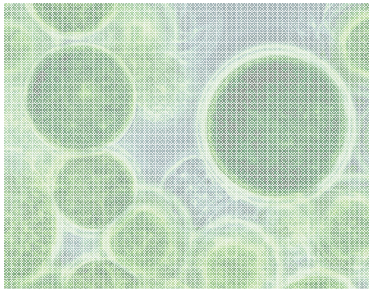
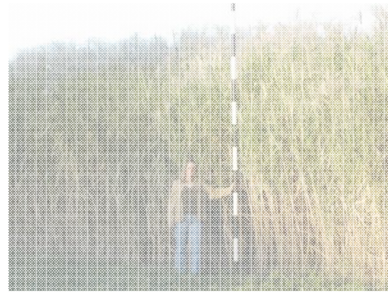
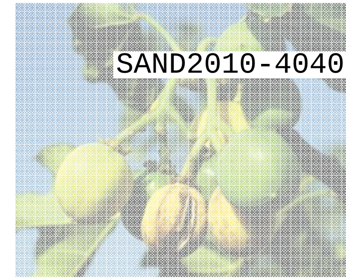

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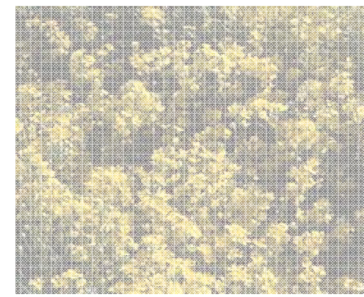
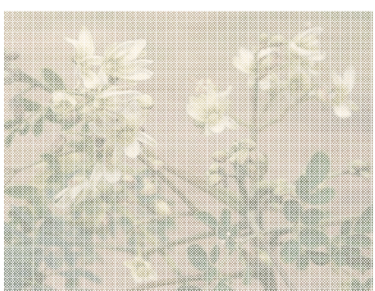
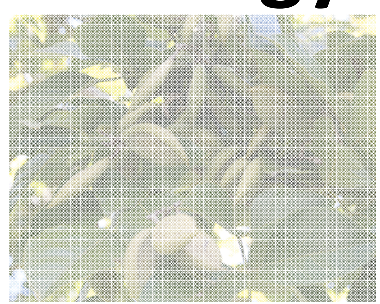
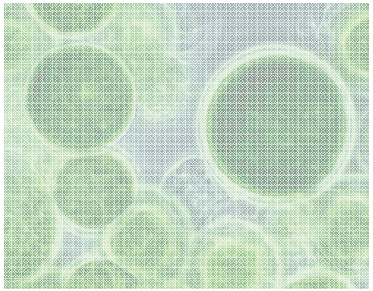
Biofuels and Biomass Energy Systems

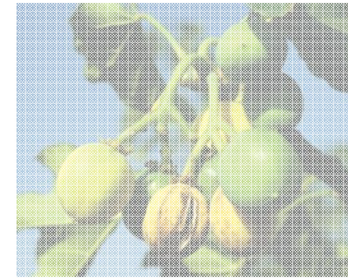



Gila River Indian Community Strategic Energy Session


Jasper (Joe) Hardesty Sandia National Laboratories June 3, 2010





Introduction to Biofuels

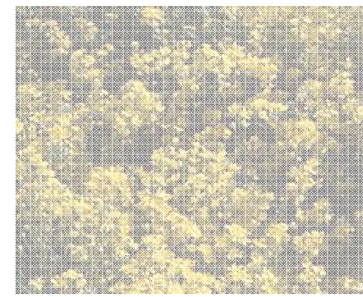
Biofuel Feedstocks

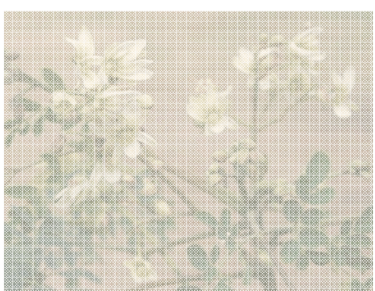
Biofuel Metrics

Biofuels & Water Use

Biofuel Processing

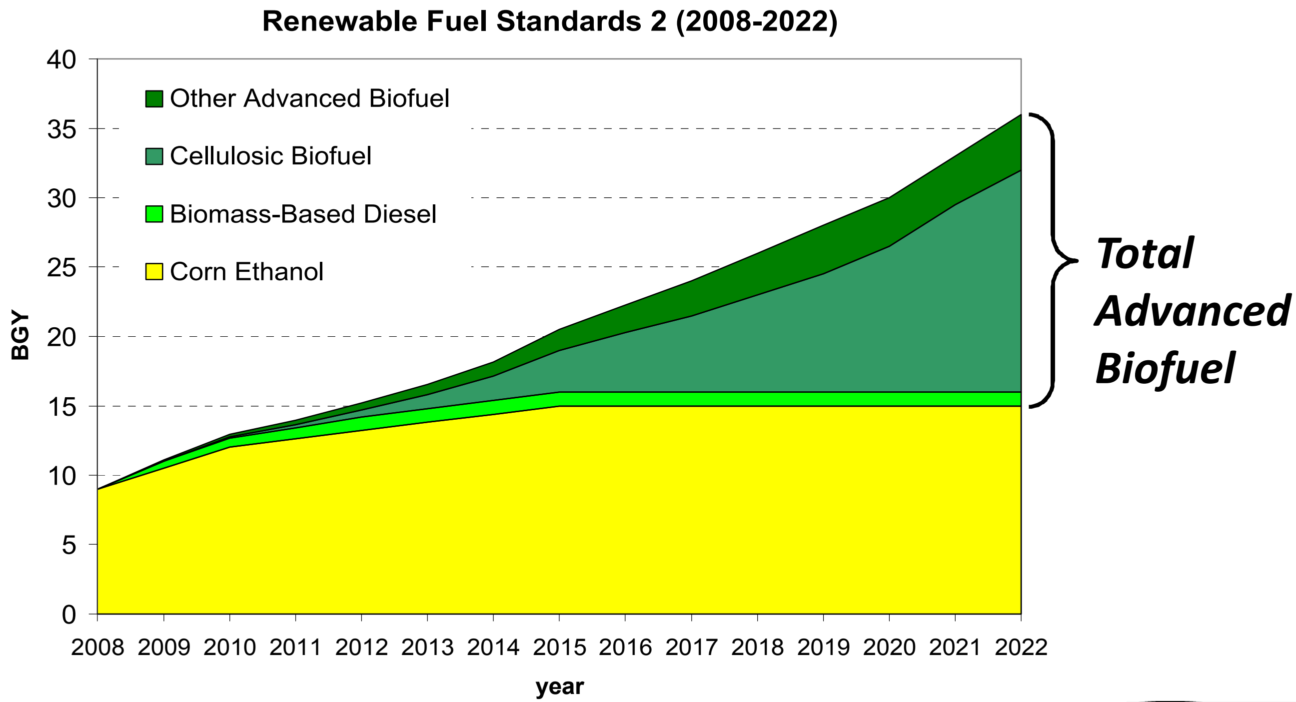
Sandia Labs Biofuel Activities





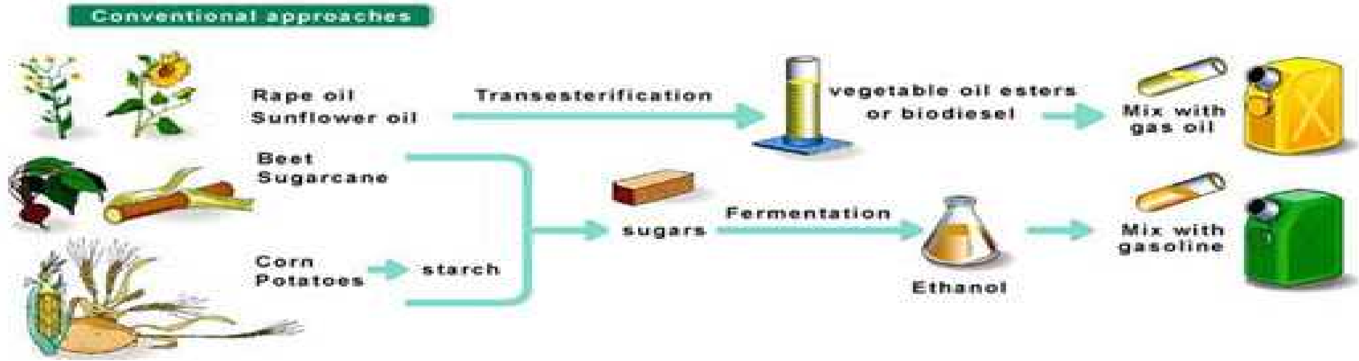
US Renewable Fuel Standards

- **Major incentives for sustainable biofuels:**
  - **energy independence**
  - **economic development**
  - **environmental benefits**

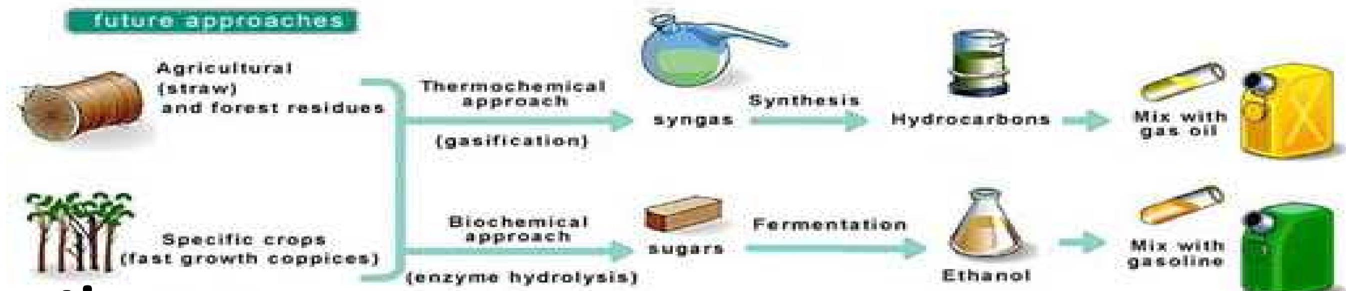


Biofuel "Generations"

– **first generation**
  • from sugar, starch, vegetable oil or animal fat • conventional technology



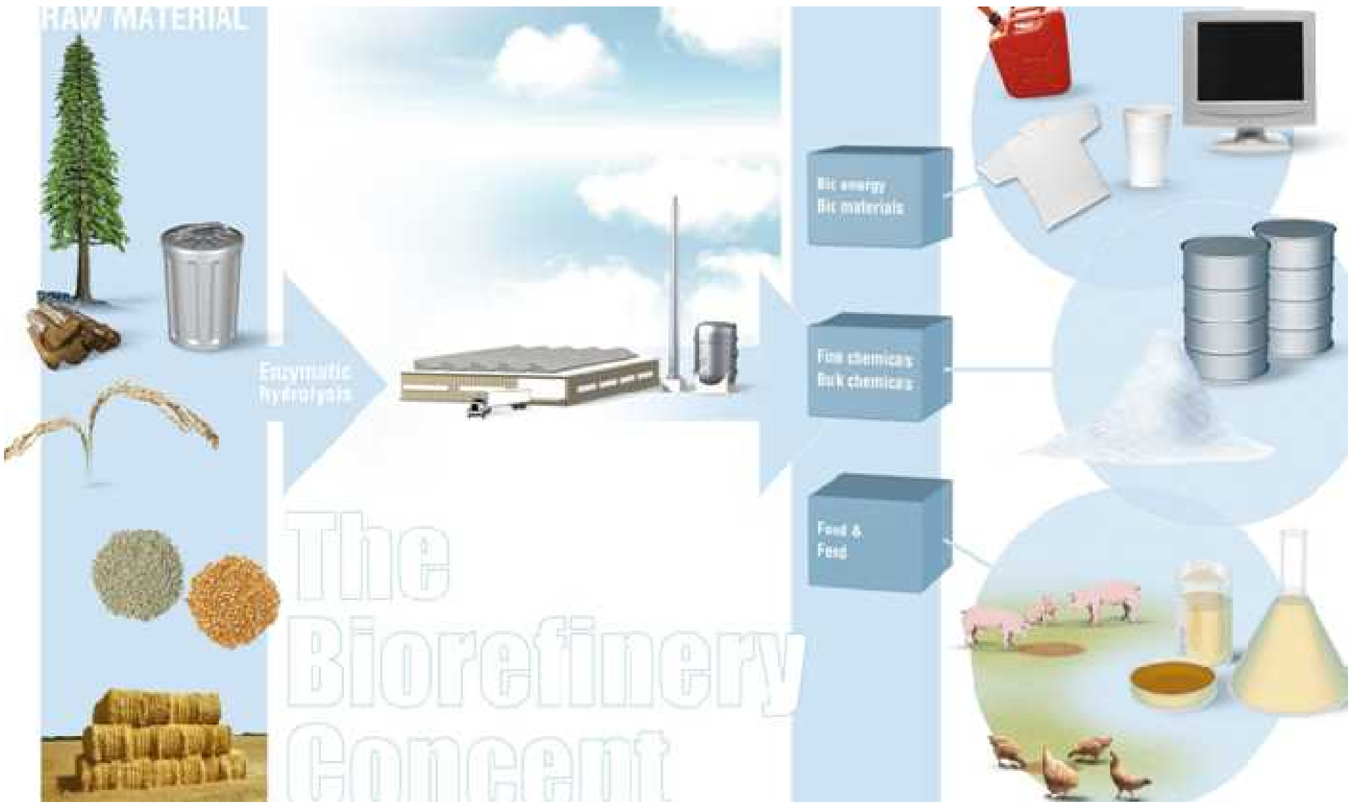
– **second generation**
  • from non-food crops and waste products • non-conventional processing



– **third generation**
  • algal oil • new approaches

Biorefineries

- Integrated biorefinery
  - various feedstocks and processes → multiple products
  - **more opportunities than fuel or energy alone**

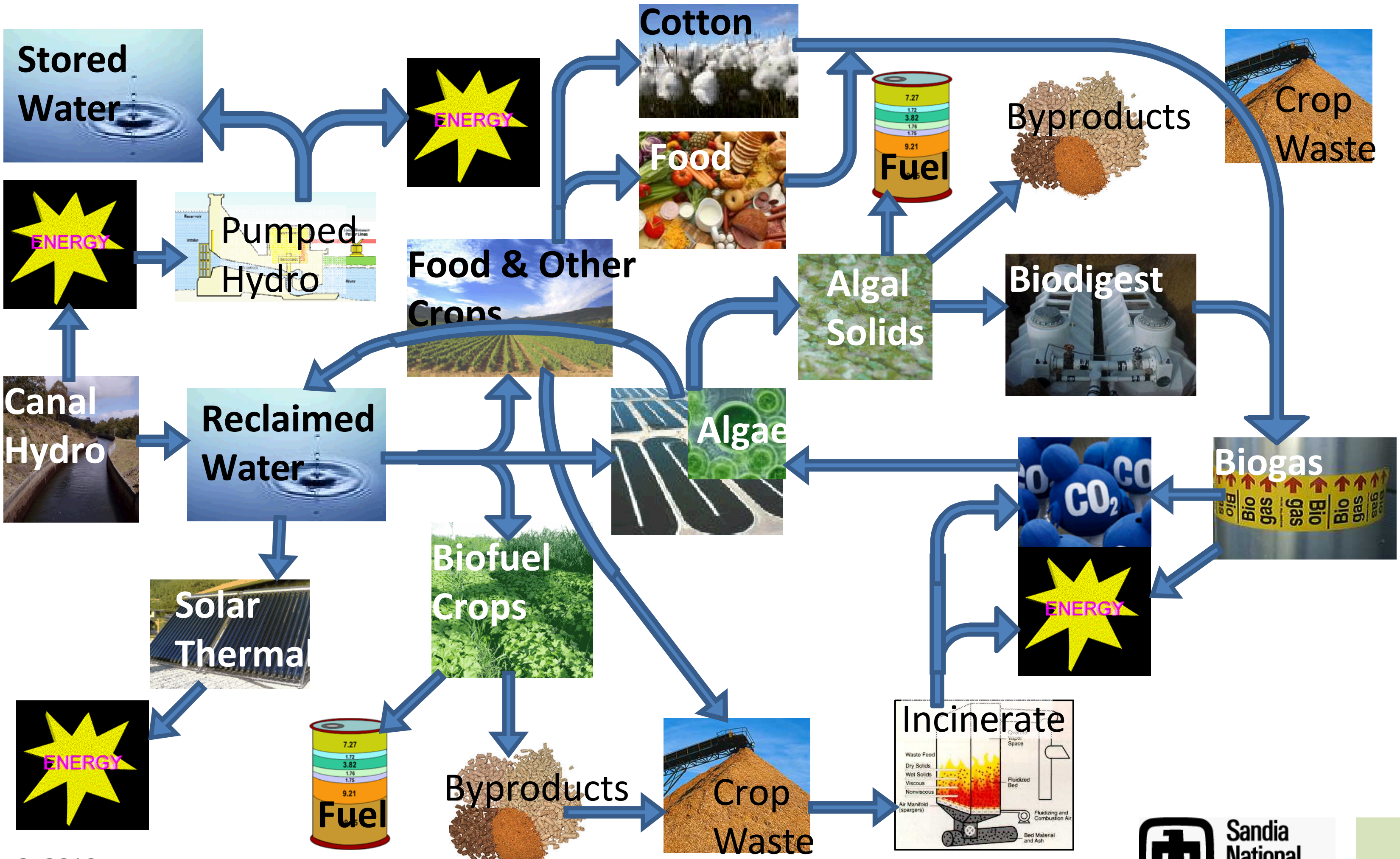


Feedstock → Processing → Products

graphic source: Novozymes, http://www.bio-economy.net/applications/files/biorefinery01.jpg

Resource Management & Sustainability

- **Comprehensive approach**:
  1) What **amount** of
  2) **which combination** of paths provide
  3) the **most beneficial** use
  4) and **preserve** vital resources?



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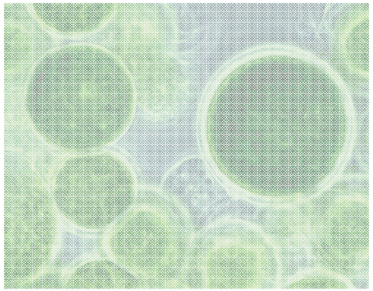
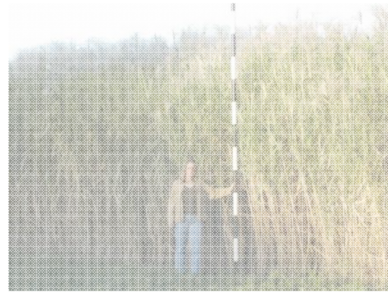
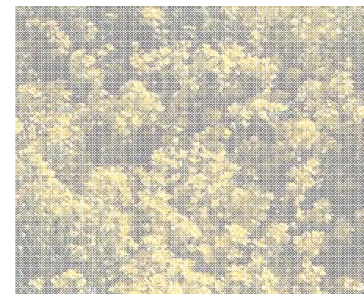




Introduction to Biofuels

Biofuel Feedstocks



Biofuel Metrics

Biofuels & Water Use

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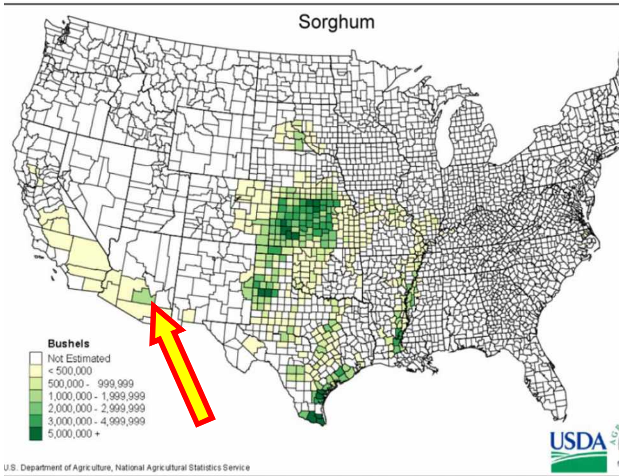
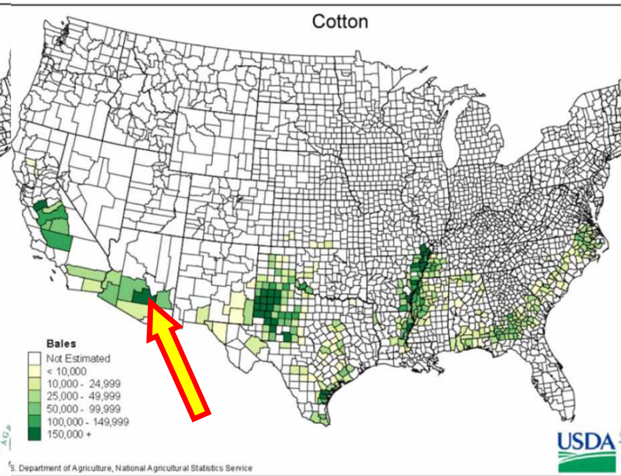
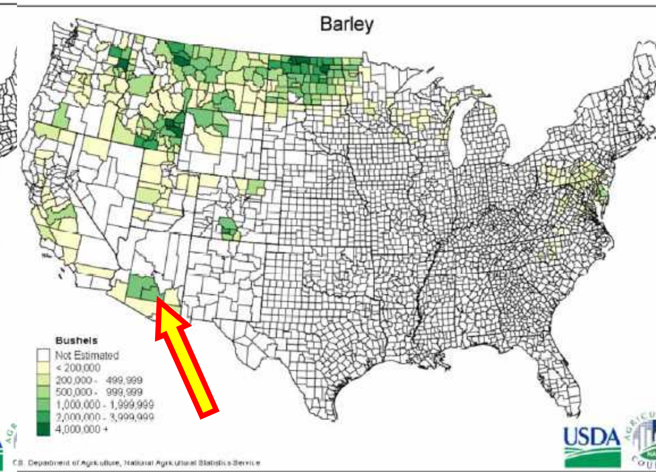
Sandia Labs Biofuel Activities

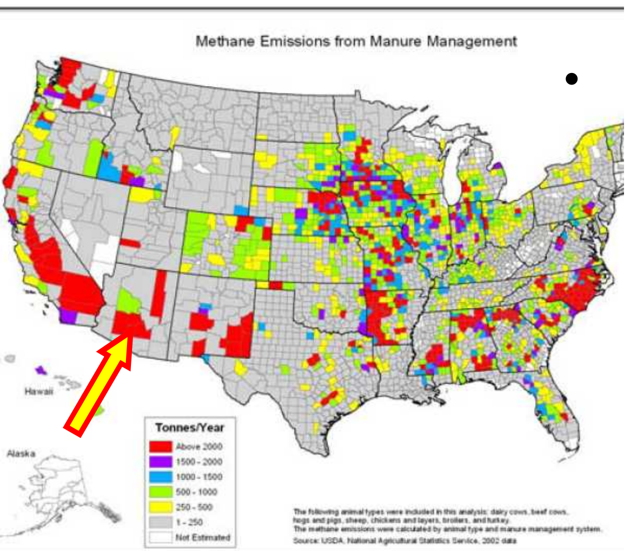


Biofuel Feedstocks

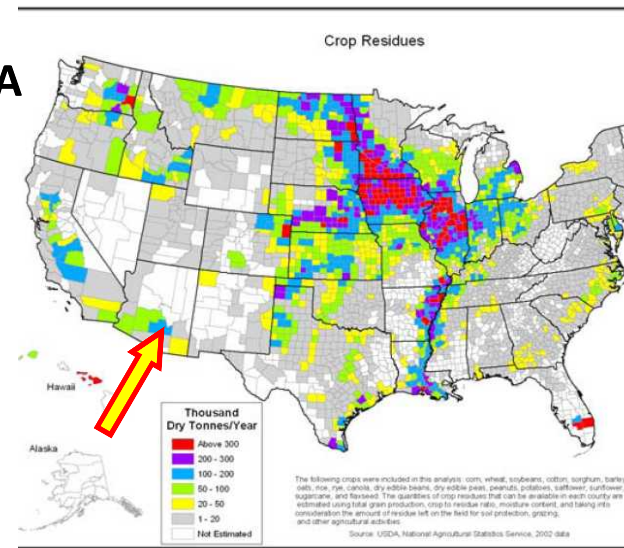








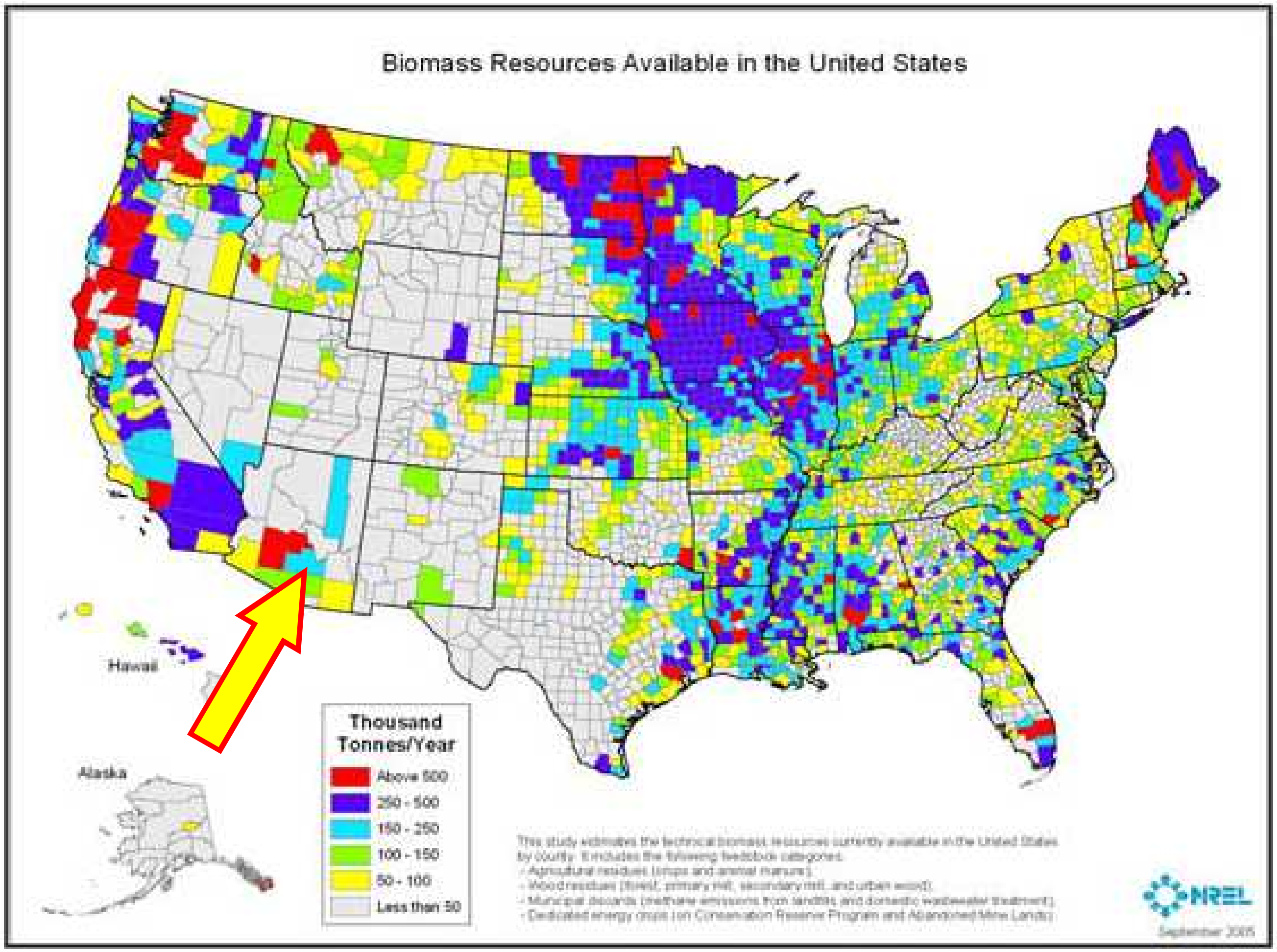
- **Major crop locations, 2007 USDA**
  - **production acreage by county**
  - **EXAMPLES ONLY…**
  - **sorghum → bioethanol**
    - **better water balance than corn**
    - **better energy balance than corn**
  - **cotton, barley, residues, etc:**
    - **short term → biomass**
    - **long term → biomass/cellulosic ethanol**
  - **methane from manure (estimated)**



graphic sources: (1) L. Wright, et al; "Biomass Energy Data Book", Edition 2, USDOE-EERE Office of Biomass Program, 2009; (2) A. Milbrandt, "A Geographic Perspective on the Current Biomass Resource Availability in the United States", Figure 11&12, USDOE National Renewable Energy Lab, 2005.

Biomass Resources

- Ag residues, forest trimming, manure, etc.



graphic source: A. Milbrandt, "A Geographic Perspective on the Current Biomass Resource Availability in the United States", Figure 13, USDOE National Renewable Energy Lab, 2005

Arid climate biofuel crops

- Arid climate biofuel crops & biofuels[1]:

  *promising due to heartiness of the crop, low water use, high biomass yield, fast growth, ability to grow in poor soil conditions, and ease of cultivation

  – jatropha curcas* – biodiesel
    - drought resistant plant from Central America grows well in many climates
    - engineered strains with greater oil production [2]
    - Phoenix-based research and development company (AZ Biofuels Research)

  – jojoba* – biodiesel
    - shrub native to Sonoran and Mojave deserts of AZ, CA and Mexico

  – lesquerella* – biodiesel
    - of mustard family, can grow in poor soil, biodiesel production in AZ, TX, and IL
    - ongoing research at USDA Arid Land Agriculture Research Center in Maricopa

  – moringa (aka malunggay)* – biodiesel
    - multipurpose feedstock tree, gaining in popularity

  – pongamia* – biodiesel
    - multipurpose feedstock tree from Australia, gaining in popularity [3]

Refs: (1) S. Howe, P. Arambula and C. Thompson Jones for the Desert Biofuels Initiative http://desertbiofuels.org (2) J. Fahey, "A New Life for Jatropha", Forbes Magazine, Feb. 24 2010. http://www.forbes.com/2010/02/23/sg-biofuels-technology-ecotech-jatropha (3) ARC Centre of Excellence for Integrative Legume Research, Australia, Pongamia bruchure, 2008.

Arid climate biofuel crops

- Arid climate biofuel crops & biofuels[1]:
  - cotton – biodiesel
    - seed for biodiesel, and cotton oil soapstock as an option for a fuel blend
  - alfalfa – biomass
    - grows well in AZ, widely grown in the US creating industry for alfalfa cultivar development and seed production, processing, and distribution
  - sweet sorghum – ethanol
    - stalks only used for biofuel production, grain for food or livestock feed
    - grows well with high heat and low water, salt tolerant
    - ~2x fuel yield as corn
  - switchgrass – ethanol
    - native to North America, fast growing, focus of extensive research, generally less expensive collection than straw or corn stover
  - microalgae – biodiesel
    - produce as much as 30x more biodiesel per acre than many terrestrial feedstocks → 100x more biodiesel per acre/year
    - grows in poor water ← treated wastewater, irrigation runoff contain nutrients for algal growth
    - can sequester GHGs from emitters (power plants, etc)

Refs: (1) S. Howe, P. Arambula and C. Thompson Jones for the Desert Biofuels Initiative http://desertbiofuels.org (2)

Biodiesel Feedstocks

- **Advantages of algae biofuel:**
  - **avoids food vs fuel controversy**
  - **high energy yield**
  - **carbon sequestration**
  - **use of brackish water**

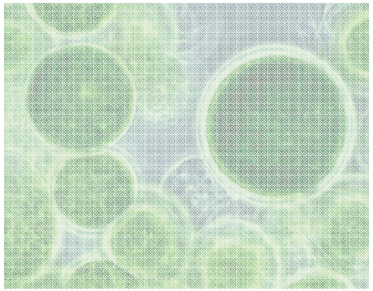
	Fuel Yield (L/Hectare)	Land required (MM hectares, for 50% supply of US transport fuels)	% existing US Crop Area
Corn	172	1,540	846
Soybean	446	594	326
Canola	1,190	223	122
Jatropha	1,892	140	77
Coconut	2,689	99	54
Oil Palm	5,950	45	24
Microalgae (70% oil content)	109,520	2.5	1.4
Microalgae (30% oil content)	46,960	6.5	3.2

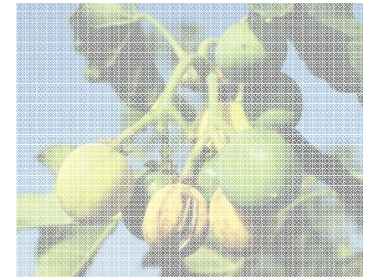
High potential as Sustainable Biofuel solution.

Source: Y. Chisti / Biotechnology Advances 25 (2007) 294–306 (corrections applied per source text)

Algae Biodiesel

- Cultivation:
  - photobioreactors (PBRs)
  - raceway ponds
- Technical cultivation issues:
  - light saturation
  - respiration
  - sustaining high-productivity algal strains
- Costs:
  - Commercial production: $5000/ton*
    * dry weight Cyanotech, HI
  - target cost: $250/ton

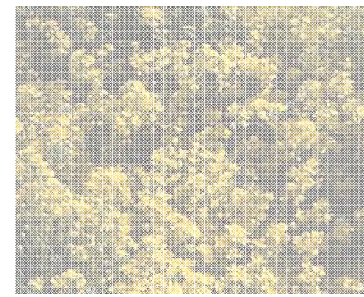




Introduction to Biofuels

Biofuel Feedstocks

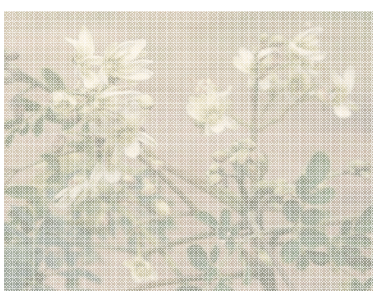
Biofuel Metrics



Biofuels & Water Use

Biofuel Processing

Sandia Labs Biofuel Activities



Biofuel Metrics: Crop Yields

- approximations – for comparison
- vary with climate & conditions

Crop	kg oil/ha/yr	litres oil/ha	lbs oil/acre	US gal/acre
maize (corn)	145	172	129	18
cashew nut	148	176	132	19
oats	183	217	163	23
lupin (lupine)	195	232	175	25
kenaf	230	273	205	29
calendula	256	305	229	33
Cotton (~13% of seed)	273	325	244	35
Hemp	305	363	272	39
Soybean (~14% of seed)	375	446	335	48
coffee	386	459	345	49
flax (linseed)	402	478	359	51
hazelnuts	405	482	362	51
euphorbia	440	524	393	56
pumpkin seed	449	534	401	57
coriander	450	536	402	57
mustard seed (~35% of seed)	481	572	430	61
camelina	490	583	438	62
Sesame (~50% of seed)	585	696	522	74
safflower	655	779	585	83
rice	696	828	622	88

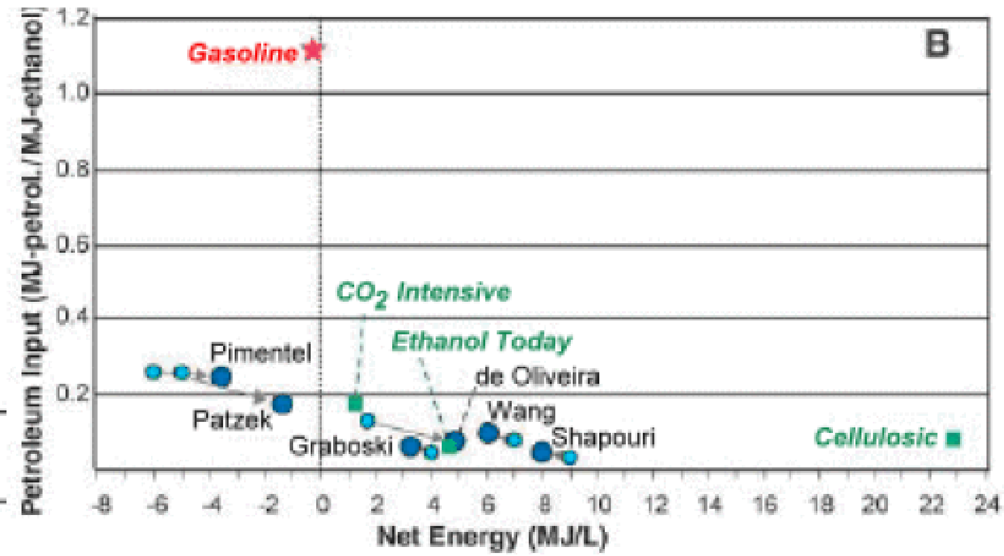
Crop	kg oil/ha/yr	litres oil/ha	lbs oil/acre	US gal/acre
tung tree	790	940	705	100
Sunflowers (~32% of seed)	800	952	714	102
cacao (cocoa)	863	1,026	771	110
peanut (~42% of seed)	890	1,059	795	113
opium poppy	978	1,163	873	124
Rapeseed (~37% of seed)	1,000	1,190	893	127
olives	1,019	1,212	910	129
castor beans (~50% of seed)	1,188	1,413	1,061	151
pecan nuts	1,505	1,791	1,344	191
jojoba	1,528	1,818	1,365	194
jatropha	1,590	1,892	1,420	202
macadamia nuts	1,887	2,246	1,685	240
brazil nuts	2,010	2,392	1,795	255
avocado	2,217	2,638	1,980	282
coconut	2,260	2,689	2,018	287
chinese tallow	3,950	4,700	3,500	500
oil palm (~36% of seed)	5,000	5,950	4,465	635
Copaifera langsdorffii		12,000		1,283
algae (open pond)	80,000	95,000	70,000	10,000

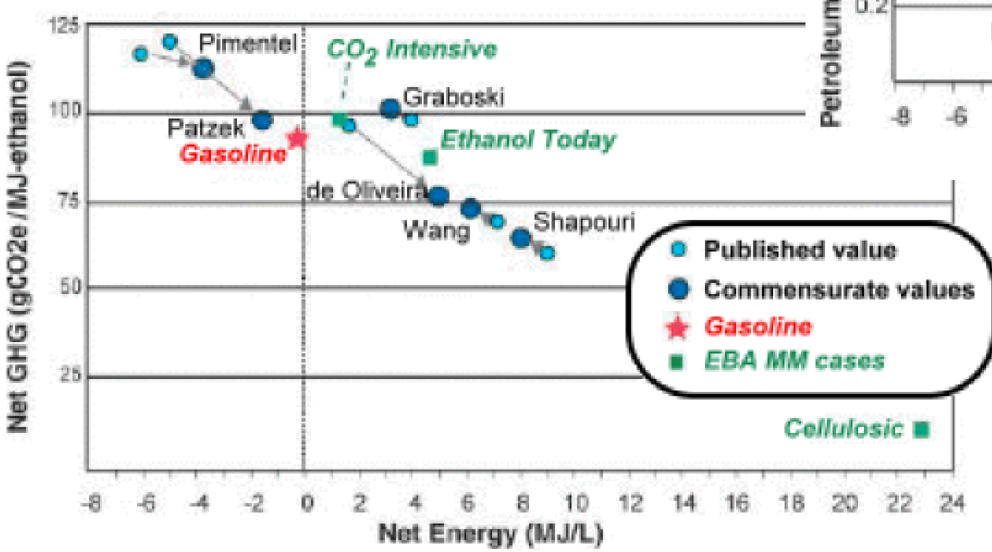
Ref: K. Addison, biofuels website: http://journeytoforever.org/biodiesel_yield.html

Biofuel Metrics: Energy & GHG Values

- **Bioethanol Energy & GHG Values**

  - Energy balances often disputed





  - GHG balances often disputed

Source: AE Farrell, et al; "Ethanol Can Contribute to Energy and Environmental Goals," *Science, Vol 311, January 27, 2006*

Biofuel Metrics: Regulations

- **Biofuel Specifications → not all (bio)fuels are created equal**
  - **compared to gasoline energy density:**
    - **ethanol ~70% of gasoline (one gallon ethanol ~ 0.7 gallons of gasoline)**
    - **diesel ~110% of gasoline (biodiesel ~same as diesel)**

Fuel Property Comparison for Ethanol, Gasoline and No. 2 Diesel

Property	Ethanol	Gasoline	No. 2 Diesel
Chemical Formula	C_2H_5OH	C4 to C12	C3 to C25
Molecular Weight	46.07	100–105	≈200
Carbon	52.2	85–88	84–87
Hydrogen	13.1	12–15	33–16
Oxygen	34.7	0	0
Specific gravity, 60° F/60° F	0.796	0.72–0.78	0.81–0.89
Density, lb/gal @ 60° F	6.61	6.0–6.5	6.7–7.4
Boiling temperature, °F	172	80–437	370–650
Reid vapor pressure, psi	2.3	8–15	0.2
Research octane no.	108	90–100	--
Motor octane no.	92	81–90	--
(R + M)/2	100	86–94	N/A
Cetane no.(1)	--	5–20	40–55
Fuel in water, volume %	100	Negligible	Negligible
Water in fuel, volume %	100	Negligible	Negligible
Freezing point, °F	-173.2	-40	-40–30[b]
Centipoise @ 60° F	1.19	0.37–0.44[a]	2.6–4.1
Flash point, closed cup, °F	55	-45	165
Autoignition temperature, °F	793	495	≈600
Lower	4.3	1.4	1
Higher	19	7.6	6
Btu/gal @ 60° F	2,378	≈900	≈700
Btu/lb @ 60° F	396	≈150	≈100
Btu/lb air for stoichiometric mixture @ 60° F	44	≈10	≈8
Higher (liquid fuel-liquid water) Btu/lb	12,800	18,800–20,400	19,200–20000
Lower (liquid fuel-water vapor) Btu/lb	11,500	18,000–19,000	18,000–19,000
Higher (liquid fuel-liquid water) Btu/gal	84,100	124,800	138,700
Lower (liquid fuel-water vapor) Btu/gal @ 60° F	76,000[a]	115,000	128,400
Mixture in vapor state, Btu/cubic foot @ 68° F	92.9	95.2	96.9[c]
Fuel in liquid state, Btu/lb or air	1,280	1,290	–
Specific heat, Btu/lb °F	0.57	0.48	0.43
Stoichiometric air/fuel, weight	9	14.7	14.7
Volume % fuel in vaporized stoichiometric mixture	6.5	2	–

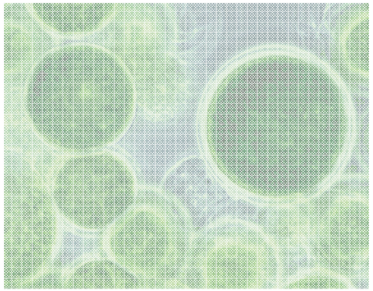
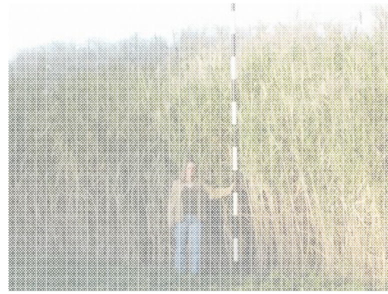
Source:
U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Alternative Fuels Data Center, http://www.eere.energy.gov/afdc/altfuel/fuel_properties.html.

Biofuel Metrics: Regulations

- **Biofuel Specifications → not all (bio)fuels are created equal**
  - higher Iodine # = higher viscosity
  - lower Cetane # = lower autoignition

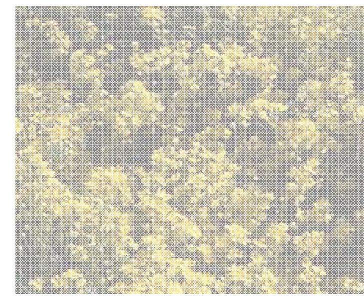
Crop/Oil Type	Melting Temperature Range (degC)			Iodine Value (# dble bonds)	Cetane Number (min >47)
	Oil/Fat	Methyl Ester	Ethyl Ester		
Rapeseed Oil (high eruc.)	5	0	(-2)	97-105	55
Rapeseed Oil (low eruc.)	(-5)	(-10)	(-12)	110-115	58
Sunflower Oil	(-18)	(-12)	(-14)	125-135	52
Olive Oil	(-12)	(-6)	(-8)	77-94	60
Soybean Oil	(-12)	(-10)	(-12)	125-140	53
Cotton Seed Oil	0	(-5)	(-8)	100-115	55
Corn Oil	(-5)	(-10)	(-12)	115-124	53
Coconut Oil	20-24	(-9)	(-6)	8-10	70
Palm Kernel Oil	20-26	(-8)	(-8)	12-18	70
Palm Oil	30-38	14	10	44-58	65
Palm Oleine	20-25	5	3	85-95	65
Palm Stearine	35-40	21	18	20-45	85
Tallow	35-40	16	12	50-60	75
Lard	32-36	14	10	60-70	65

Ref: K. Addison, biofuels website: http://journeytoforever.org/biodiesel_yield.html


Introduction to Biofuels

Biofuel Feedstocks

Biofuel Metrics

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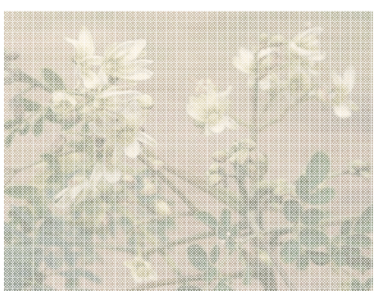
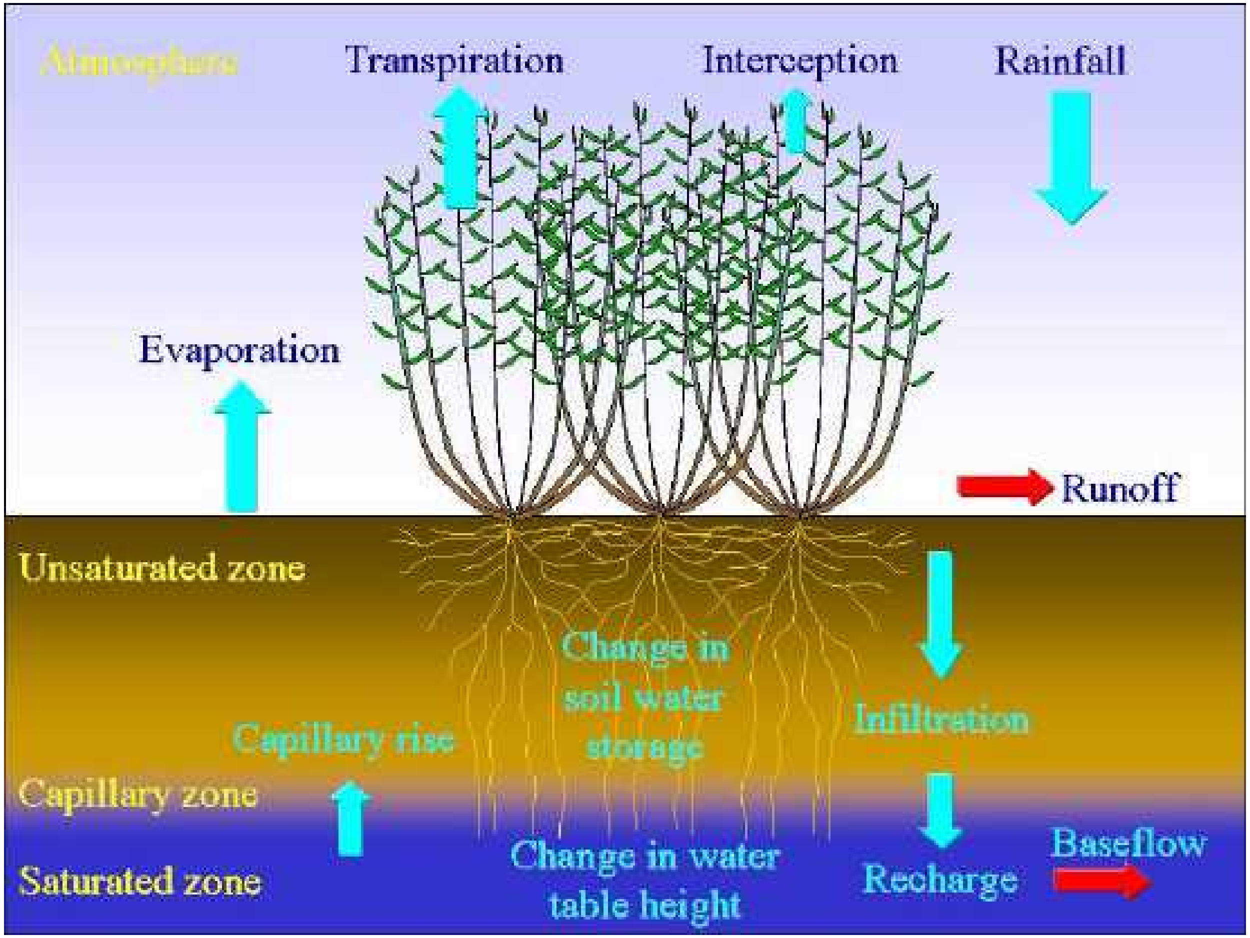
Sandia Labs Biofuel Activities



Biofuels & Water & Hydrology

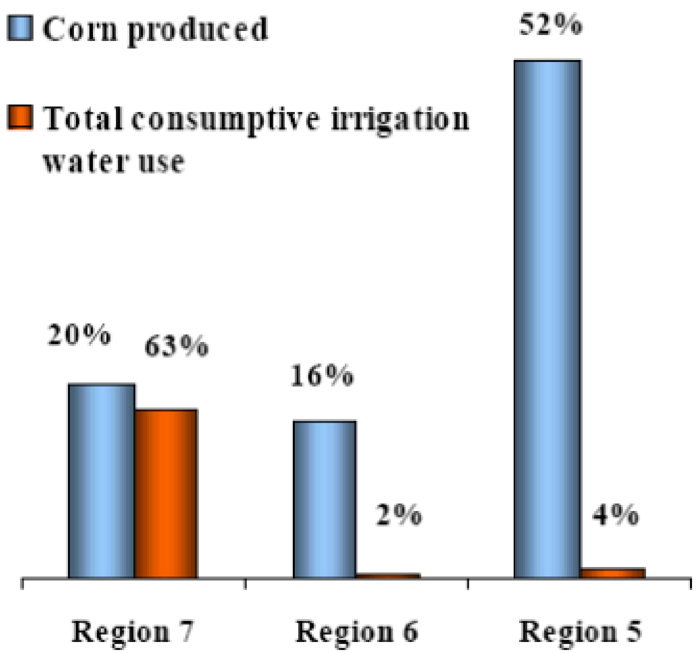
- **water balance schematic for energy crops**

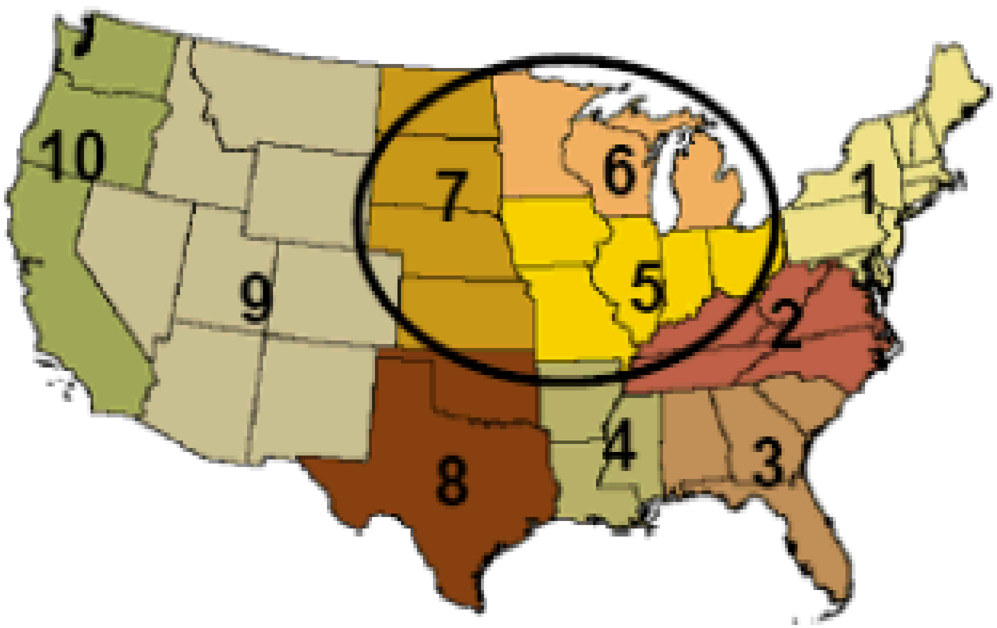


graphic source: W Stephens, et al; "Review of the Effects of Energy Crops on Hydrology", Inst. of Water & Envir., Cranfield Univ., 2001

Bioethanol & Water Consumption

- **corn ethanol in arid lands is water-wasteful**





Regional Consumptive Irrigation versus Corn Production in the US

Refs: (1) ANL, (2008), Consumptive water use in the production of ethanol and petroleum gasoline, Argonne National Laboratory.

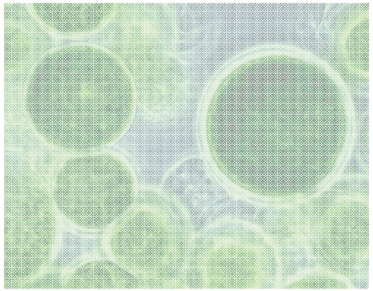
Biofuels & Water Use

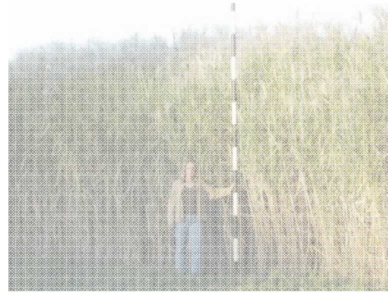
Fuel Type and Conversion Process	Biomass Feedstock	Feedstock Water Use Intensity				Processing Water Use Intensity (gal H_2O/gal fuel)		Normalized[e] Processing Water Use Intensity (gal H_2O/gal oil equiv)	
		Feedstock Water Demand (Ac-ft/Acre)	Biofuel Yield (gal fuel/acre)	Feedstock Water Consumption[d] (gal H_2O/gal fuel)	Normalized[e] Feedstock Water Consumption[d] (gal H_2O/gal oil equiv.)	Process Water Use	Process Water Consumption	Process Water Use	Process Water Consumption
Ethanol, Starch or sugar-based, Wet or dry mill	Corn	1.2	400	1,000	**1,500**	2-6	4	3-9	**6**
	Sorghum	1.0	170	1,900	**2,850**				
	Sugar cane	2.0	560	1,200	**1,800**				
	Sugar beet	2.3	550	1,400	**2,100**				
Ethanol, cellulose-based[a], biochem or thermochem	Switchgrass	2.3	500-800 (700 est.)[b]	1,100	**1,650**	6-14 (est.)	8 (est.)	9-21	**12**
	Woody biomass	n/a	n/a	n/a	**n/a**				
Biodiesel, oil extraction and trans-esterification	Soybean	0.8	40	7,000	**6,300**	1-3	2	0.9-2.7	**1.8**
	Sunflower	1.0-2.0	80	4,000	**3,600**				
	Jatropha	n/a	162	n/a	**n/a**				
	Oil palm	n/a	510	n/a	**n/a**				
	Algae[c]	n/a	3,000-15,000 (5,000 est.)	100	**90**				

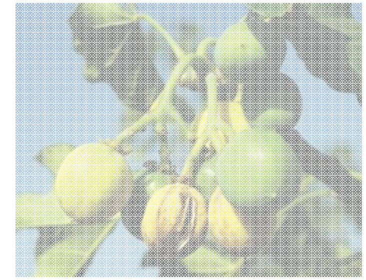
[a] Cellulose-based ethanol yields of 100 gal/dry ton based on laboratory data, processes are still experimental
[b] Switchgrass yields have exceeded 10 dry tons/acre experimentally, but more routinely range from 3 to 7
[c] Algae values are estimates based on laboratory data, high-yield processes are experimental
[d] Aggregate water consumption intensity assuming 5% feedstock production with irrigation combined with fuel processing consumption
[e] Normalized values based on energy densities relative to petroleum (ethanol ~70%, diesel ~110%)

- considerations:
  - use & consumption for crop & processing
  - rain & surface water vs groundwater withdrawal

Ref: M. Hightower, et al; "Energy-Water Challenges and Research and Development Issues", USDOE Sandia National Labs, 2009

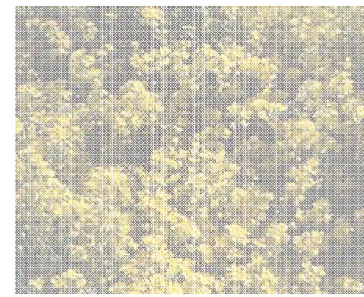






Introduction to Biofuels

Biofuel Feedstocks

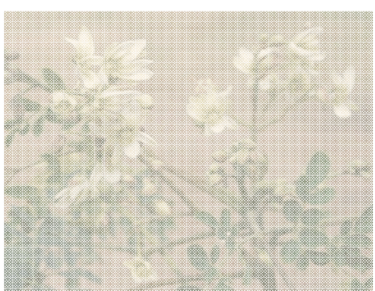


Biofuel Metrics

Biofuels & Water Use

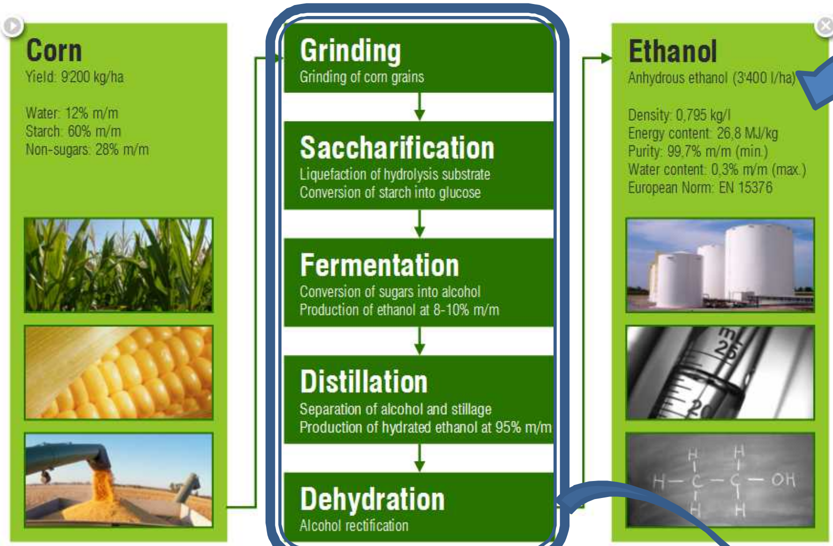
Biofuel Processing

Sandia Labs Biofuel Activities

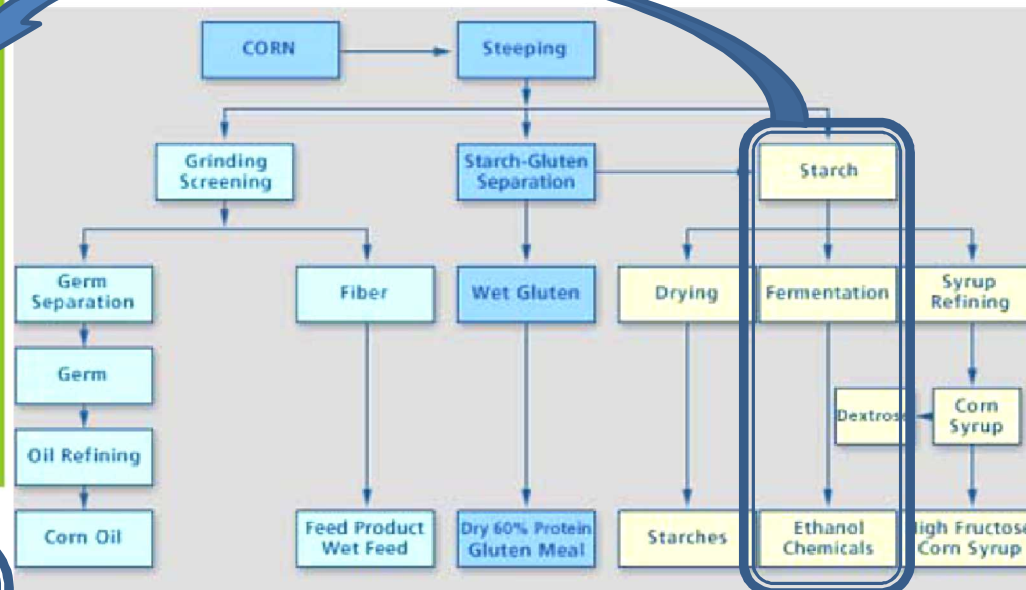


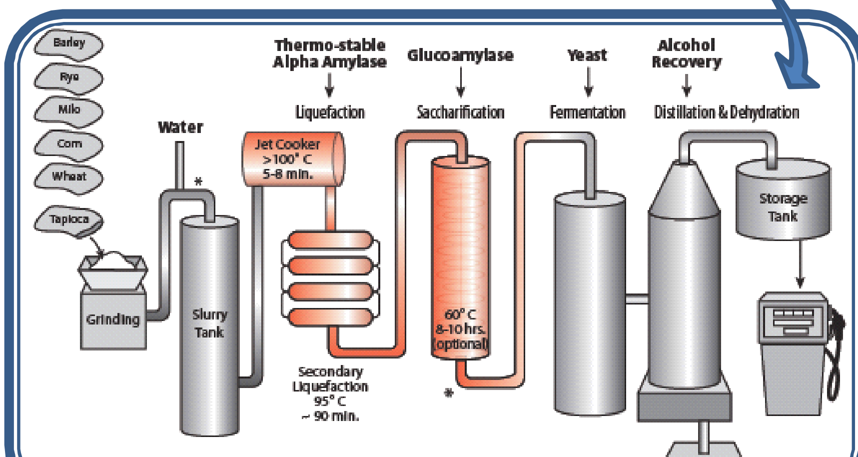
Biofuels Processing

- corn-based ethanol production:
  - integrated biorefinery and other products



Production of bioethanol from corn
bioethanol (5/6)



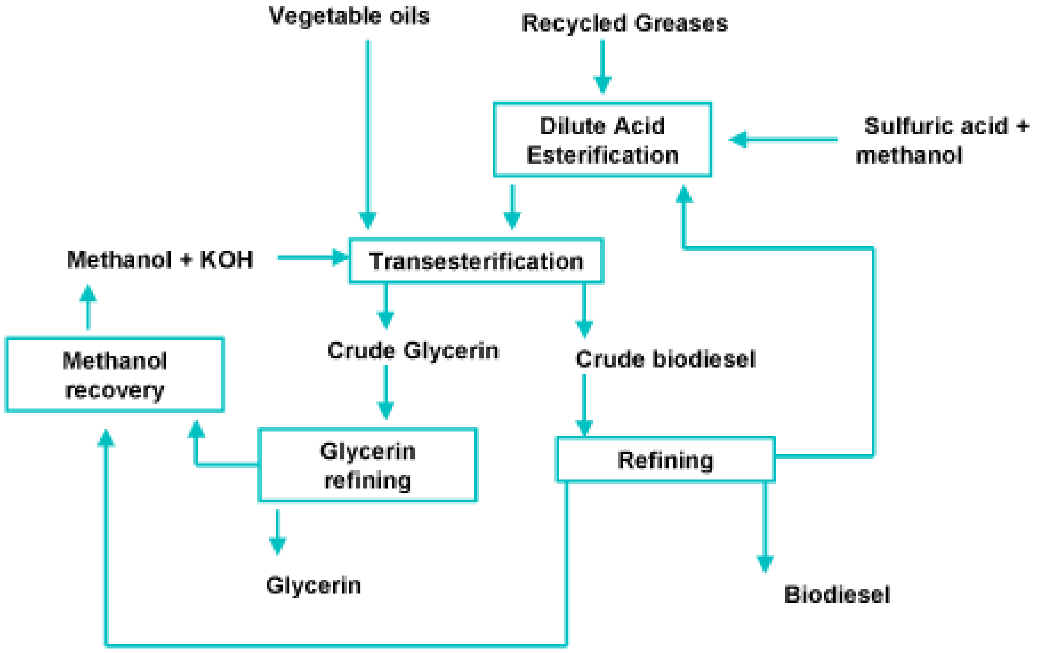


Conventional Dry Mill Ethanol Process

- cellulose-based ethanol production:
  - extra steps to separate hemicellulose and lignin
- sorghum-based ethanol production:
  - fewer steps for soluble feedstock

Biodiesel Processing

- bio-based diesel production:
  - different feedstocks:
    - different byproducts
    - different processing (acid, weak acid, base catalysts)
- algae biodiesel issues:
  - harvesting
  - dewatering
    - flocculation
    - centrifugation
  - extraction
    - electroporation
    - heat/pressure
    - osmotic shock



Biomass Resources & Recycling

Biomass Feedstock

- **Forest Residues**
- **Short Rotation Woody Crops**
- **Wood Waste**

Conversion Processes

- **Manufacturing**
- **Co-firing**
- **Combustion**
- **Gasification**
- **Enzymatic Fermentation**
- **Gas/liquid Fermentation**
- **Acid Hydrolysis/Fermentation**

USES

Fuels:
- Renewable Diesel
- Ethanol

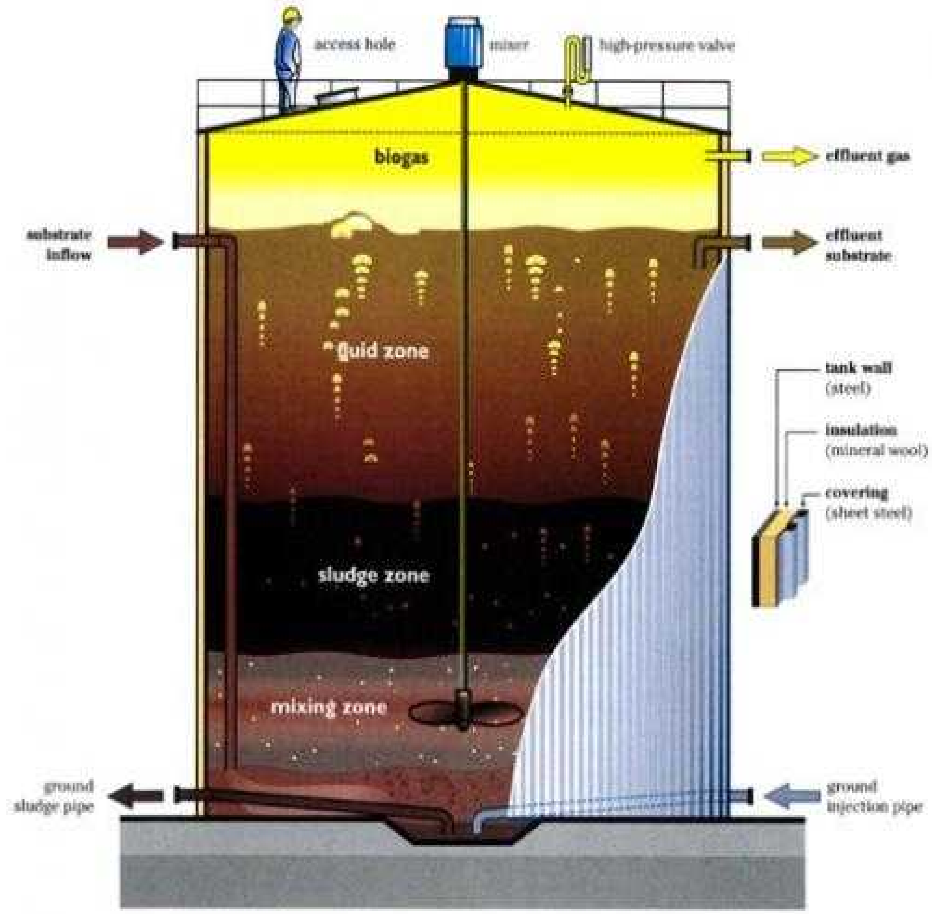
Electricity and Heat

Biobased Products
- Composites
- Chemicals
- Traditional Products
- Specialty Products
- New Products

Biomass Resources & Recycling

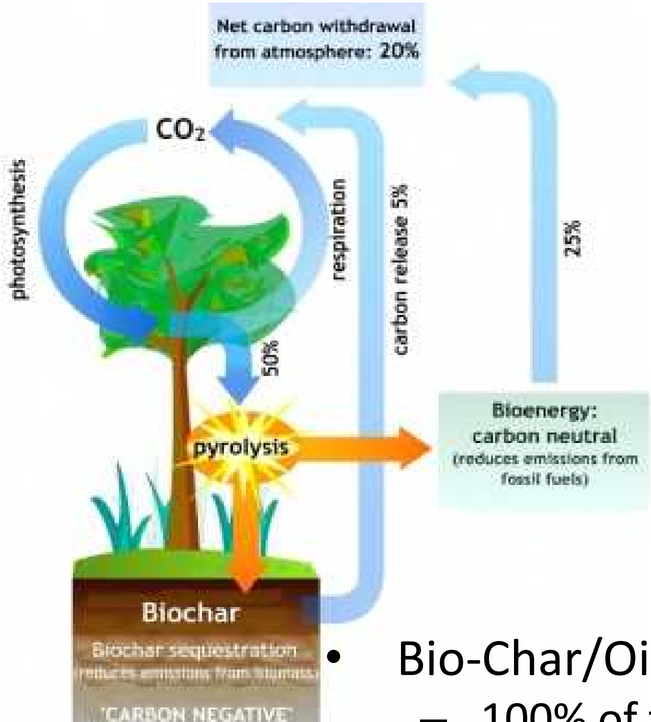
- **Wastewater/solid waste at GRIC could be converted to useable energy**

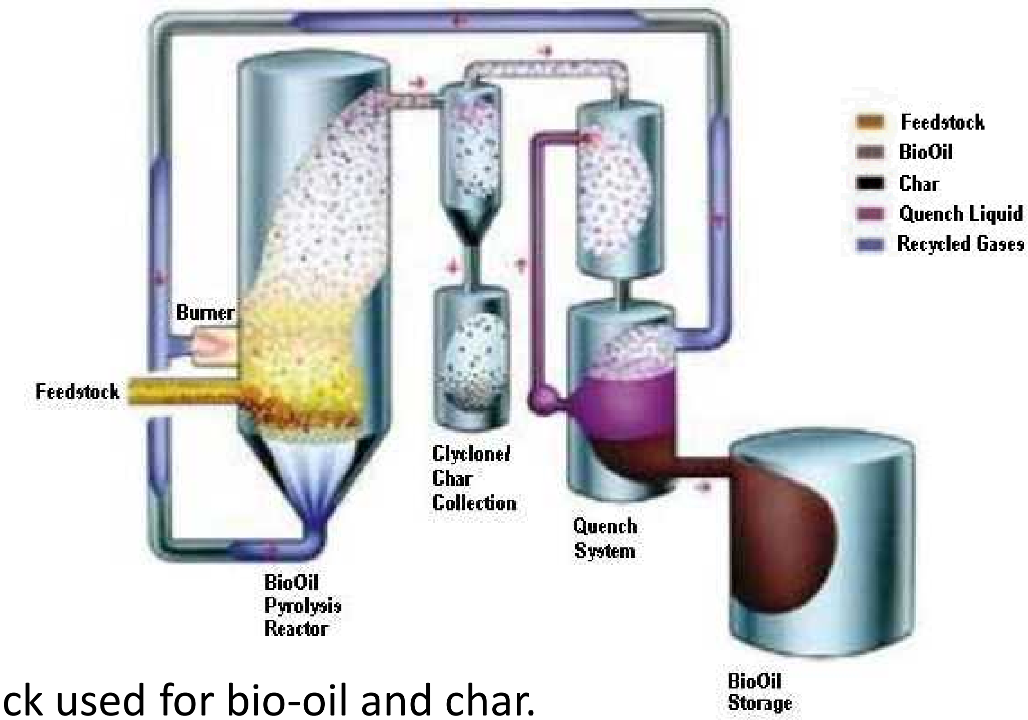
- Anaerobic Digester Gas:
  - primarily methane
  - use directly or process
    - for export
    - reformate → fuel cells
  - methane GHG factor ~24
    - CO_2 factor = 1
    - combustion/conversion of methane → **negative carbon footprint**



Graphics source: Clean Energy Applications Center, "Anaerobic Digesters", USDOE Penn State Univ., http://www.maceac.psu.edu/oppfuels/oppfuels.htm

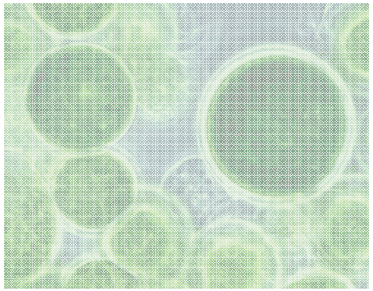
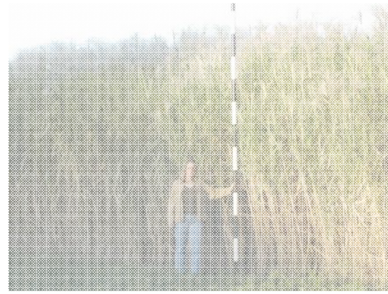
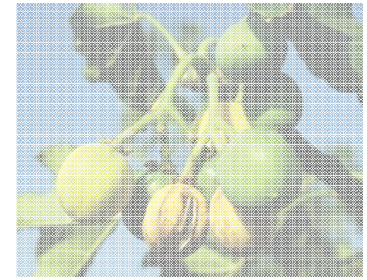
Pyrolysis: BioChar & BioOil





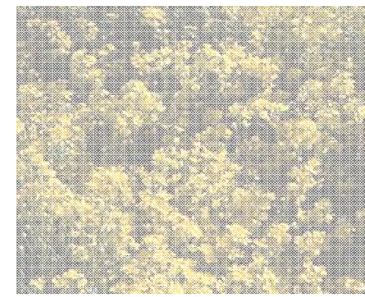
- Bio-Char/Oil:
  - 100% of feedstock used for bio-oil and char.
  - *Bio-Oil has many of the advantages of petroleum*
    - *can be stored, pumped and transported*
    - *combusted directly in boilers, turbines, and generators for heat and power.*
  - Bio-Char is a high Btu value solid fuel
    - used in kilns, boilers and by the briquette industry,
    - can blend back into the bio-oil to make a fuel slurry,
    - gases are re-circulated to fuel ~75% of the energy for the pyrolysis process
    - yields of bio-oil, char, and gases vary with feedstock.

Graphics sources: (1) Biochar: www.bioenergywiki.net,
(2) Pyrolysis: http://blogs.princeton.edu/chm333/f2006/biomass/bio_oil/02_chemistryprocessing_the_basics/02_processing/

Introduction to Biofuels

Biofuel Feedstocks

Biofuel Metrics

Biofuels & Water Use

Biofuel Processing

Sandia Labs Biofuel Activities



Tools for Techno-economic Analysis

System-Level Modeling
- Life Cycle Analysis
- System dynamics
- Integrated Analysis with Multiple Tools

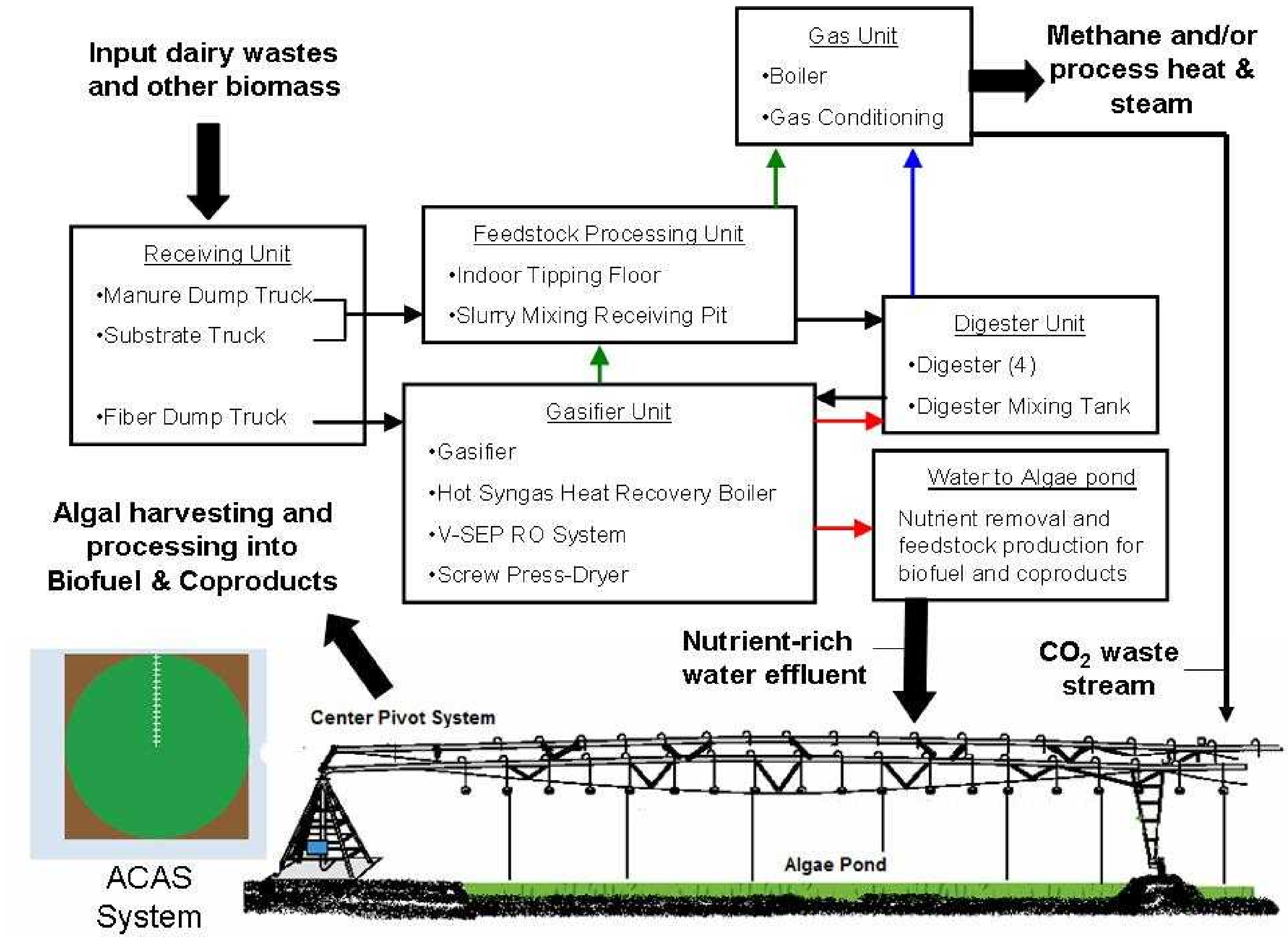
Engineering Modeling
- Back of the envelope
- Computational Fluid dynamics
- Mass & energy balance calculations (ASPEN+)
- Process GHG footprint assessment

Geographic Information System (GIS) Analysis and Visualization
- Land resources (characteristics, availability, etc.)
- Water resources (fresh, wastewater, other)
- Solar resource (insolation)
- Climate/Weather/Temperature Conditions
- Water evaporation loss
- CO_2 resources (point source emitters, pipelines)
- Fuel processing, transport, storage infrastructure
- Other infrastructure and environmental features

Static Capital & Operating Expense (CAPEX & OPEX) Calculations
- System and process equipment cost estimates
- Discounted cash flow analysis
- Spreadsheet Cost Analysis
- Carbon and co-product credit

NM-TRC Project Systems Analysis

- Inputs, outputs and processes



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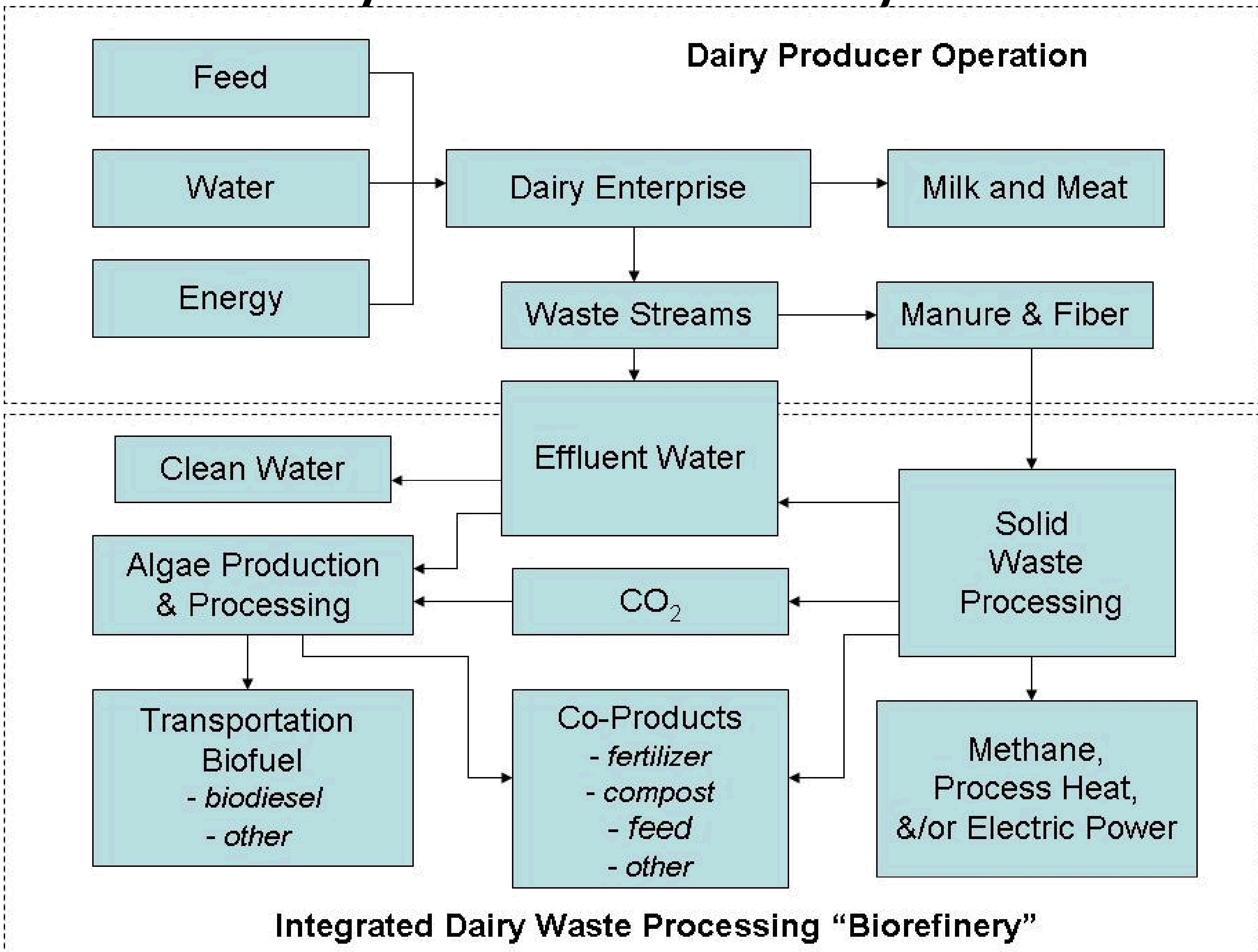
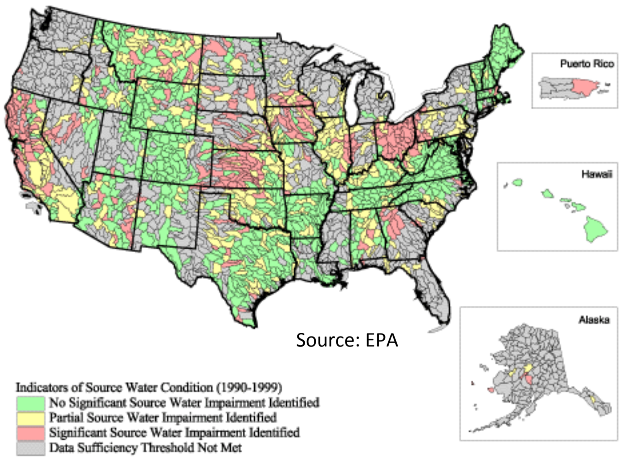
NM-TRC Project Systems Analysis

- Systems model layout



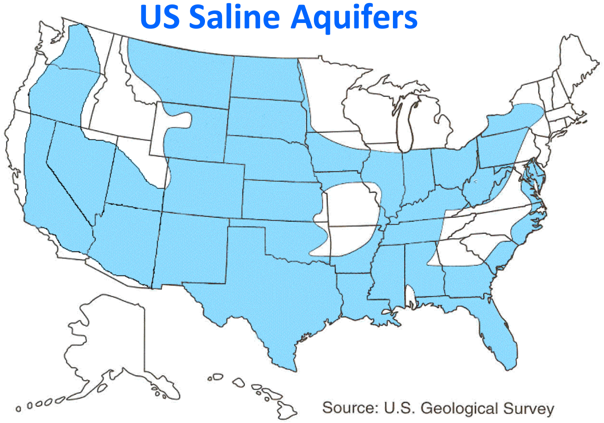
Algae Biofuels & Water

- **Pairing algae to impaired water to maximize algoil production**



Water Resources **+** **Microalgae**

US Saline Aquifers



Source: U.S. Geological Survey

Optimal matches among water properties and algae growth and survivability

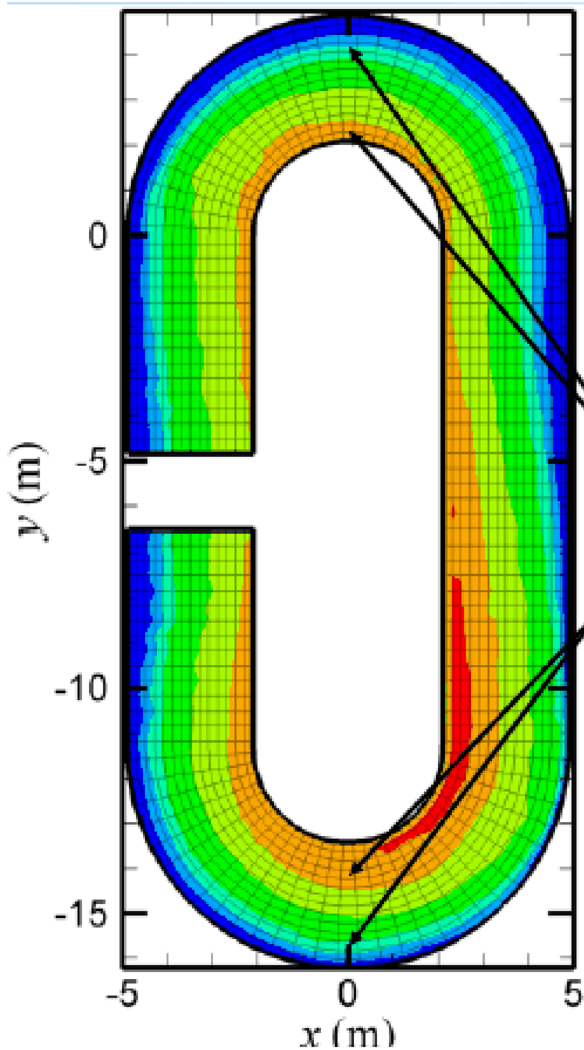
↓

Maximize triacylglycerol production

↓

Maximize algal-based biodiesel and other biofuels

Algal Growth Model (Raceway)



Algal growth is affected by helical flow patterns that mix the water column

- Algal growth kinetics are based on US Army Corp of Engineers' CE-QUAL model
- Includes solar radiation, nutrient availability, predation, temperature, respiration, etc.

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- combines hydrodynamic, atmospheric and growth models

Biofuels & GHGs

GREET v1.8 Comparative results of GHG Emission			
Btu or gm per mmBtu of Fuel Available at Fuel Station Pumps	Baseline CG and RFG	CIDI Vehicle BD20	% change from Baseline
Total Energy	250,743	520,149	107.44%
WTP Efficiency	80.00%	65.8%	-17.77%
Fossil Fuels	228,700	230,145	0.63%
Coal	40,433	54,651	35.16%
Natural Gas	92,970	102,646	10.41%
Petroleum	95,297	72,848	-23.56%
CO2 (w/ C in VOC & CO)	16,812	3,315	**-80.28%**
CH4	108.738	95.674	**-12.01%**
N2O	1.14	1.800	57.86%
GHGs	19,871	6,243	-68.58%
VOC: Total	27.345	26.413	-3.41%
CO: Total	14.229	12.621	-11.30%
NOx: Total	47.526	42.920	-9.69%
PM10: Total	10.99	12.296	11.88%
PM2.5: Total	4.27	4.326	1.32%
SOx: Total	23.734	25.935	9.27%
VOC: Urban	15.527	2.558	-83.53%
CO: Urban	3.805	3.055	-19.72%
NOx: Urban	10.417	8.488	-18.52%
PM10: Urban	1.838	1.356	-26.20%
PM2.5: Urban	1.071	0.791	-26.12%
SOx: Urban	7.222	6.817	-5.60%

http://www.transportation.anl.gov/software/GREET/

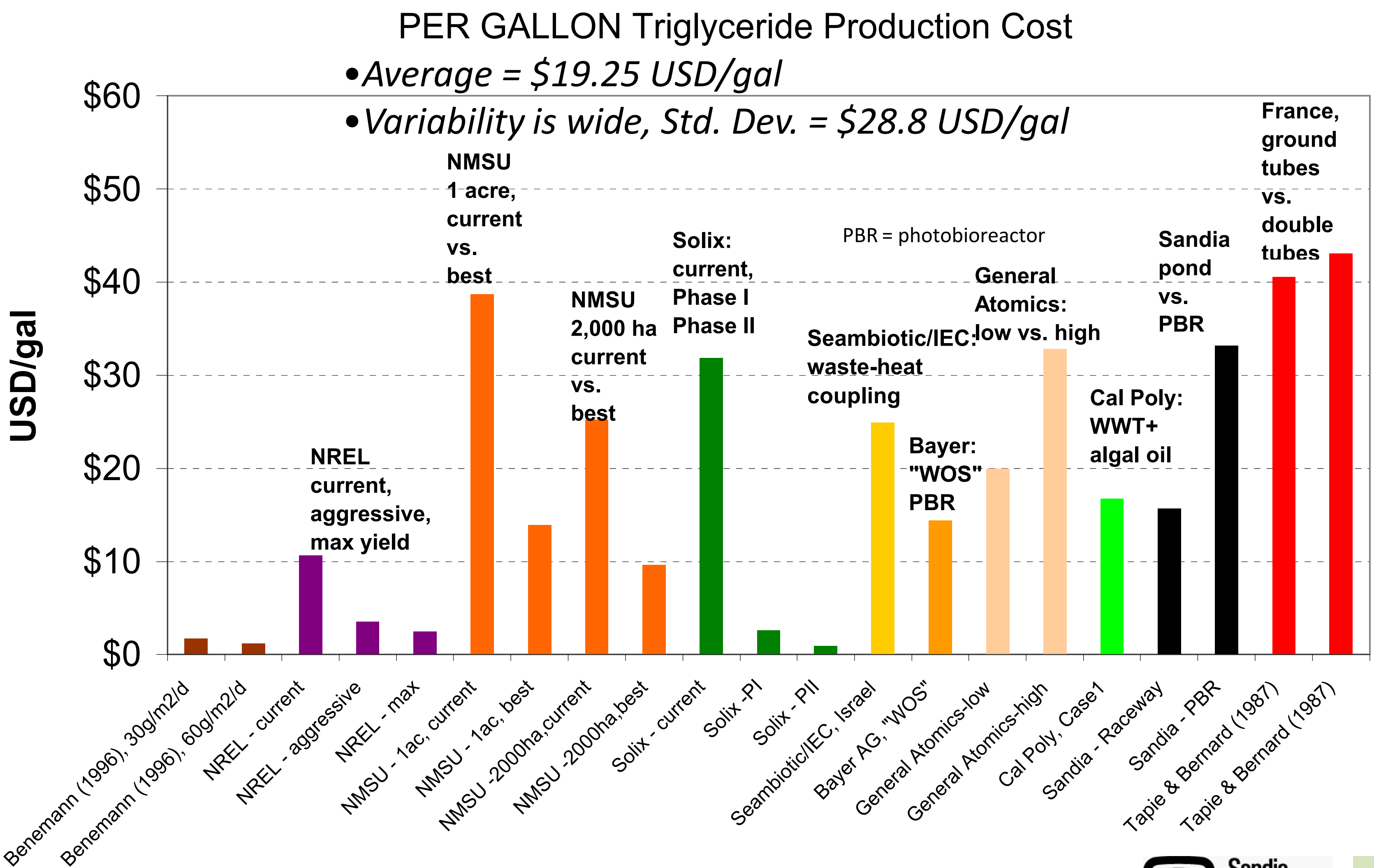
[1] For this analysis, the GREET Biodiesel soybean input parameters have been modified to accommodate Open Pond Algae Energy Input.

Illustrative Example:
The GREET model
(Greenhouse gases, Regulated Emissions, and Energy use in Transportation)

Conventional gasoline (baseline) vs Diesel blend with 20% algae biodiesel

Algae Production: Cost Comparison

- **Wide variation in cost estimates**



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Algae Biodiesel Costs

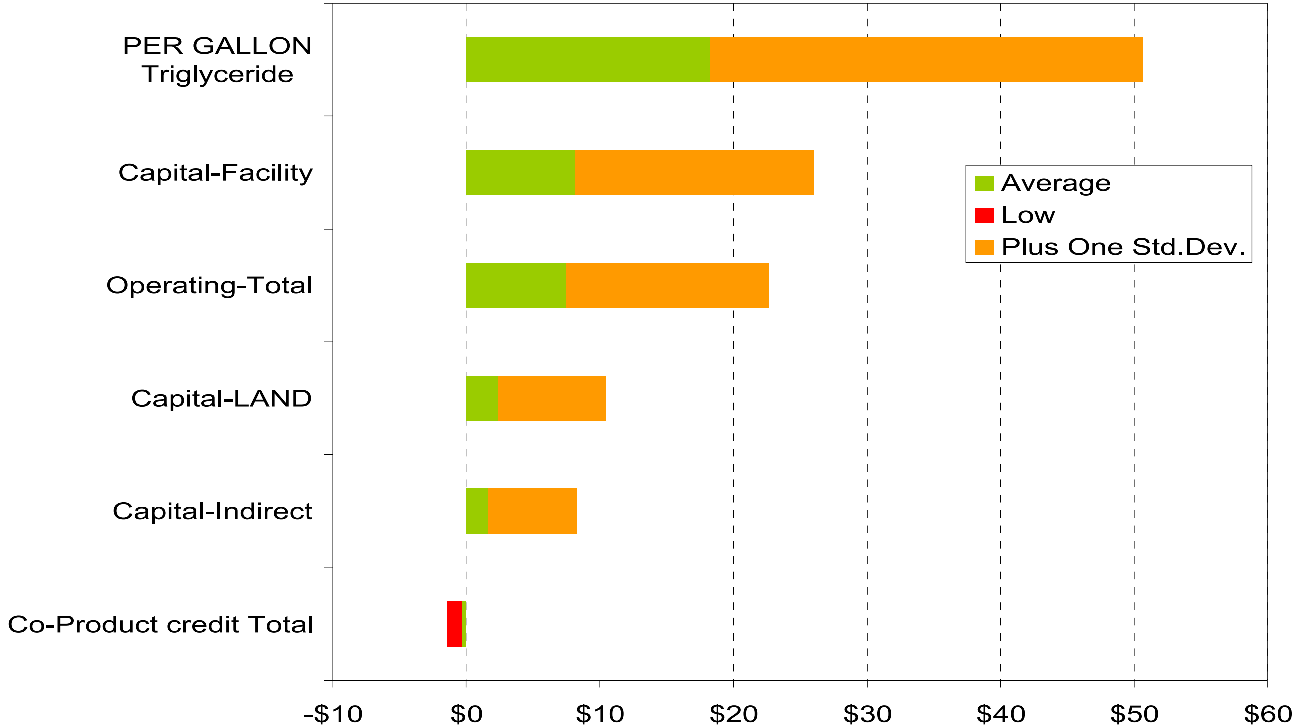
- **Assumptions vary considerably:**

	SCENARIO	Reactor Type	Lipid yield (wt% of dry mass)	Algae Mass Yield (g/m2/day)	Loan Period (yrs)
Benemann	per ha basis	open pond	50%	30	5
Benemann	per ha basis	open pond, max	50%	60	5
NREL	Current Case	open pond	25%	20	15
NREL	Aggressive Case	open pond	50%	40	15
NREL	Maximum Case	open pond	60%	60	15
NMSU	current yield	open pond	35%	35	20
NMSU	highest yield	open pond	60%	58	20
Solix	Current	hybrid	16% - 47%	0 - 24.5	unk
Solix	Q2, 2009	hybrid	16% - 47%	30-40	unk
Seambiotic/IEC, Israel	Best Yield	open	35%*	20	unk
Sandia	Raceway&PBR	both	35%	30	20
Bayer Tech Services	Germany	PBR	33%	52	10
Bayer Tech Services	El Paso, TX	PBR	33%	110	10
General Atomics	100 acres	open/hybrid	unk	unk	unk
Cal Poly, Case1	100 ha	wastewater treatment + digester	25%	20	8
Tapie & Bernard	10 ha	T-PBR	35%*	20	5

* Assumed quantity required to convert from weight-basis to oil-basis

Algae Biofuel Cost Uncertainties

- Cost Uncertainties dominated by ***uncertainties in Facility and Operating cost*** *estimation.*
- ***Land cost is small*** in most sources ***relative to Total Capital Cost***.
- ***Co-product credit does not reduce the overall uncertainty*** in cost estimation.



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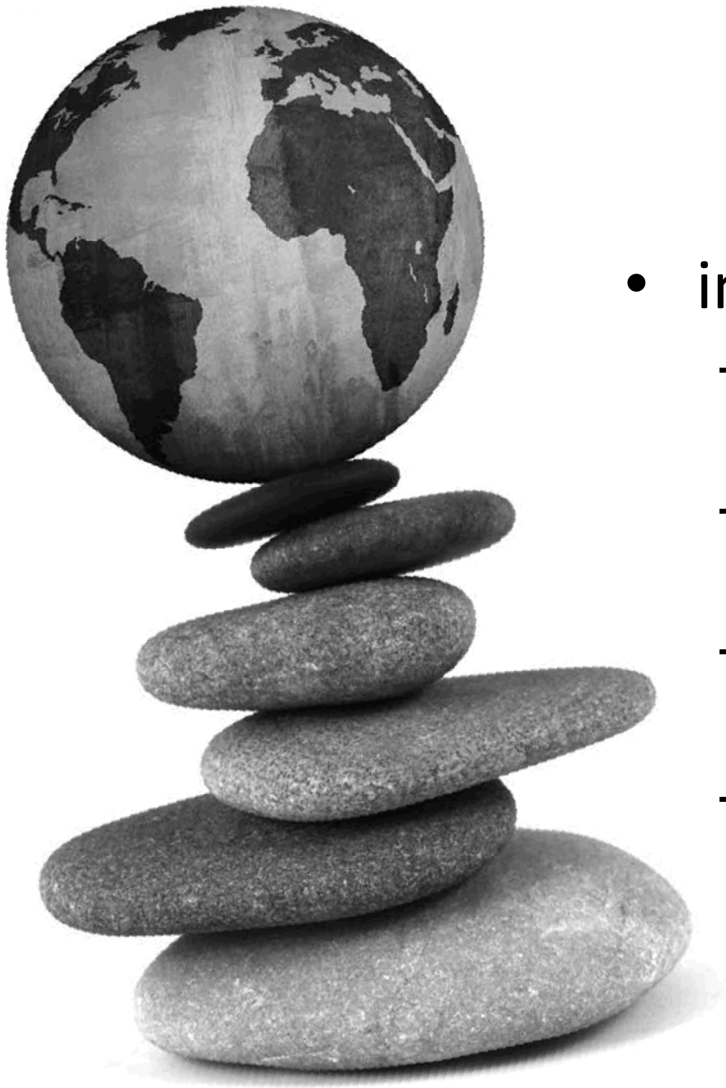
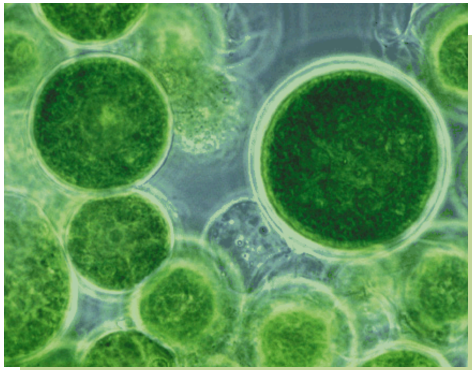
Decisions

- factors:
  - balance
    - goals
    - priorities
    - resources
  - direction
    - planning
  - stability
    - economic
    - community
    - ecology
  - risk
    - short/long term



- information:
  - useful?
    - priorities
  - useless?
    - goals
  - sensitivity
    - balance
  - analysis
    - stability
    - risk

Graphics source: The H. John Heinz III Center for Science, Economics and Environment, www.heinzctr.org,


algae


switchgrass


jatropha

Thank You


jojoba


lesquerella


moringa


pongomia


sorghum