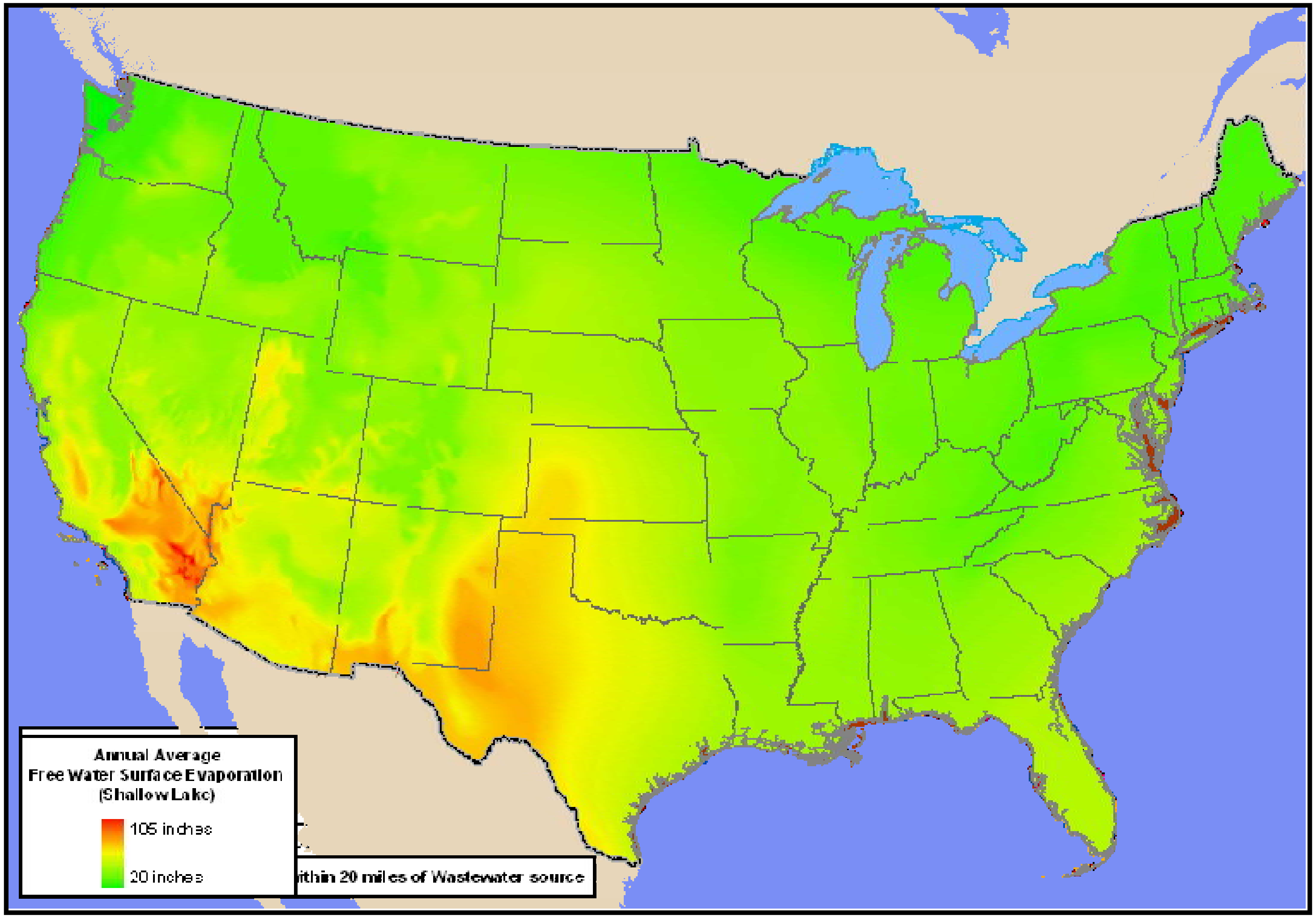
Thank You !

Questions ?

Sandia
National
Laboratories

Back-Up

Preliminary Look at Preferred Siting of Inland Algal Biomass Production Facilities



Sandia National Laboratories