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Algal Biofuels: Promises and Challenges

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Outline of Discussion

- Motivation and Policy Drivers
- Promise of Algal-Derived Biofuels
- Challenges
- How Will We Get There?
  - Overview of DOE Funded Efforts
  - Overview of Research Efforts at Sandia
- Recap and Resources

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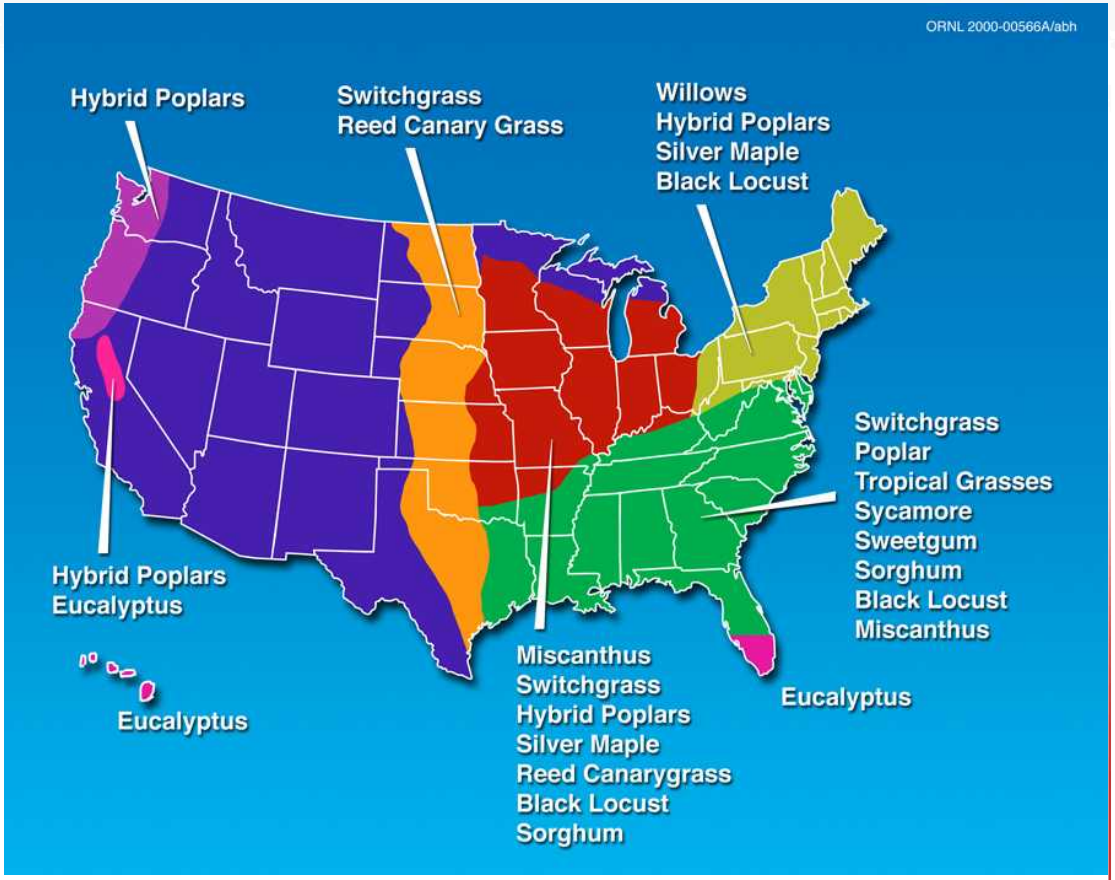
2006 State of the Union Address

President Bush called for a new national initiative to make cellulosic ethanol viable as a transportation fuel by 2012 and to reduce U.S. dependence on foreign oil by as much as 30%.



US Sources of Biomass

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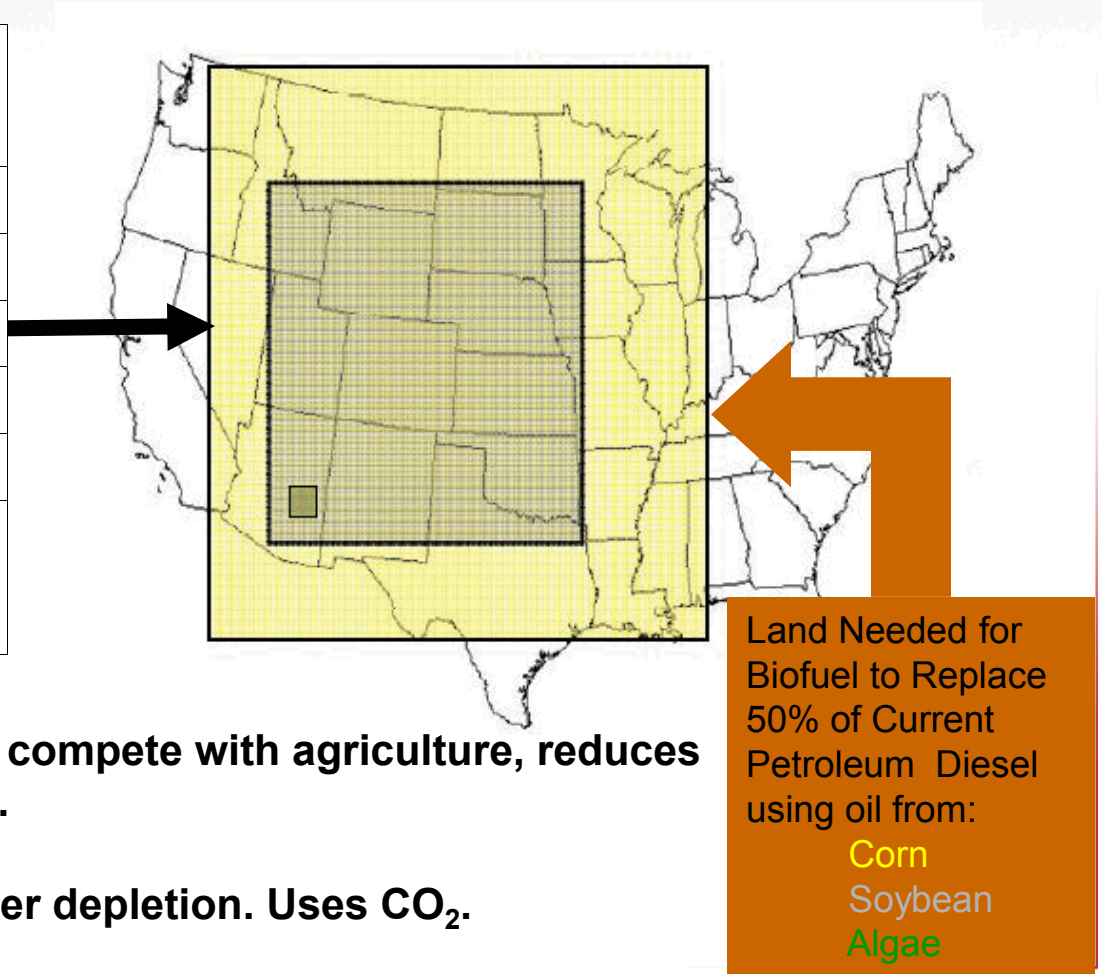
The Promise of Algae-Based Biofuels

Gallons of Oil per Acre per Year	
Corn	**18**
Soybeans	**48**
Rapeseed	**127**
Oil Palm	**635**
Micro Algae	**1000 – 7000***

* Projected oil yields … but have not yet been demonstrated reliably or affordably at large scale.



- **Land use**: Far less, does not compete with agriculture, reduces deforestation (*Science, 2008*).
- **Resources**: Avoids fresh water depletion. Uses CO_2.
- **Fuel Production**: Produces higher energy content fuels.

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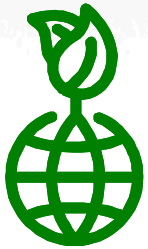
Generations of Biofuels

Corn Ethanol

- Commercially available (no DOE research ongoing)
- Reduced GHG emissions
- Capped by RFS



Cellulosic Ethanol

- Focus of current DOE research
- Potential to lower GHG emissions 86%
- Uses biomass from waste and non-agricultural land

Advanced Biofuels

- DOE scoping effort in progress for algae, new biofuels & pathways
- Exploit opportunities to reduce environmental footprint
- Energy content and fuel economy similar to petroleum-based fuels

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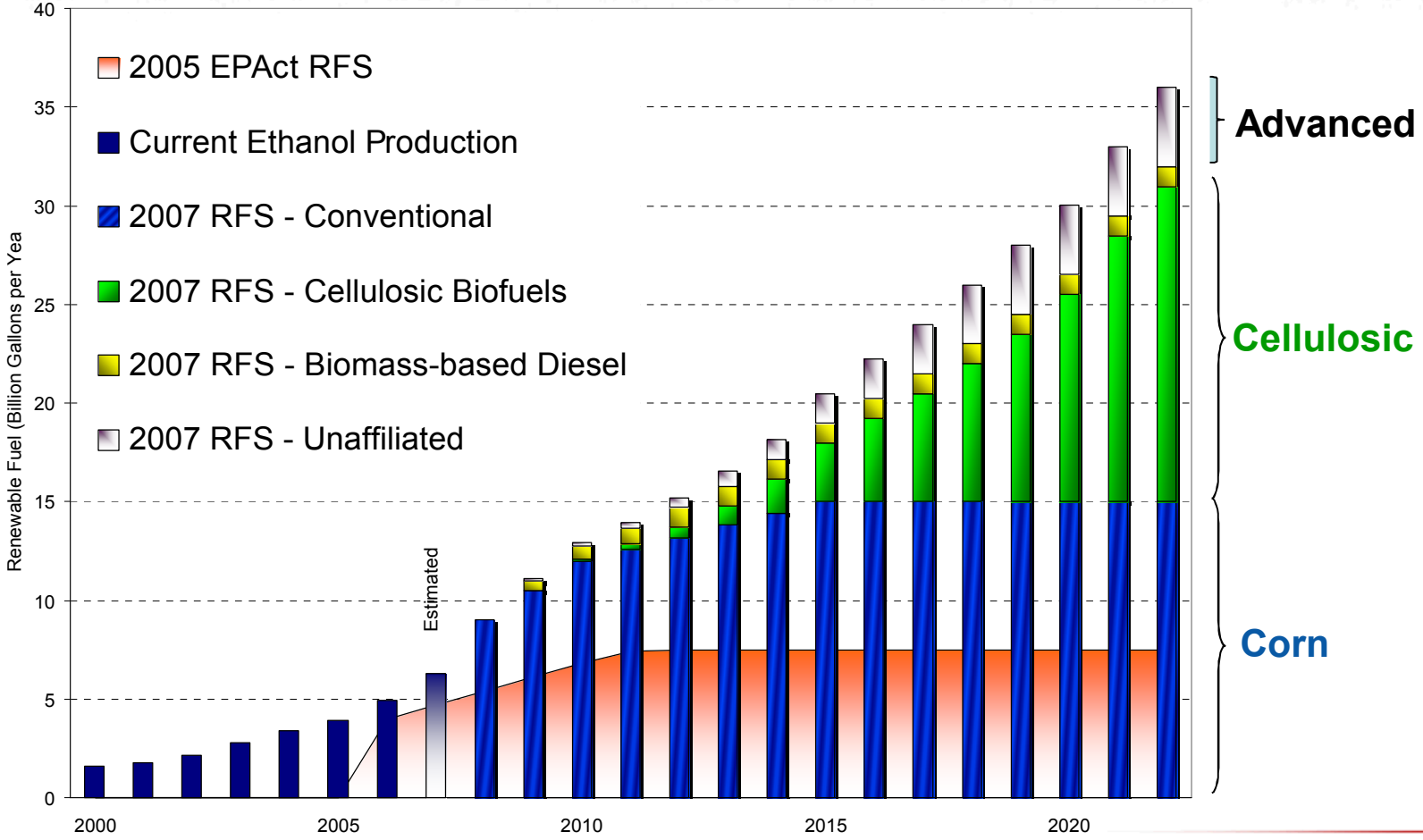
Policy Driver: *Advanced Biofuels in 2007 EISA Renewable Fuel Standard*

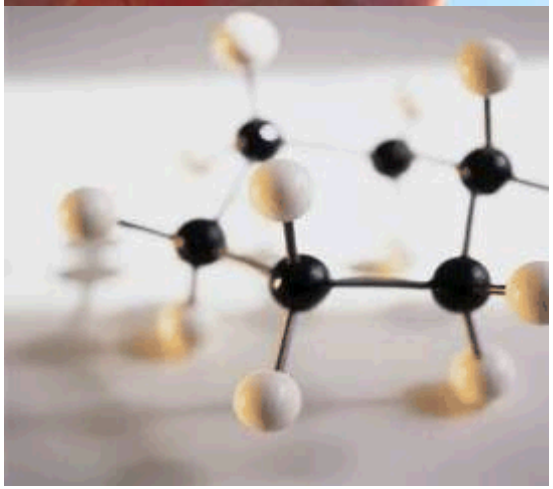
36 billion gallons of renewable fuels by 2022



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

DOE/EERE Office of Biomass Program

Biofuels Trends and Algae Biofuels Investments



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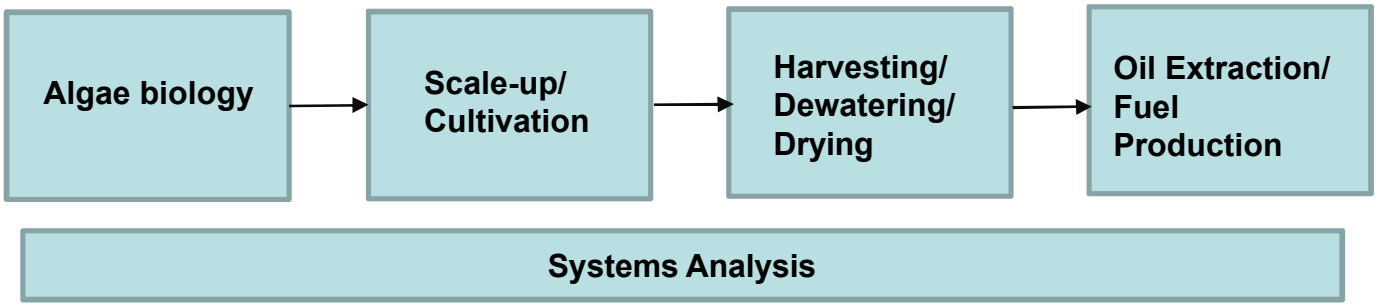
Solutions to technical issues are required

Simplified algal biofuels process chain:



Algae Biology: species, basic biochemistry of lipid production, breeding, genetic modifications.

Scale-up/Cultivation: Culturing protocols, dynamics/stability, water/nutrient issues.

Harvesting/Drying: Harvesting protocols, energy consumption, recycling.

Oil Extraction/Fuel Production: Methods and options, separations/process contaminants.

Systems Analysis: Integrated processes, techno-economic modeling

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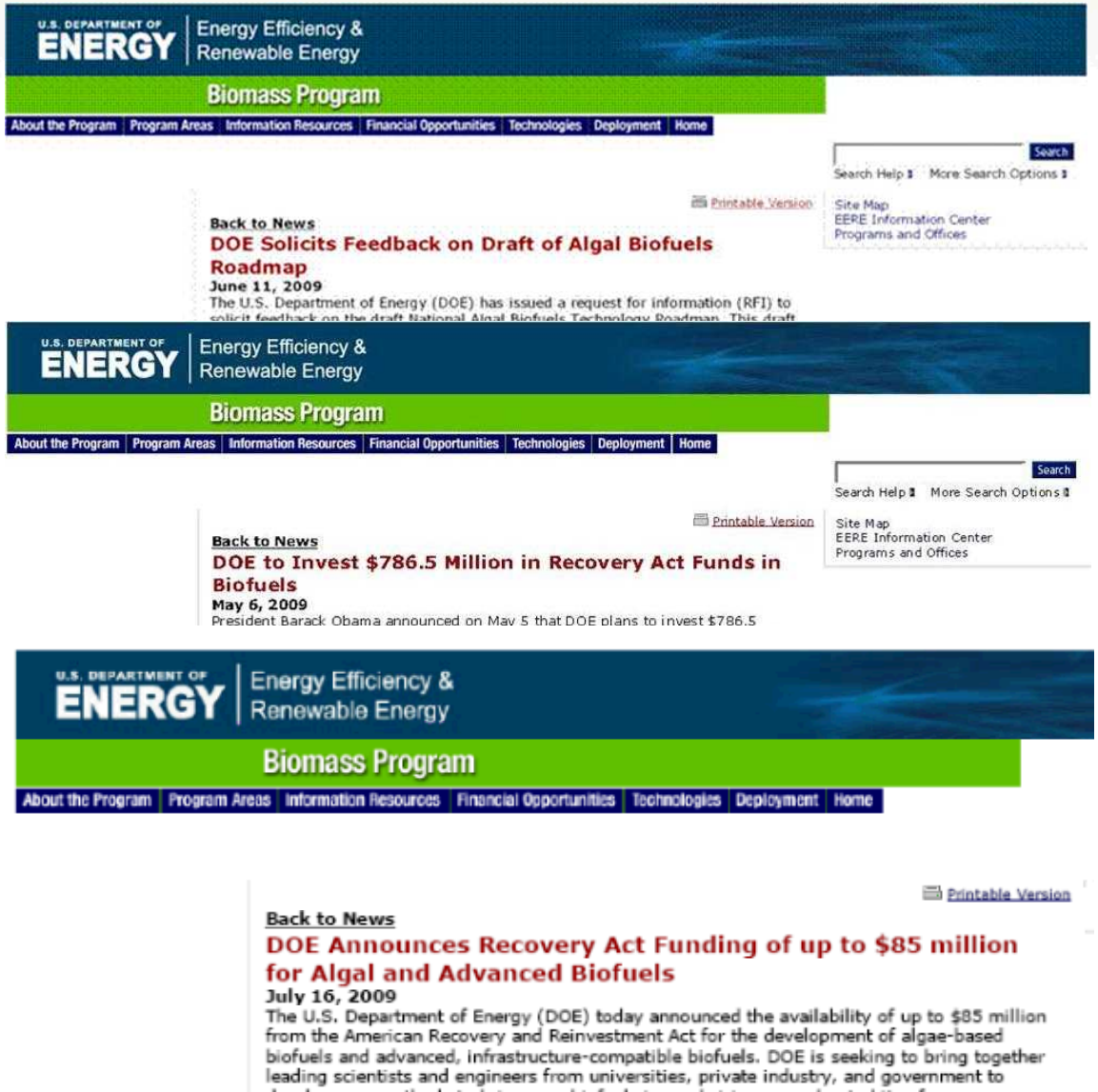
The nation has invested approximately $150M in algal biofuels research largely through EERE/OBP.



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Sandia Conducts Research for National & Internal Programs

SABC
Sustainable Algal Biofuels Consortium
cultivating energy solutions

Biochemical Conversion of Algal Residuals in Fuel Production and Testing

Sapphire Energy

CO_2 Distribution and Use in an Algal Biorefinery

International Programs

Systems Analysis and Techno-Economic Modeling

LDRD Internal Investments

- *Metabolic Engineering in Biodiesel Feedstocks: Cyanobacteria and Diatoms*
- *From Algae to Oilgae*
- *Cultivation Scale-up: From Benchtop to Raceways*
- *First Principles in Flocculation of Algae*
- *Modeling Algae Growth in Raceways*

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Sandia operates both lab-scale and model cultivation systems for algae biology and scale-up research.

Algae biology → Scale-up/ Cultivation

Botryococcus braunii
Neochloris oleoabundans
Chlamydomonas reinhardtii
Thalassiosira Pseudonana
Nannochloropsis

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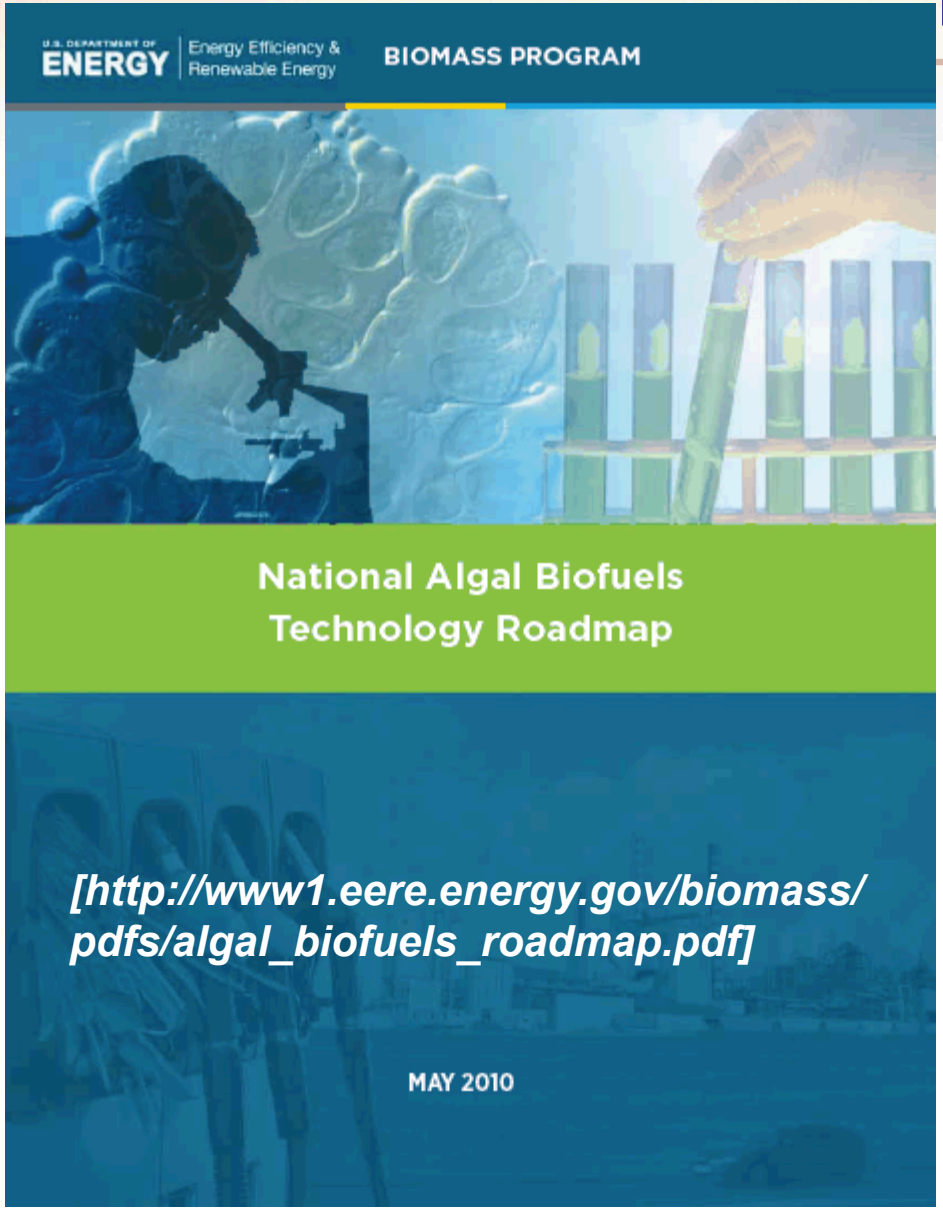
National Algal Biofuels Technology Roadmap



Initiated early-FY09 to identify research needs, gaps, resolve uncertainties and reduce technical risks to enable and accelerate commercial-scale algal biofuel production. Scope of Roadmap includes:

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

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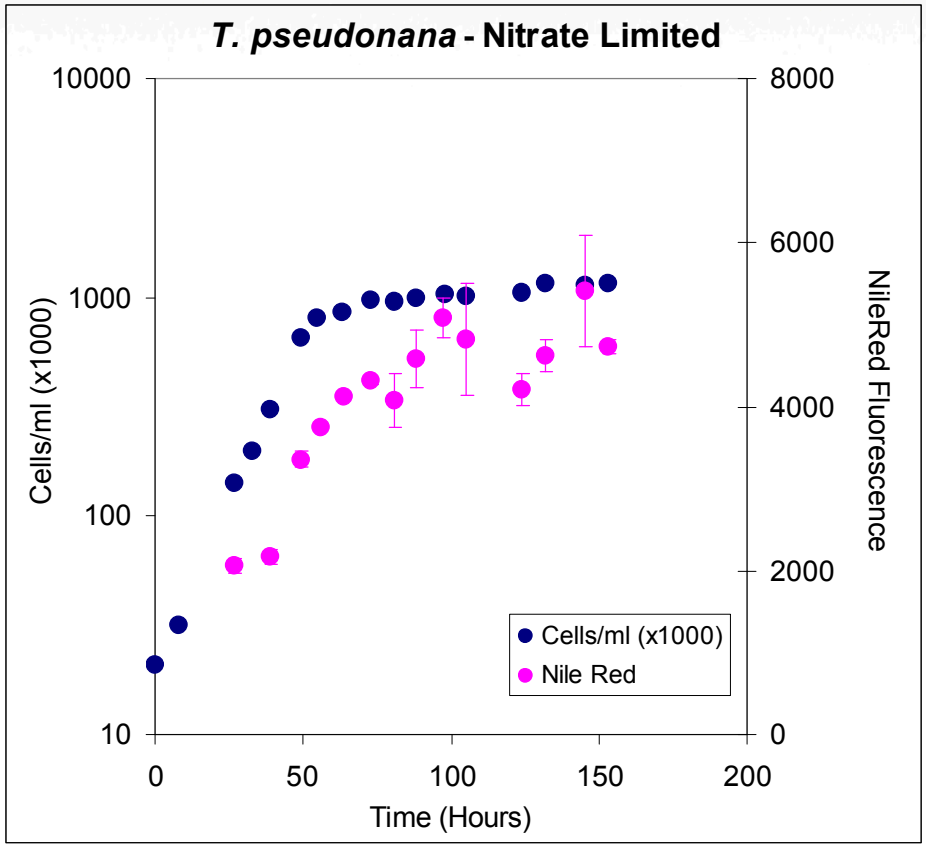
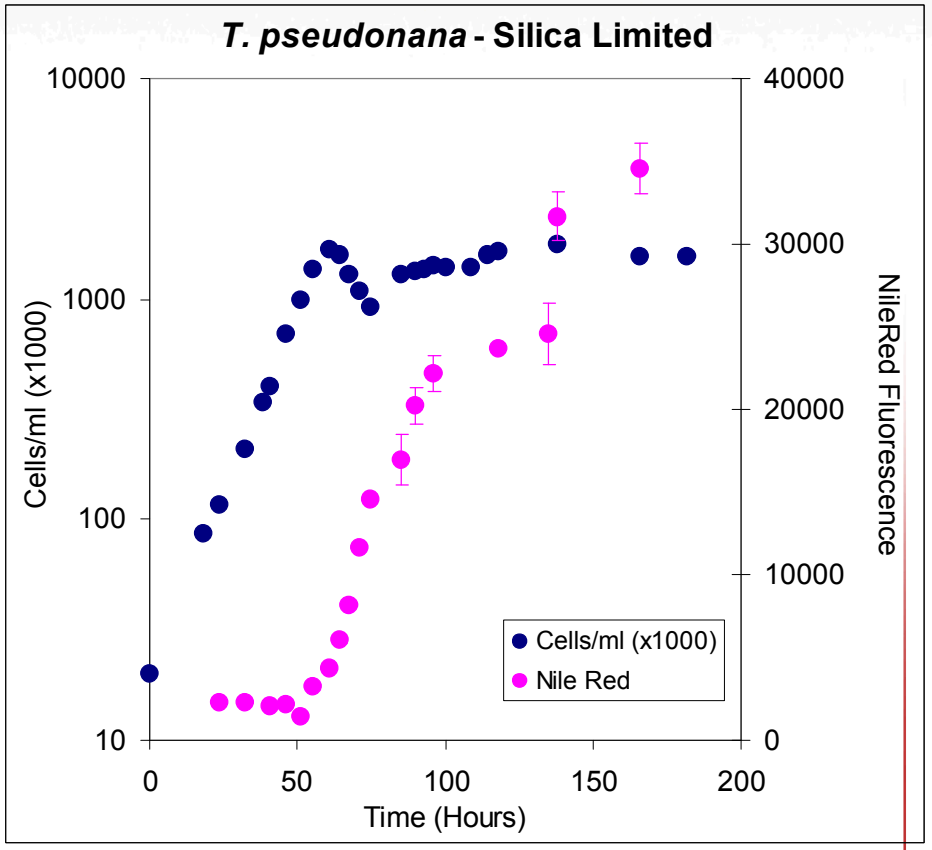
We want to understand, observe, and control the biochemistry of lipid production.





Growth curves correlated to TAG accumulation as function of nutrient starvation.

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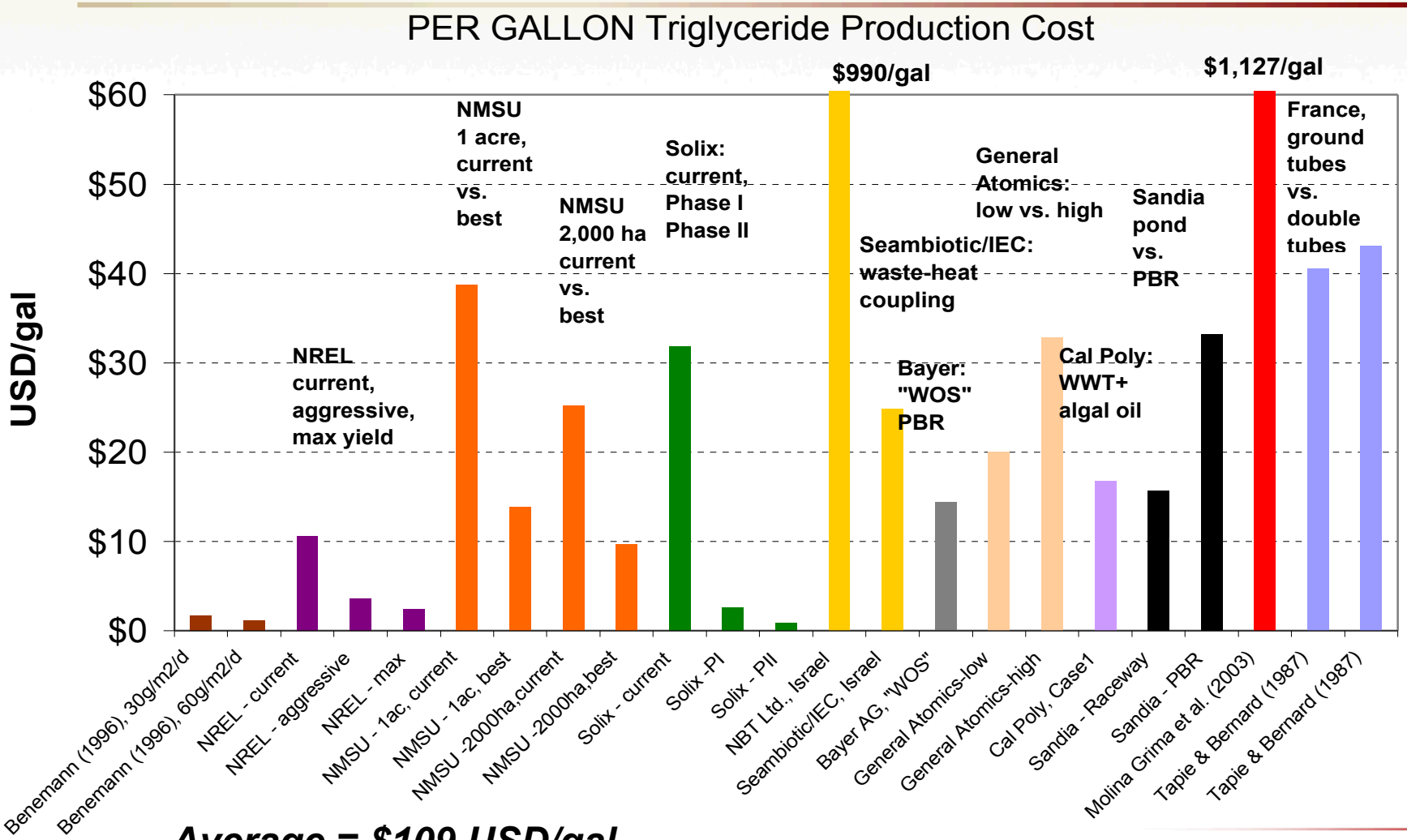
In-situ spectroscopic data, remote sensing, and CFD modeling provide the best method for continuous on-line pond characterization and systems optimization.

- ***Optimize system parameters to improve efficiency (raceway designs, nutrient loads, temperatures, etc.).***
- ***Impact of various climates on growth rates and biomass productivity.***
- ***Evaluate the impacts of various system parameters without having to risk an algal colony.***
- ***Determine the feasibility and potential benefits of scaling up.***
- ***Quantify the benefits of integrating algae culture ponds with waste treatment plants and fossil-fuel-based power plants.***

Techno-Economic modeling informs technical and policy decisions.

- *Assess technical performance & cost/benefit tradeoffs among different technologies, systems, and processes*
- *Assess economic and environmental impact of R&D strategies & investments*
- *Assess consequences & constraints of alternative pathways for algal feedstock, biofuels, & coproducts industry build-up*

No Consensus on Feasibility of Algae



Average = $109 USD/gal

Variability is wide, Std. Dev. = $301 USD/gal

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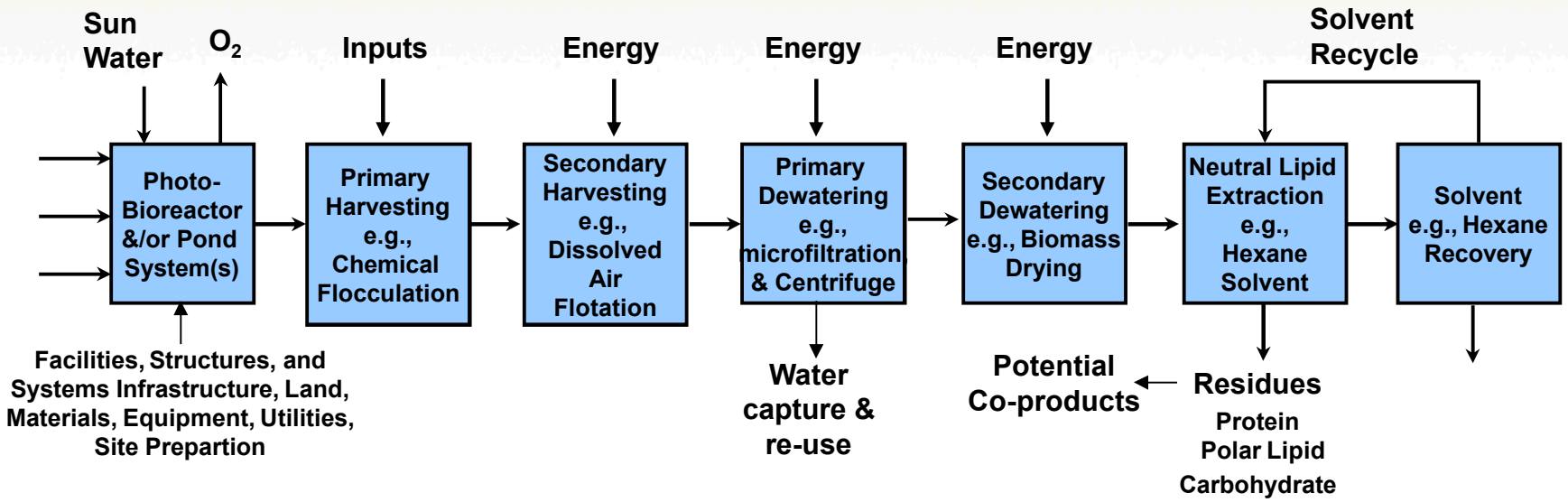
Sandia has developed an algal oil production systems/processes cost/performance analysis.

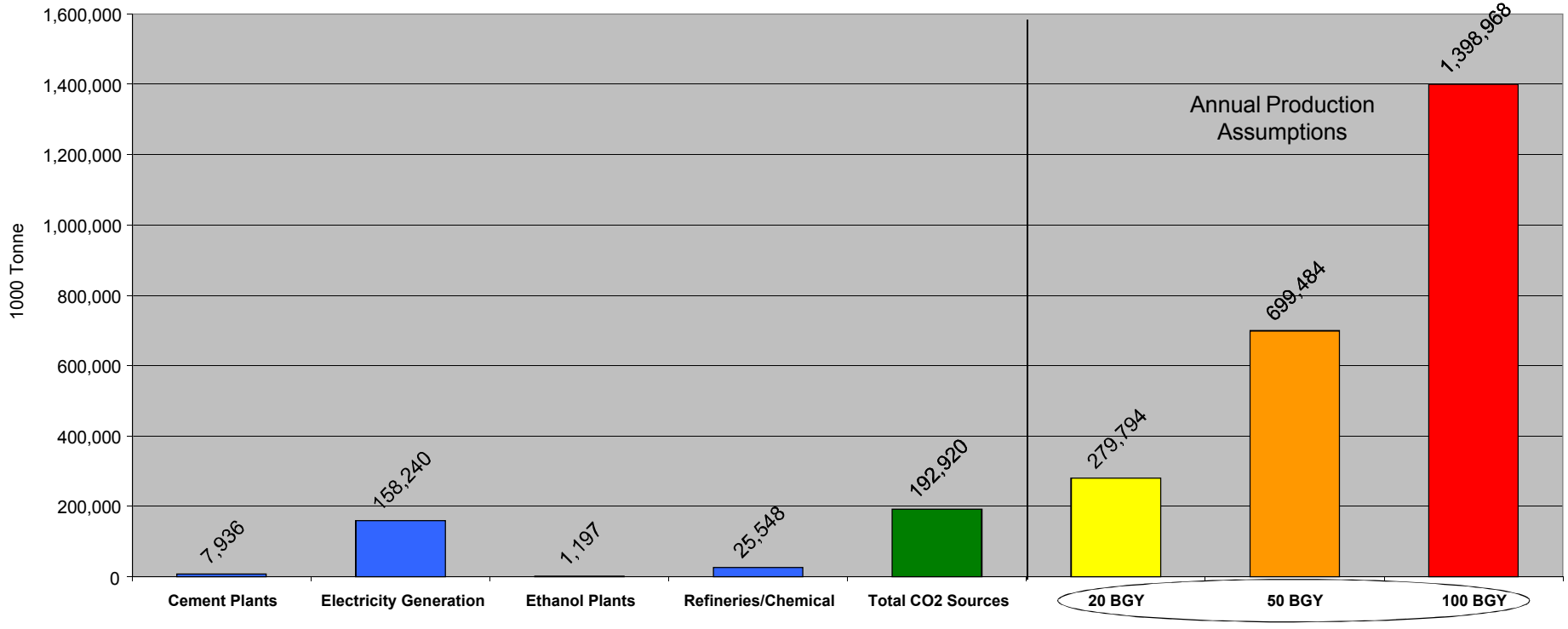


Approach to microalgae oil production cost estimation

- 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
- Modeling and analysis 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.

The estimated total CO_2 *use* for algae production indicates a deficit compared to available sources.

Systems Analysis



*CO2 Data is from NATCARB Database

**7.7 lbs/gallon algal TAG conversion and 4 lbs CO2 for 1 lbs algal biomass @ 50% oil

***Total US CO2 Emissions* ~ 3.28 billion metric tonnes**

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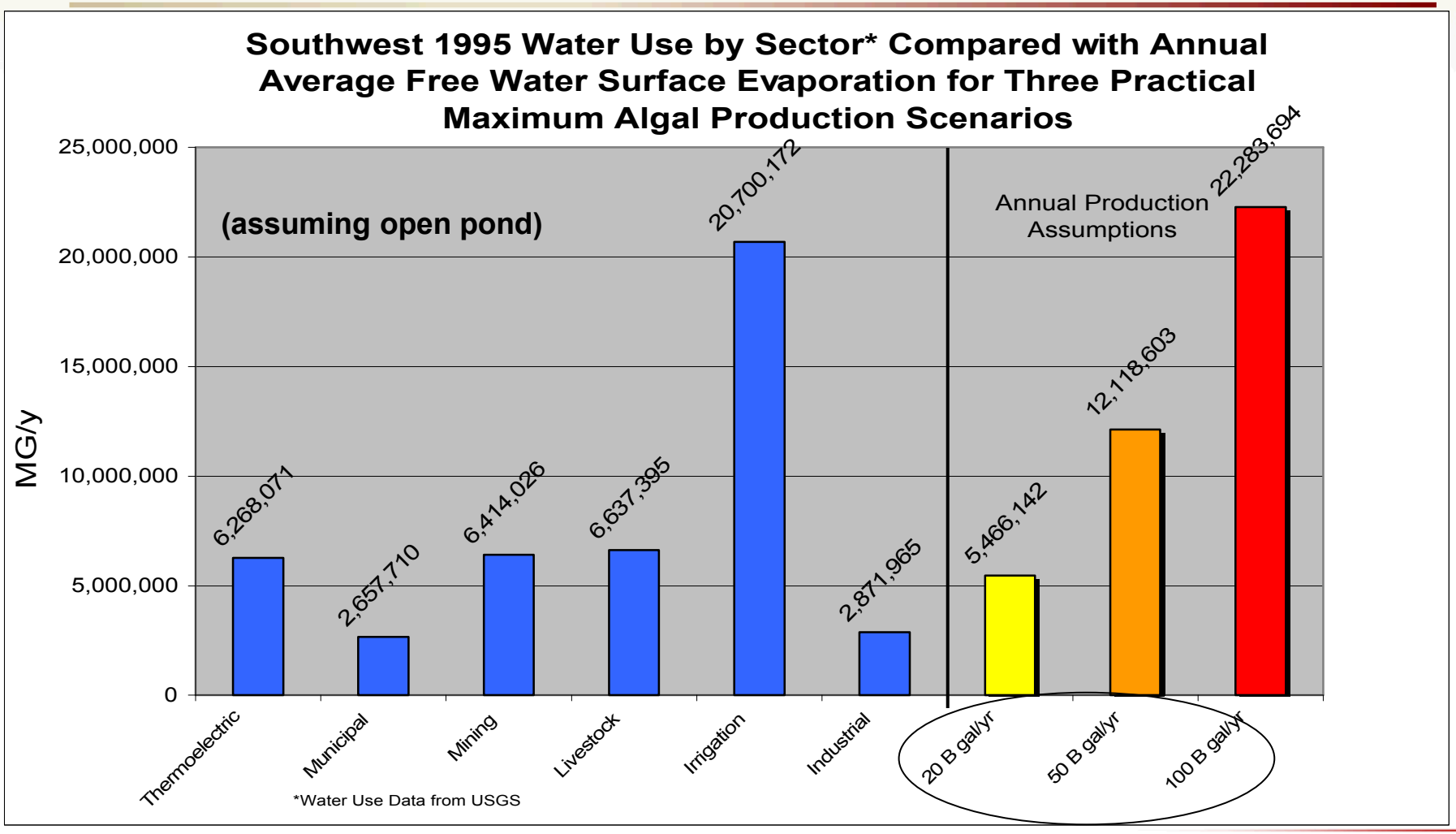
The estimated total *water use* for algae production indicates we would need as much as is currently being used for irrigation.



Total Combined Water Use by Sector in CA, AZ, & NM;
Total Irrigation Water Use in Contiguous 48 States ~ 51 million Mgal/yr

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Some Parting Thoughts

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- We've been growing grass (e.g. corn) for food for thousands of years. Cellulosic bioenergy crops will be a straightforward development
  - We can use the existing agricultural economy
  - Starch now, cellulosic ethanol soon, cellulosic hydrocarbon fuels thereafter
- Algae present the greatest scale, sustainability, AND risk
  - Risk = cost
  - Regulations target EXISTING industries, it's harder to regulate to a future state
  - There is no real algae cultivation industry (sans nutraceuticals)
  - Algae to transportation fuels (long term, high risk, big market) vs Algae to "co-products" to fuels (short-to-long term, risk mitigation)

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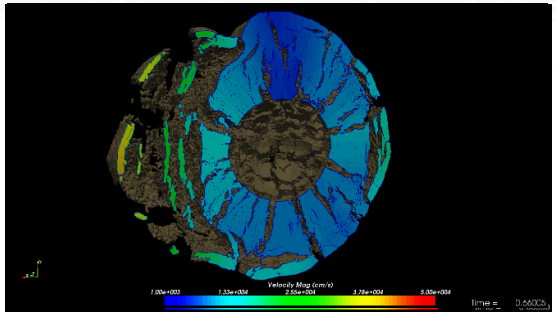
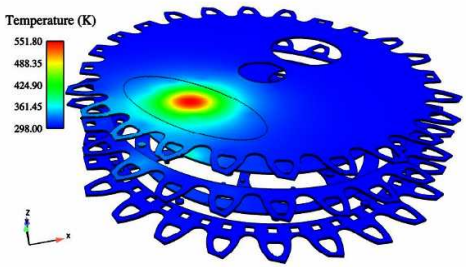
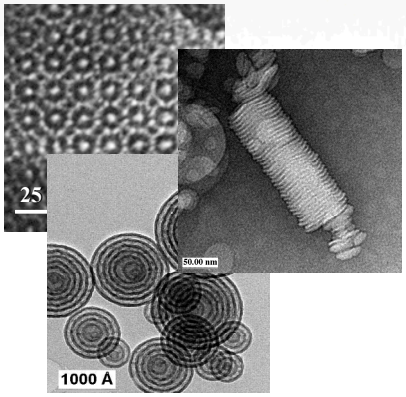
Biosciences is One of Six Research Foundations at Sandia



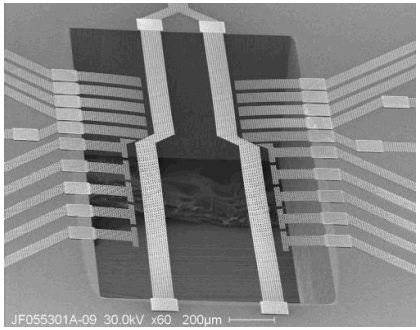
Computational and Information sciences



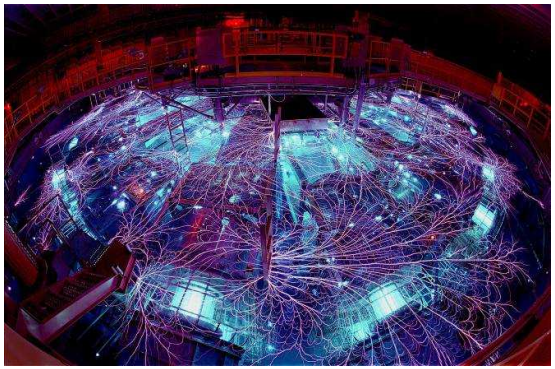
Engineering Sciences



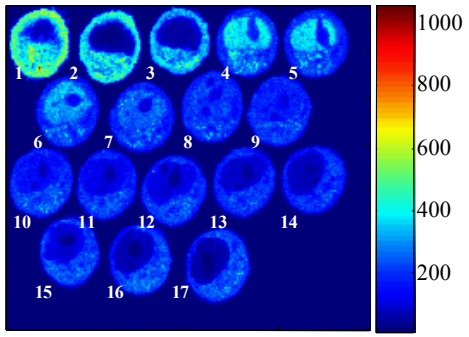
Materials Science and Technology



Microelectronics and Photonics



Pulsed Power



Bioscience

NNSA
National Nuclear Security Administration

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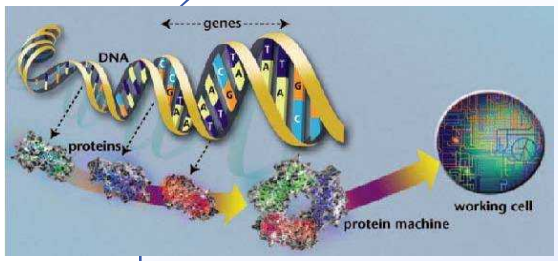
Sandia's Fuels & Water Systems "Line of Business" Works to Secureour Nation's Energy Resources

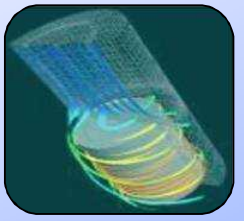
Provide systems perspective and critical technological solutions for fuel and water that assure secure and sustainable supply, safe and resilient delivery infrastructure, and clean and efficient use of resources

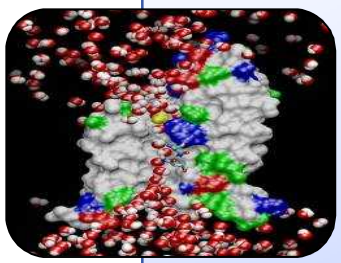


Fuels for the 21st Century

Launch Joint Bioscience Energy Institute

Implement Synthesized Fuels





Clean and Abundant Water

Create "New" Water

Provide Decision Support Tools

Infrastructure Security and Resilience

Secure Oil/Gas Infrastructure

Improve Military Base Energy Surety