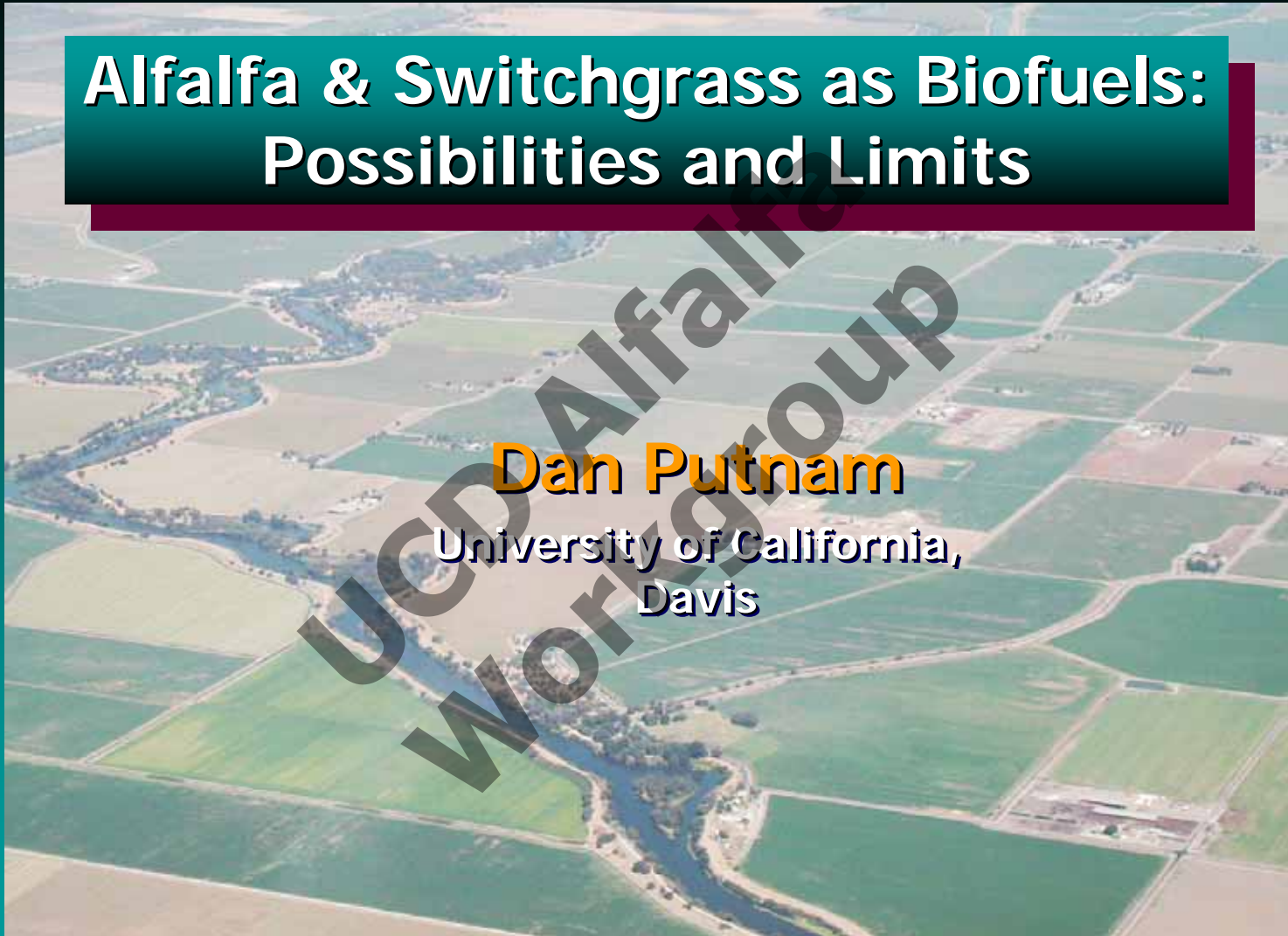


Alfalfa & Switchgrass as Biofuels: Possibilities and Limits

Dan Putnam

University of California,
Davis



Why Biofuels?

- **World Demand for petrochemicals**
 - **America – 1/3 of world autos, uses 25% of the worlds' oil**
 - **Last 10 years +2 'Americums' (350 m people >\$15,000/yr)**
 - **New 'Americum' developing every decade or so**
 - **Climate Change (one-way carbon street) 'the grand experiment'**
 - **Fuel Security, self-sufficiency, economics**
 - **Petro-dictators**
- **Biofuels - One of many 'alternatives'**
 - **Including conservation**

Types of Biofuels

- **Grain Biofuel Crops** (starch to ethanol)
- **Biodiesel Crops** (esterification of oils)
- **Sugar Ethanol Crops** (sugar to ethanol)
- **Cellulosic Energy Crops** (cellulose to ethanol or combustion)

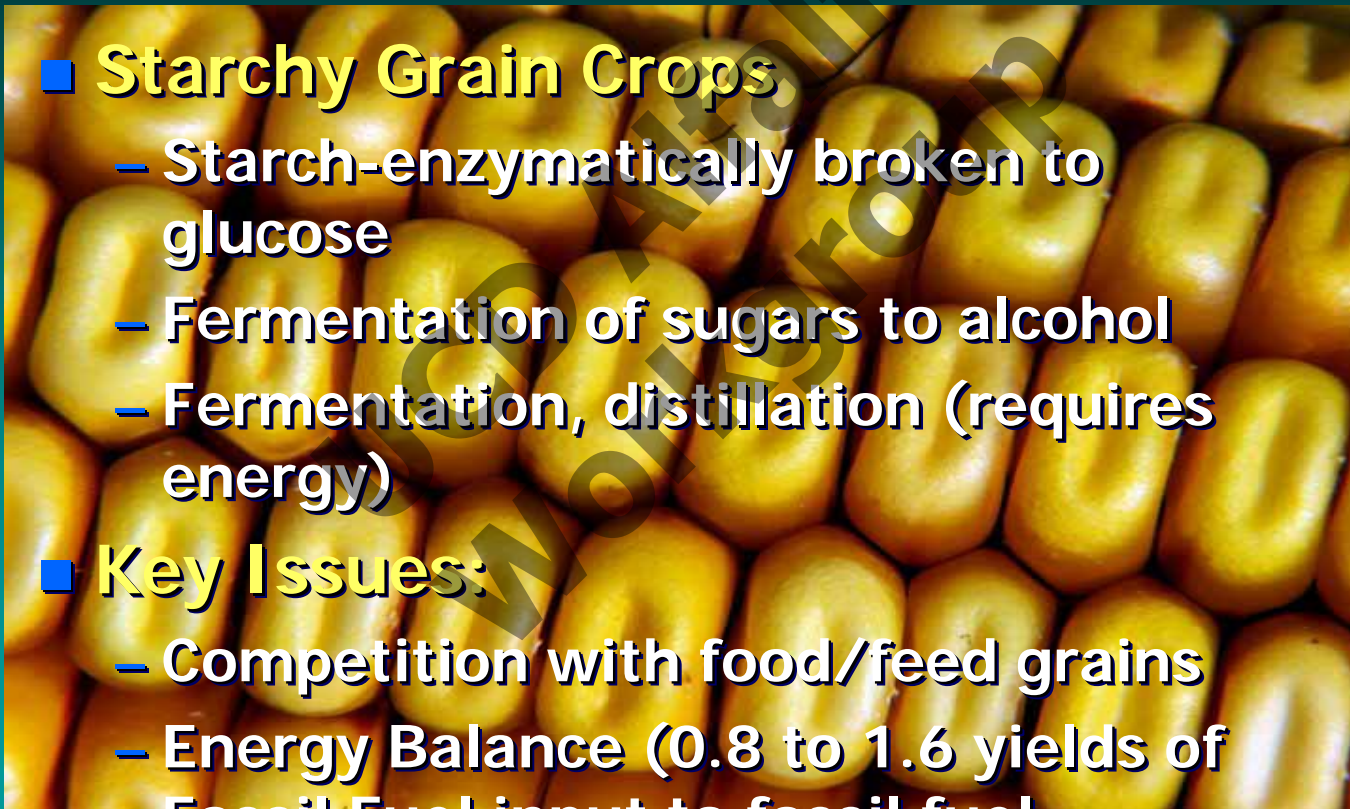
Grain to Ethanol

■ Starchy Grain Crops

- Starch-enzymatically broken to glucose
- Fermentation of sugars to alcohol
- Fermentation, distillation (requires energy)

■ Key Issues:

- Competition with food/feed grains
- Energy Balance (0.8 to 1.6 yields of Fossil Fuel input to fossil fuel)



Plant oils to Diesel

- **Biodiesel Crops**
 - Oilseeds (canola, soybean, camelina)
 - Waste vegetable and animal oils
- **Key Issues:**
 - Simplicity - scalable
 - Cost/resource inputs
 - Yields/percent oil
 - Competition with edible oils
 - Energy Balance



Camelina sativa

Sugar to Ethanol

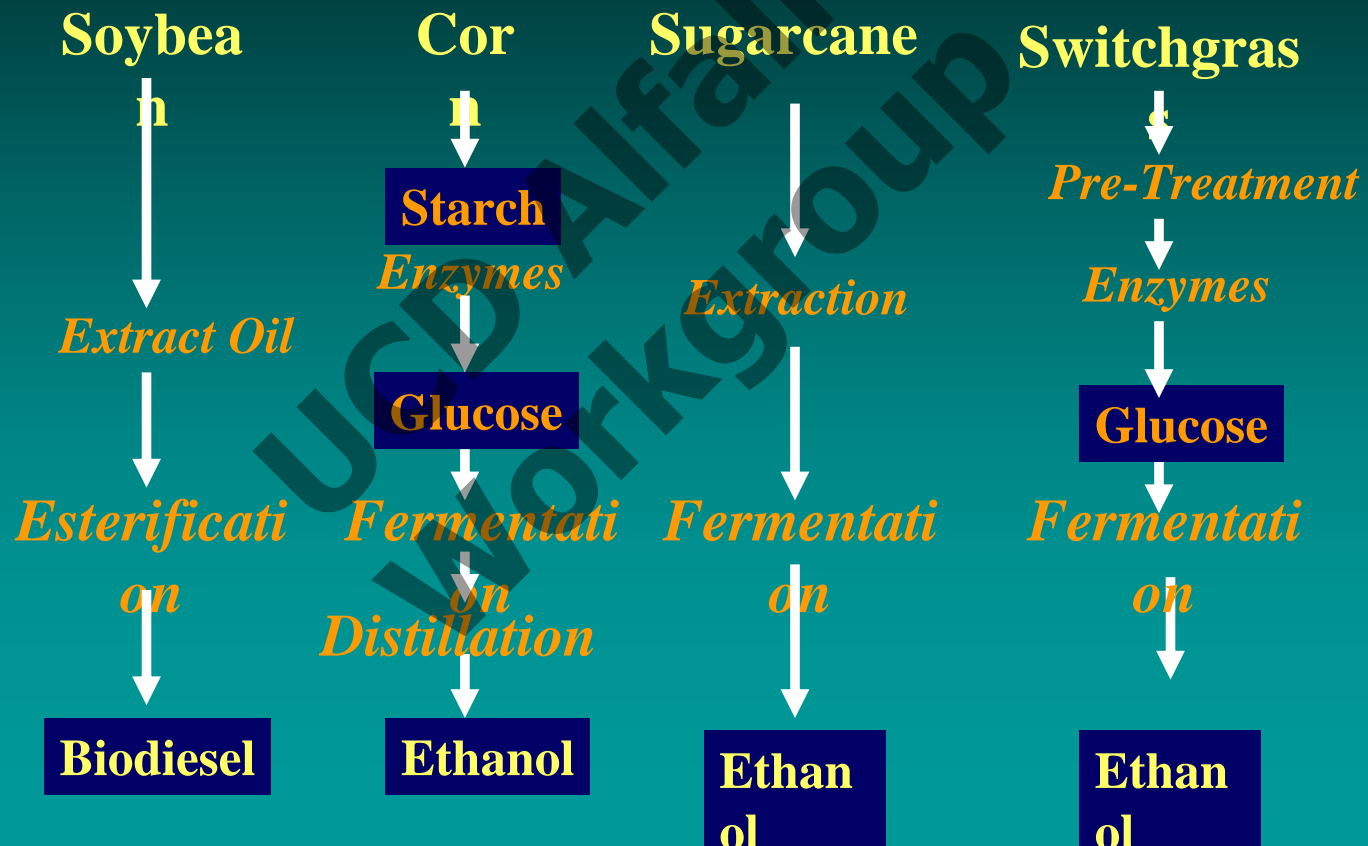
- Sugar crops
 - Sugarbeets, sugarcane, sweet sorghum
- Key Issues:
 - Highly productive
 - Direct Fermentation/Simplicity
 - Bulky Materials (transport)
 - Concentrated processing
 - 'Transient' product (timeliness)



Cellulose to Ethanol

- Cellulosic crops
 - Wood, wastes, straws/stovers, cellulosic crops
- Key Issues:
 - High yields
 - Bulky Materials
 - Transportation/Storage
 - Conversion technology limiting
 - Pretreatment requirements
 - Enzymatic conversion technology

Energy Conversions:



Govt. Impetus:

- 2007 – Bush proposed: 20 in 10 – Reduce petroleum-based gasoline use by 20% in 10 years
- 35 billion gallons/yr by 2017
- Congress: renewable fuel standards: 2022
- 2008 Farm Bill - \$1 billion on biofuels.
- 2008 Implementation Plan: Sustainability
 - Food, environmental, economic
 - Cellulosic biofuels important

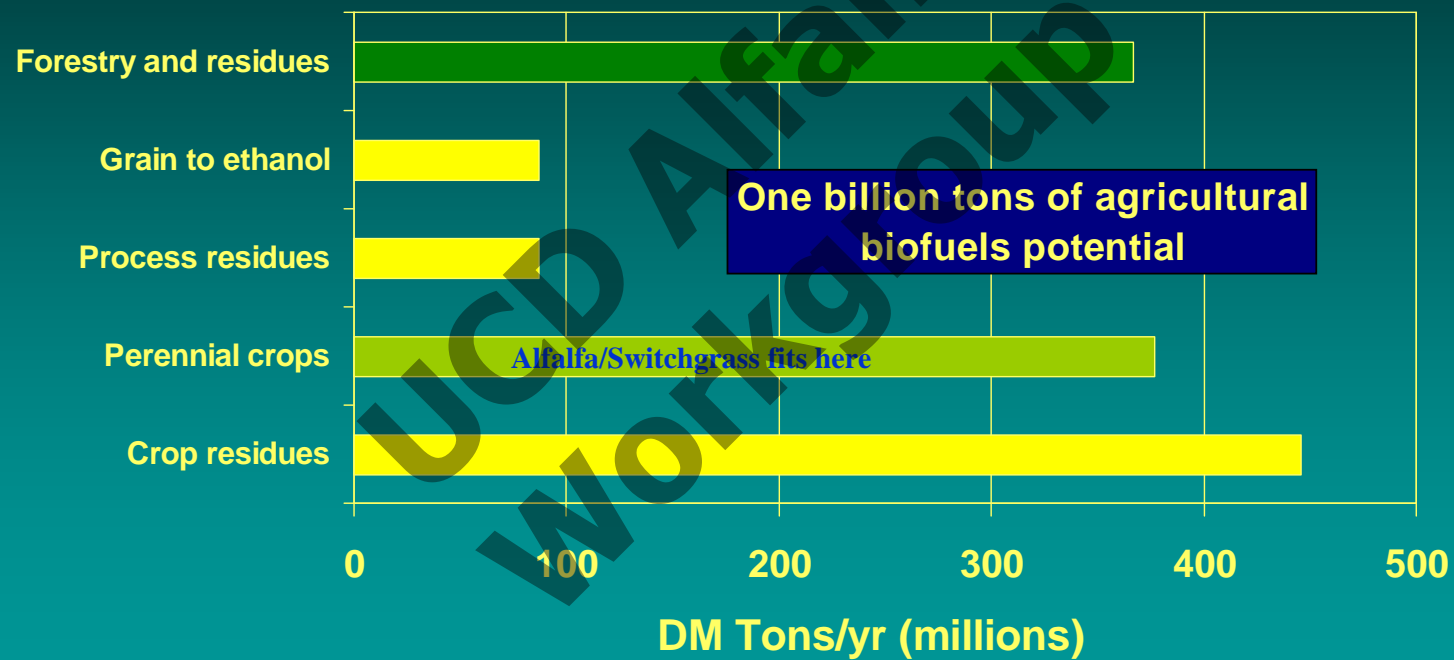
US DOE Biofuels Initiative

Assumptions (DOE biofuels goals)

- Modest growth in ethanol production from grain
 - Double current production
- >80% of growth in ethanol is from cellulosic fermentation
 - Forestry and wood byproducts
 - Crop residues
 - Perennial “energy crops”

DOE Billion Ton Vision - 2006

Summary of potential forage and agricultural biofuel resources



It will take a collection of regionally adapted biofuel crops to hit these targets

Feedstocks (DOE, Oct. 2008)

- **First Generation (current):**
 - Corn – ethanol
 - Soybean/canola – biodiesel
- **Second Generation**
 - Crop residues, stovers, municipal and forest wastes
 - Need improved cellulosic conversion technology
- **Third Generation:**
 - Dedicated Energy Crops (perennial grasses, alfalfa)
 - Fast Growing Dedicated Tree Crops
 - Algae

Cellulosic Feedstocks

- Little doubt that wastes will be prime first candidates
 - Landfills (30-40% paper)
 - Tree/forestry by-products
 - Straws & stovers (wheat, barley, corn)
- Dedicated Feedstocks
 - Fast Growing trees, switchgrass, Miscanthus, annuals (grains, sorghums), alfalfa

Criteria to Choose Cellulosic Feedstocks:

- Don't Start with the answer!
- Keep asking the question!
- Likely to be multiple answers

Criteria to choose Feedstocks

- **High Biomass Yields.**
 - Reduce the cropping area
 - Efficiency of resource use
 - High rates of conversion of solar to stored plant energy
 - Yield per unit resource
 - Genetic/Systems innovations

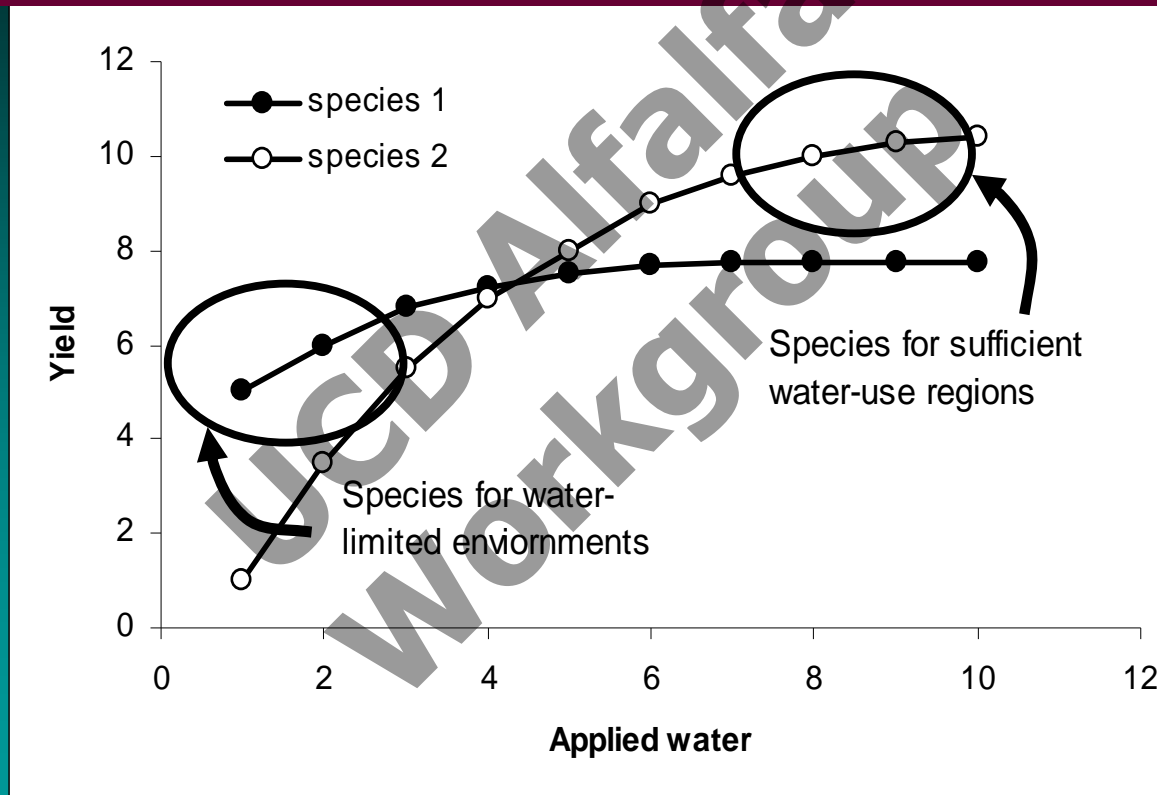
Criteria to choose Feedstocks

- **Quality of Conversion.**
 - Not all cellulosic materials can be converted into biofuel with the same efficiency
 - Ethanol yield per unit weight crop
 - Conversion is affected by species, N, maturity, irrigation, fertility
 - Enzymatic recipe

Criteria...

- **Water Use Efficiency**
 - **THE critical issue for CA**
 - **EFFICIENCY is one issue (max. DM per unit water)**
 - **FLEXIBILITY of water use may be as important**
 - **Coping with water deficits (yields OK under both high and low water situations)**
 - **Using Saline water/degraded water sources**

Criteria for selection of Biofuels



Irrigated Biofuels????

- CA-\$37 billion food-producing powerhouse
- A non-starter? Not necessarily
- Key advantages –
 - Stability of production
 - Very high yield potential
- Key negatives:
 - Competition with food production

Criteria...

- **Nitrogen Fertilizer Requirement.**
 - **N requirement is a major limiting factor due to its high fossil-fuel footprint and significant economic impact, influencing conversion and emissions.**
 - **Impact on food grains**

Why is N fertilizer so high priced?

- It requires Fossil Fuels!

Nitrogen (atm) + Natural gas \longrightarrow Anhydrous Ammonia

Approx 32 mcf Natural gas \longrightarrow 1 ton of Ammonia

Criteria...

- Impact upon food production.
 - Candidate species which has less impact upon food production may be favored, Competition for land, water
- Secondary Impacts (fertilizers)
- Remember: All crops will compete to some degree
- Integration with food production

Criteria...

- Utilization of waste/resource efficiency
 - Species adapted to wastewater, salty conditions, marginal land or utilize resources which are not otherwise used may be favored.
- The “marginal lands” model (switchgrass, Miscanthus)

Criteria...

- **Management of Biological Risk.**
 - Species which have high resistance to stress, pathogens, pests, and weeds, or compacted situations would be favored.
- **Invasive Species create problems:**
 - **Arundo donax**
 - **Johnsongrass**
 - **Switchgrass? (listed as a Class B invasive, but not clearly a risk)**

Criteria...

- **Infrastructure Support.**
 - A developed seed industry, approved chemicals, commercially-available equipment, and University research data will have early advantages for production.

Criteria...

- **Ecosystem Services.**
 - **Species which can be demonstrated to sequester additional soil carbon, reduce air pollution potential, conserve soil, water, or other resources, and provide wildlife habitat will be favored.**

Criteria...

- **Multiple Use Scenarios**
 - Most successful crops have multiple markets (e.g. soy used for protein, oil)
 - Grain, Stover of grains
 - Sugar, alcohol, bagass (burning)
 - Forages/cellulosic crops
- **Tremendous demand for forages – can we envision combination forage-cellulosic biofuel systems?**

Multiple uses of bulky Biomass Crops

- **Fulfills two purposes:**
 - Creates a forage product of higher quality
 - Two income streams
 - Isolates N-containing compounds from cellulosic
- **Two scenarios:**
 - Via cutting Schedule (1 cut-forage, 1 cut biomass)
 - Post-harvest Separation of leaf stem
Field Separation? (
 - In-field separation?

Can we envision?

\$120/ton Coarse forage (12 tons)



\$170/ton high quality Fraction (6 tons)

\$80/ton high quality Fraction (6 tons)

Advantages of perennial crops



Image courtesy of Mike Russelle

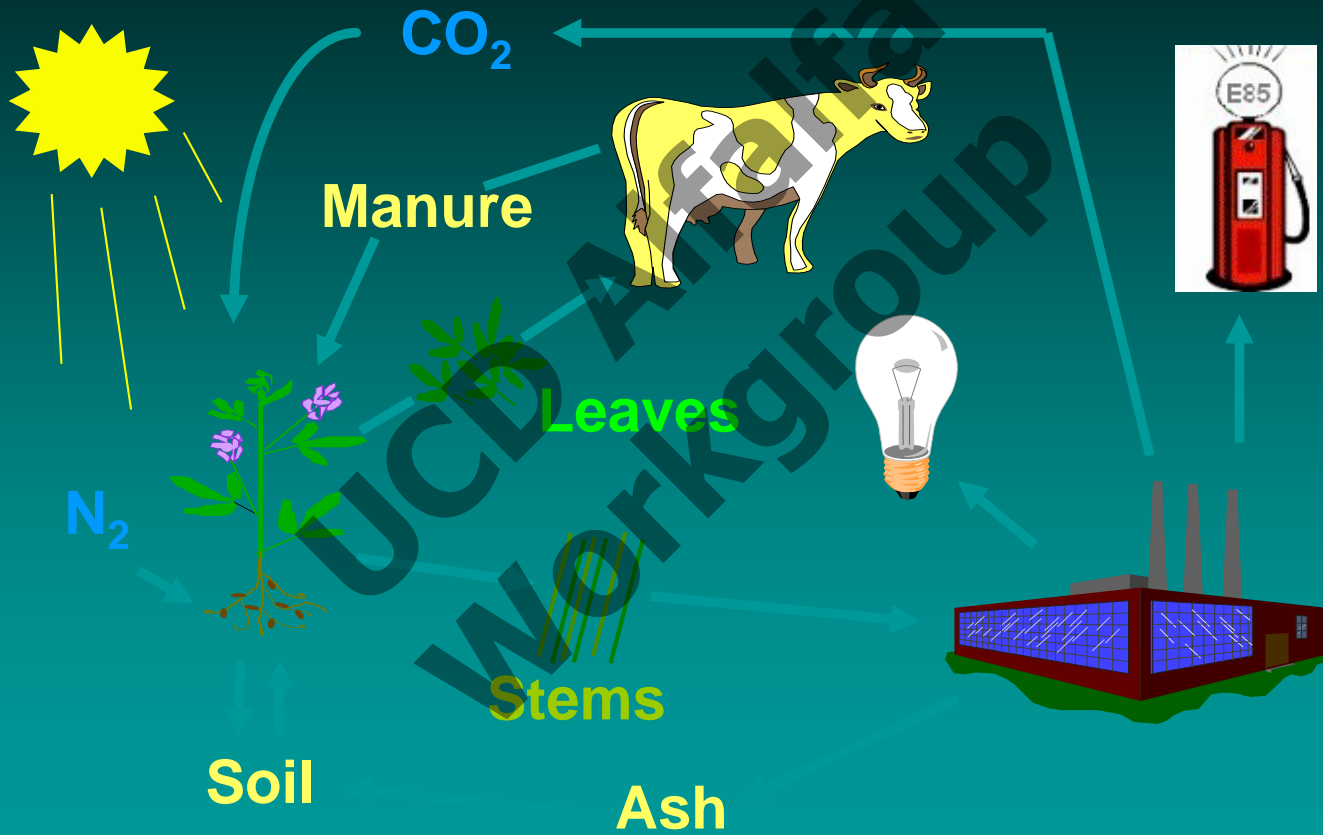
- **High yield**
 - **Use full growing season**
- **Reduced runoff**
 - **Reduced nutrient losses**
 - **Reduced soil erosion**
- **Deep and extensive root system**
 - **Efficient water use**
 - **Improved soil tilth**
 - **Carbon sequestration**

Alfalfa as a potential energy crop



DOE Photo

An Alfalfa Biomass System



N – Advantage of Alfalfa

- Estimate that to replace the protein produced each year by 1 million acres of alfalfa in CA would require 5 million acres of corn.
- Trillions of BTUs fossil fuel savings
- A Key issue for biofuels!

Compatibility with corn



Tim McCabe, NRCS



Don Reicosky, USDA-ARS

- Nitrogen credit
- Residue cover
- Erosion control
- Aesthetics
- Wildlife habitat

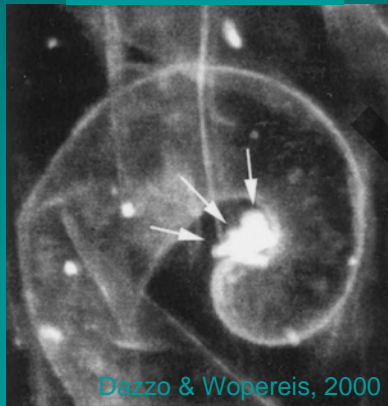
Symbiotic N₂ fixation

Sinorhizobium



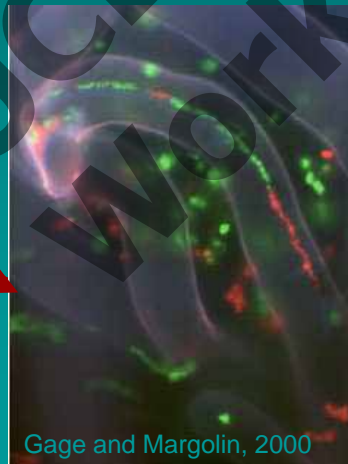
Dazzo & Wopereis, 2000

Root hair curling around rhizobia



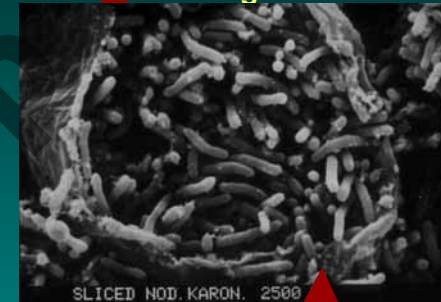
Dazzo & Wopereis, 2000

Bacteria reproduce in infection threads



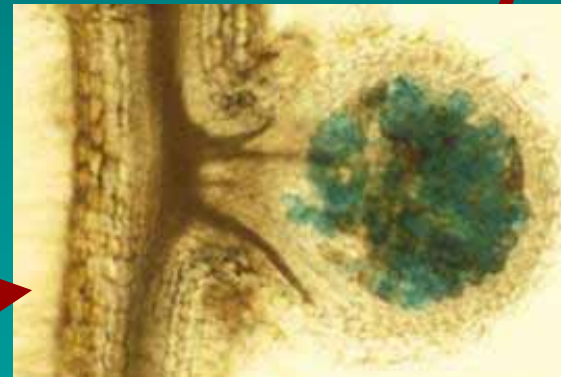
Gage and Margolin, 2000

Bacteroids filling a single cell



Vance et al., 1980

Alfalfa root nodule



M. Barnett



One-pass separation of leaves and stems is feasible

90% leaves
27% protein
20% fiber

90% stems
13% protein
50% fiber



M. Russelle, USDA-ARS

Shinners & Digman
U Wisc and USDFRC

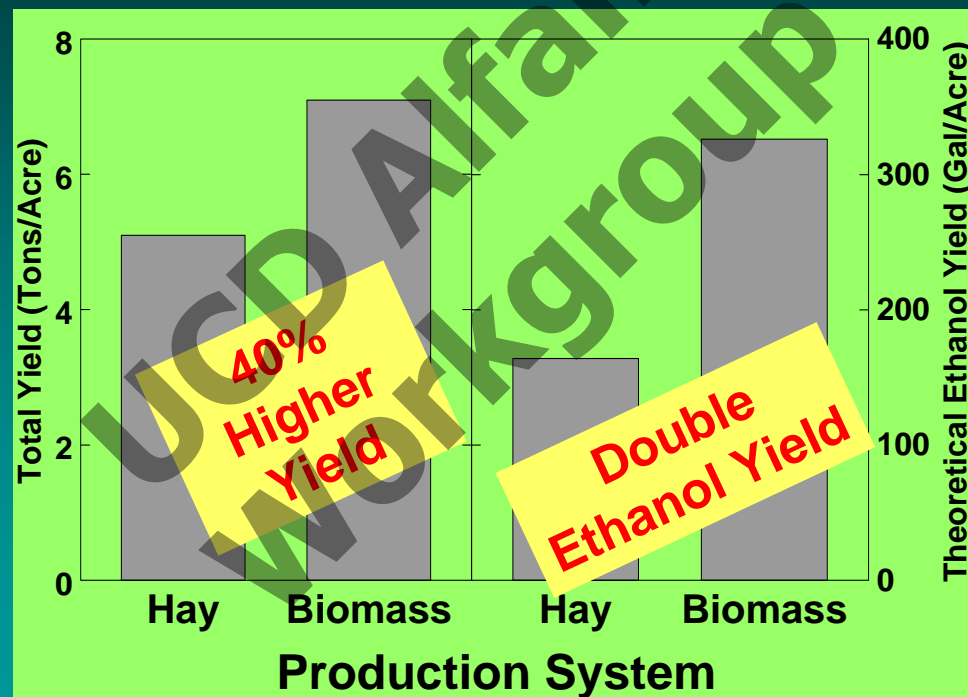


Alfalfa:

- Genetic advances
 - Breakdown of cellulose
 - Downregulated lignin

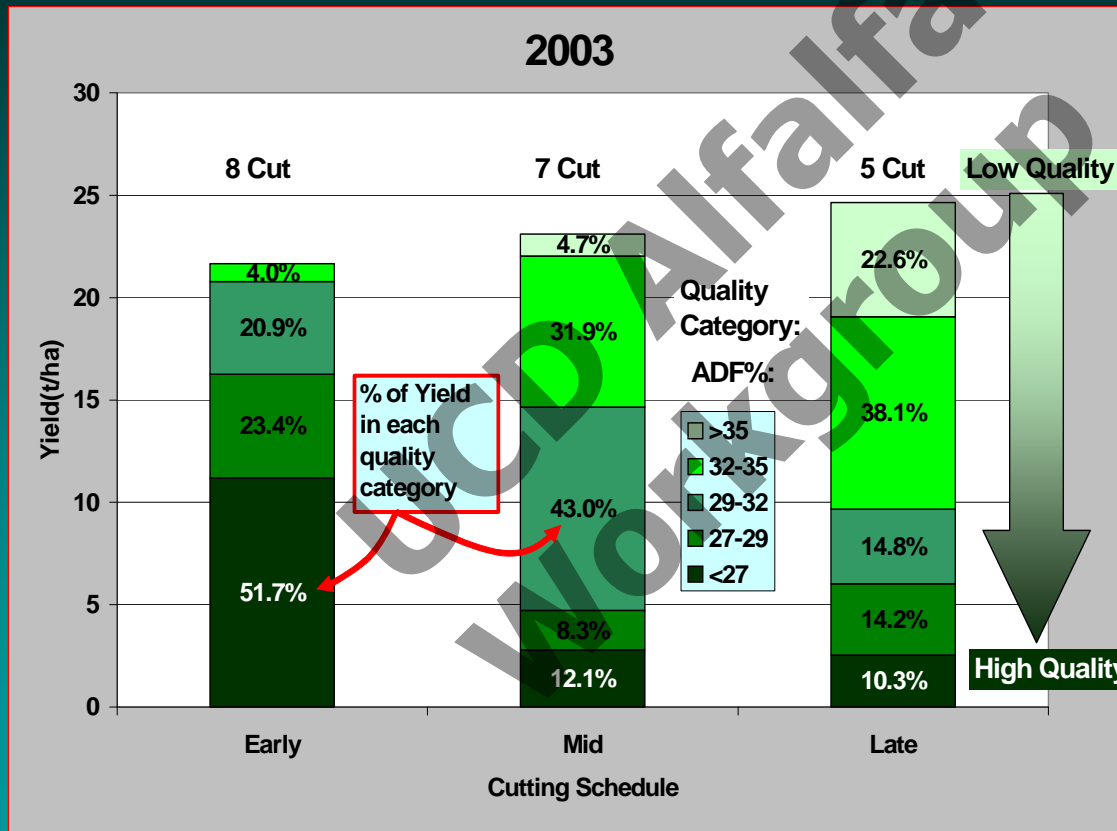
New alfalfa biomass management system (MN v

- > Biomass type alfalfa (reduce lodging, increase yield)
- > Thinner stand (60% less seed, save \$ and energy)
- > Harvest less frequently (save \$ and fuel)



Lamb et al., 2007

Late Cutting Schedules:



2 ton/
acre yield
Advantage
Late
Cutting
(Davis)

Theoretical Yields

Improved Cropping Systems

Species	Corn	Ethanol		Total	Protein
		Gal/Acre			
Continuous Corn Grain (5% yield loss)	616	0		616	0.32
Corn/Soybean (alternate years)	324	40		364	0.38
Corn Silage/Improved Alfalfa (5% yield boost)	780	138		918	0.42

Theoretical Program: Alfalfa

- 10-12 ton irrigated yields
 - Late cutting schedules
 - Improved Varieties
 - Low densities, other techniques
- 4-5 tons/acre – high value leafy product
- 5-6 tons/acre – stemmy cellulosic product

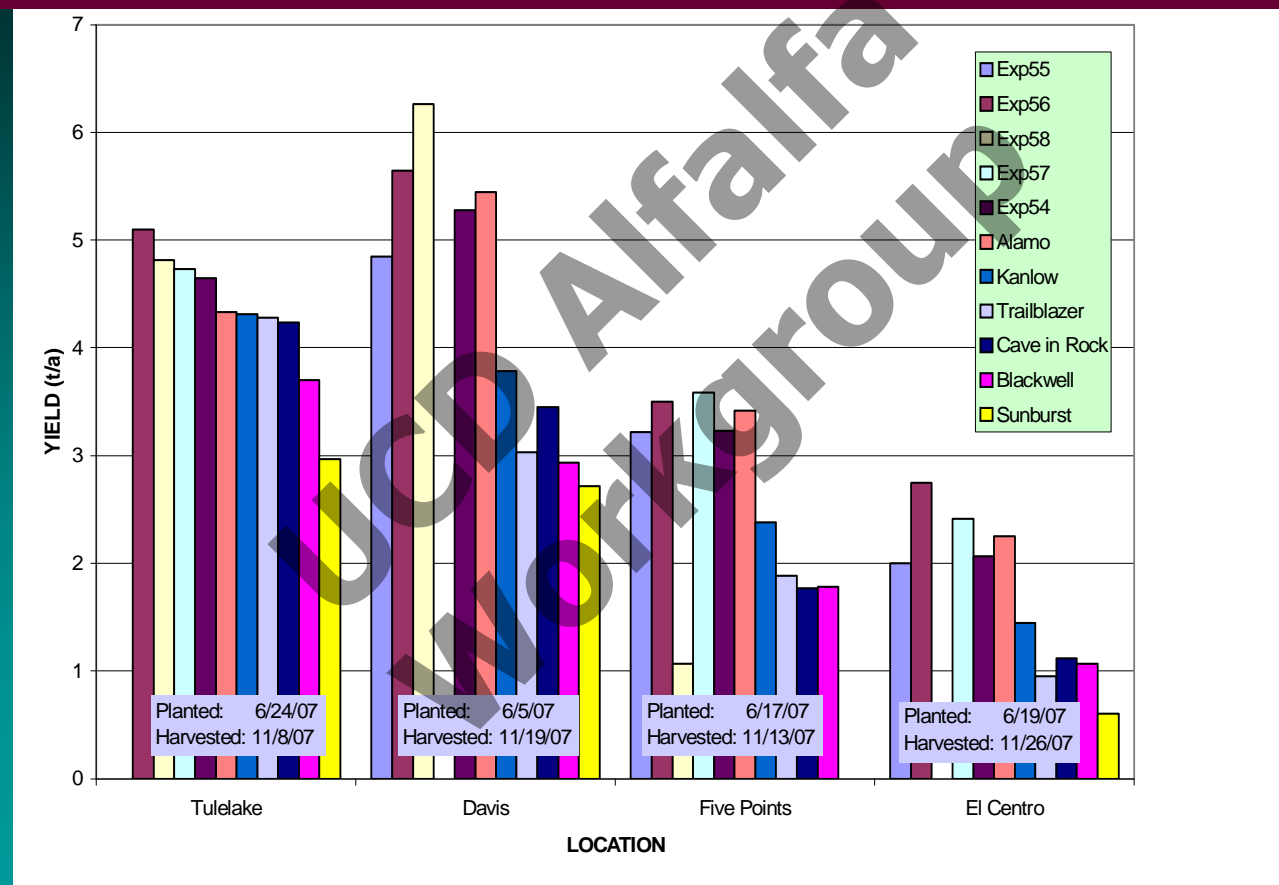
Switchgrass



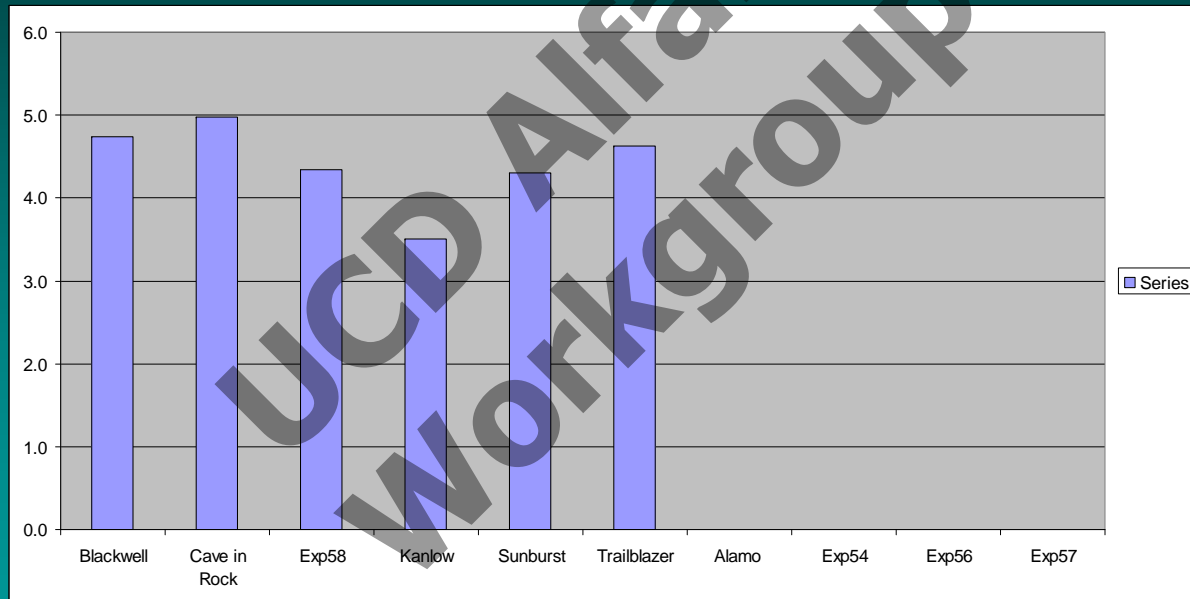
Switchgrass Trials:

- 4 locations: Tulelake, Davis, Fresno, El Centro
- Summer planting (June-July)
- 10 varieties (N. Great Plains to Texas)
- Irrigate to est. ET_0
- Moderate N applications

Switchgrass – Year 1 yields

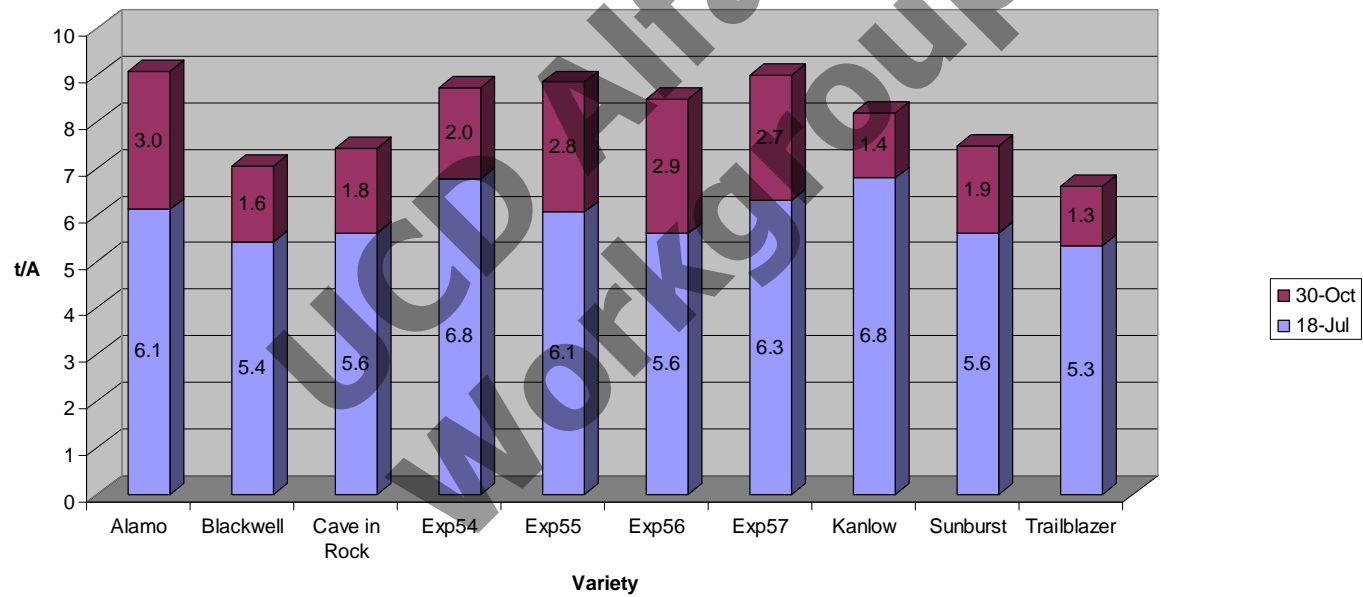


Switchgrass - Tulelake 2008

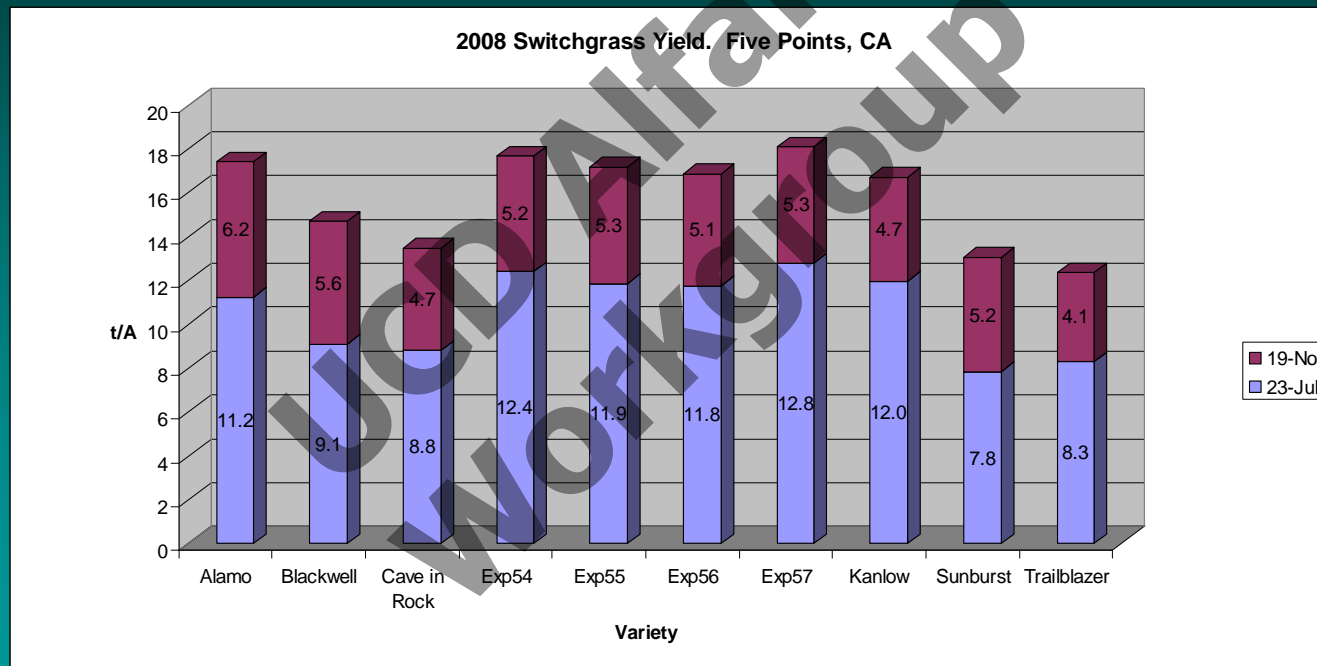


Switchgrass – Davis 2008

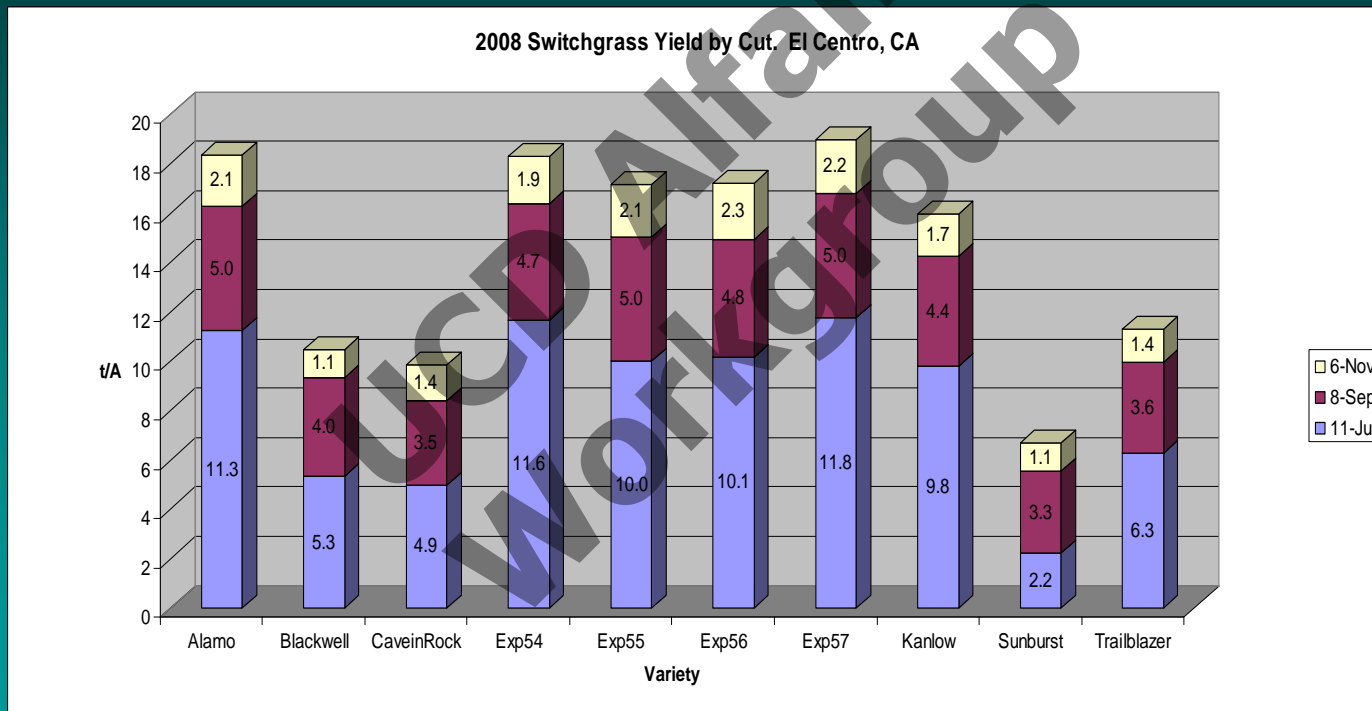
2008 Switchgrass Yield by Cut. Davis, CA



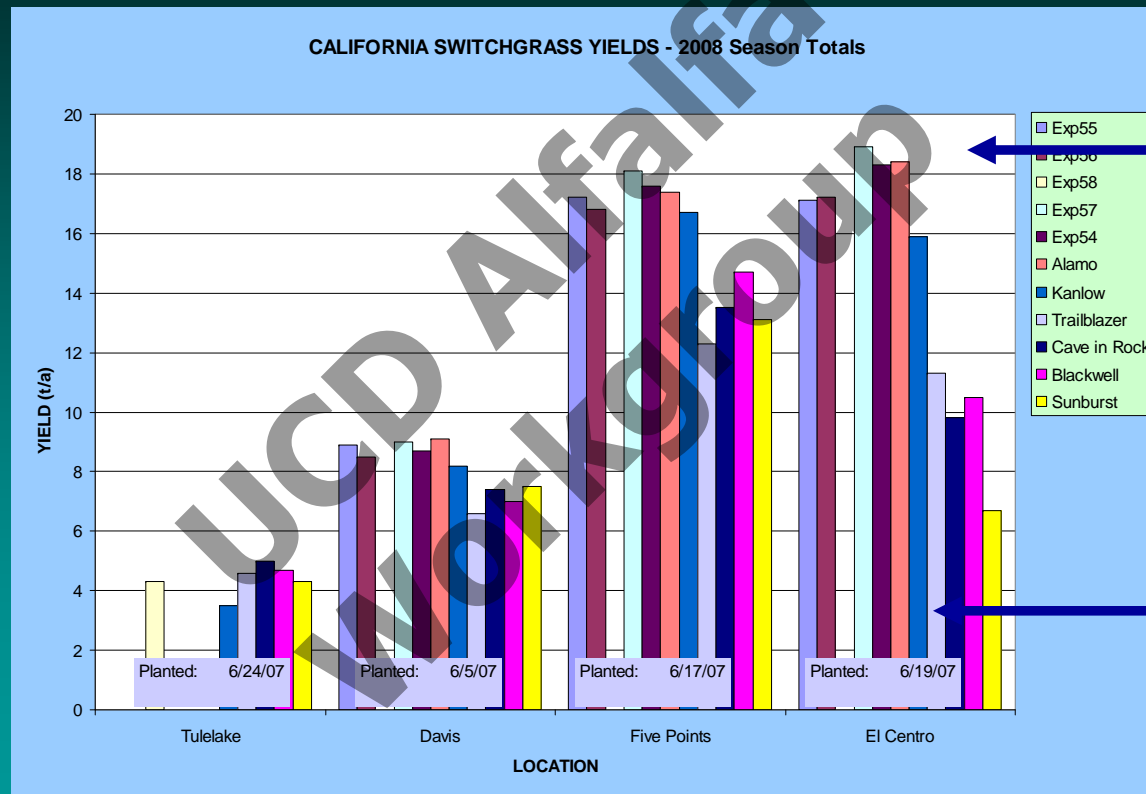
Switchgrass – Fresno Co. 2008



2008 Switchgrass – El Centro



2008 CA Switchgrass Yields



18 t/a

4 t/a

Scenarios:

- **Low Input Scenario:** Average 3-6 t/a 'low input' model (Nebraska Model)
- Net energy 540% more Fossil Fuel energy than consumed (5x). (Science, 2007)

Scenarios:

- **High Input, Multiple Use Scenario:**
What about 15 ton yields with 5-7 for forage, and 5-7 for biofuels?
- Lessens Food vs. fuel issue
- Economic 'driving forces'
- By definition: irrigated agriculture is not 'low input'
- Need innovation

Key Points

- **Biofuels must meet sustainability criteria**
 - **Economic (!)**
 - **Environmental**
 - **Resources**
- **Alfalfa & Switchgrass are interesting possibilities:**
 - **N₂ fixation (alfalfa)**
 - **High-yield/heat adaptation (switchgrass)**
 - **High Water Use Efficiency**
 - **Wildlife habitat/environmental services**
 - **Integration with forage production**
- **Longer term Concepts**
 - **Development of conversion technologies**
 - **Life-cycle analysis – impact on resources**
 - **We need to practice 'systems' thinking**
 - **Further research**

