Alfalfa & Switchgrass as Biofuels: Possibilities and Limits

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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

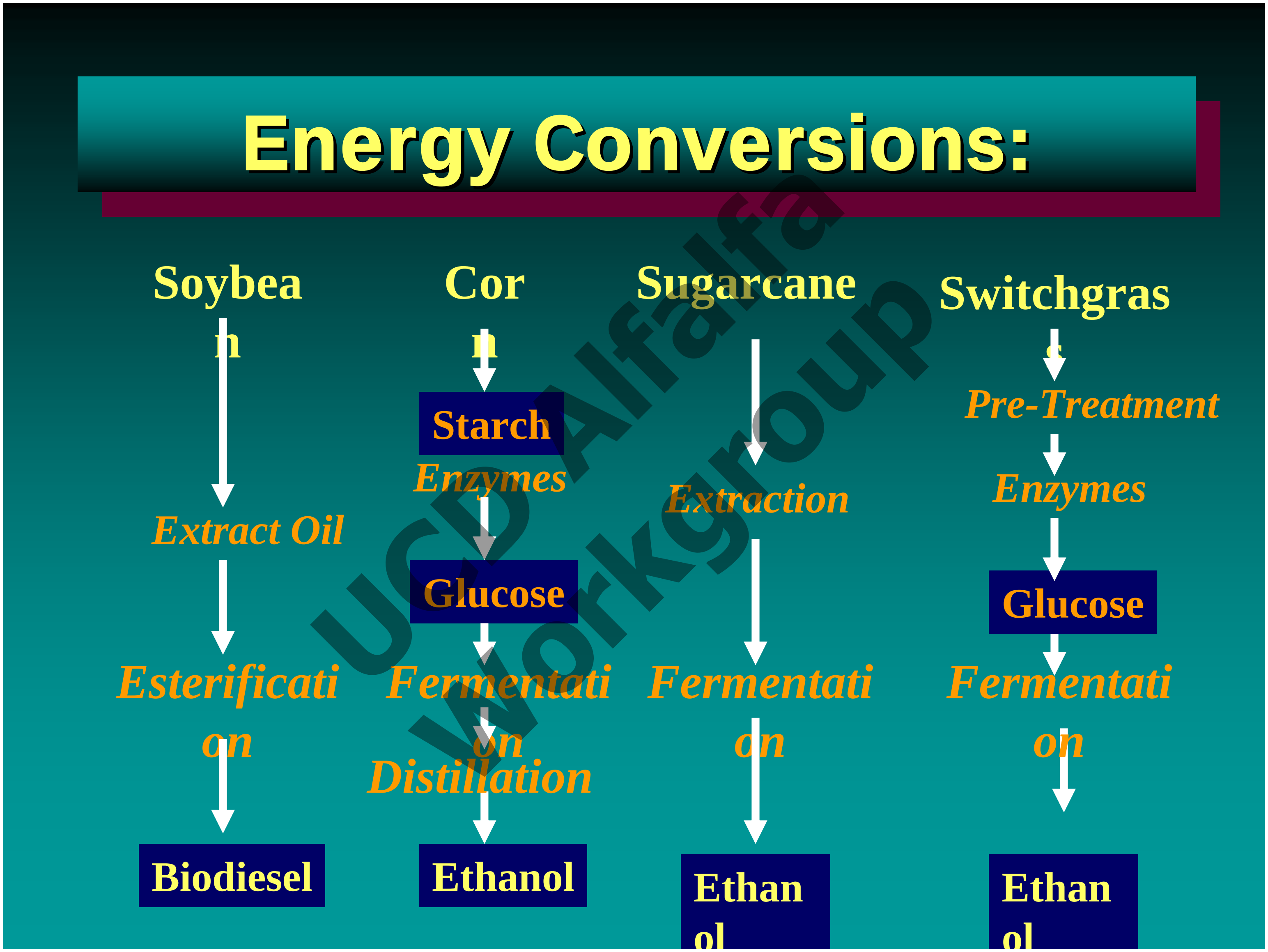
- Biodiesel Crops
  - Oilseeds (canola, soybean, camelina)
  - Waste vegetable and animal oils
- Key Issues:
  - Simplicity - scalable
  - Cost / resource inputs
  - Yields / percent oil
  - Competition with edible oils
  - Energy Balance

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:
Soybea
n
Cor
n
Sugarcane
Switchgras
s
Starch
Pre-Treatment
Enzymes
Extraction
Enzymes
Extract Oil
Glucose
Glucose
Esterificati
on
Fermentati
on
Fermentati
on
Fermentati
on
Distillation
Biodiesel
Ethanol
Ethan
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Ethan
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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

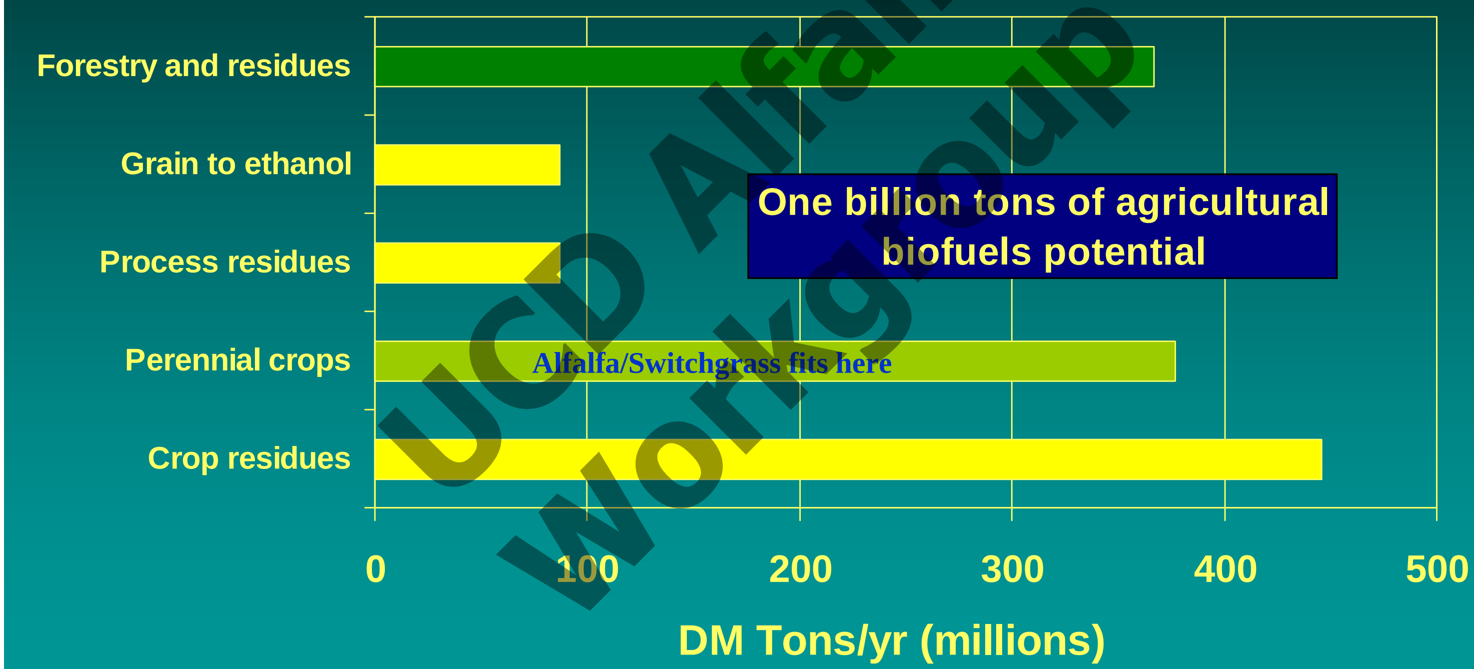
US DOE Biofuels Initiative

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



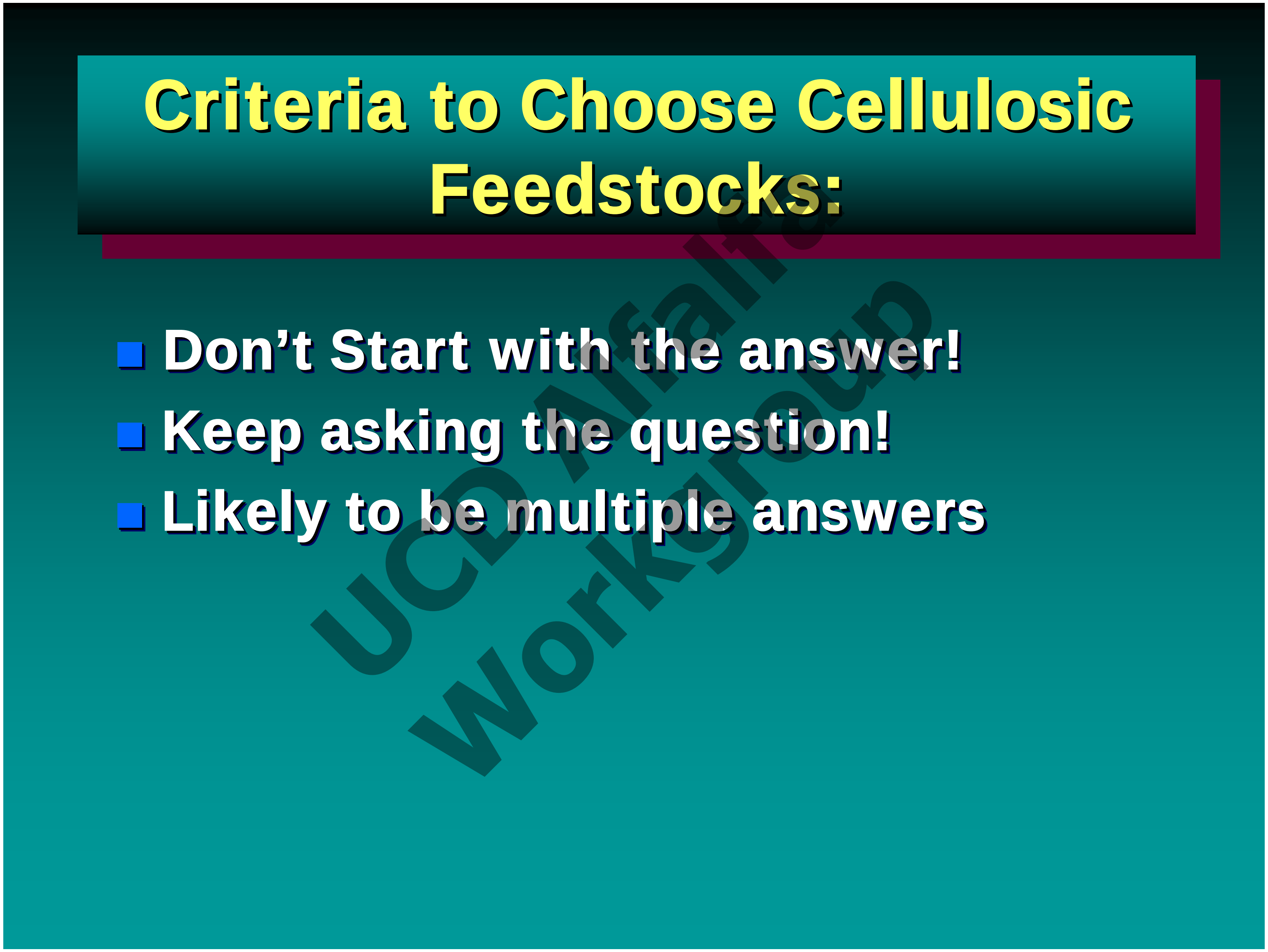
It will take a collection of regionally adapted biofuel crops to hit these targets

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

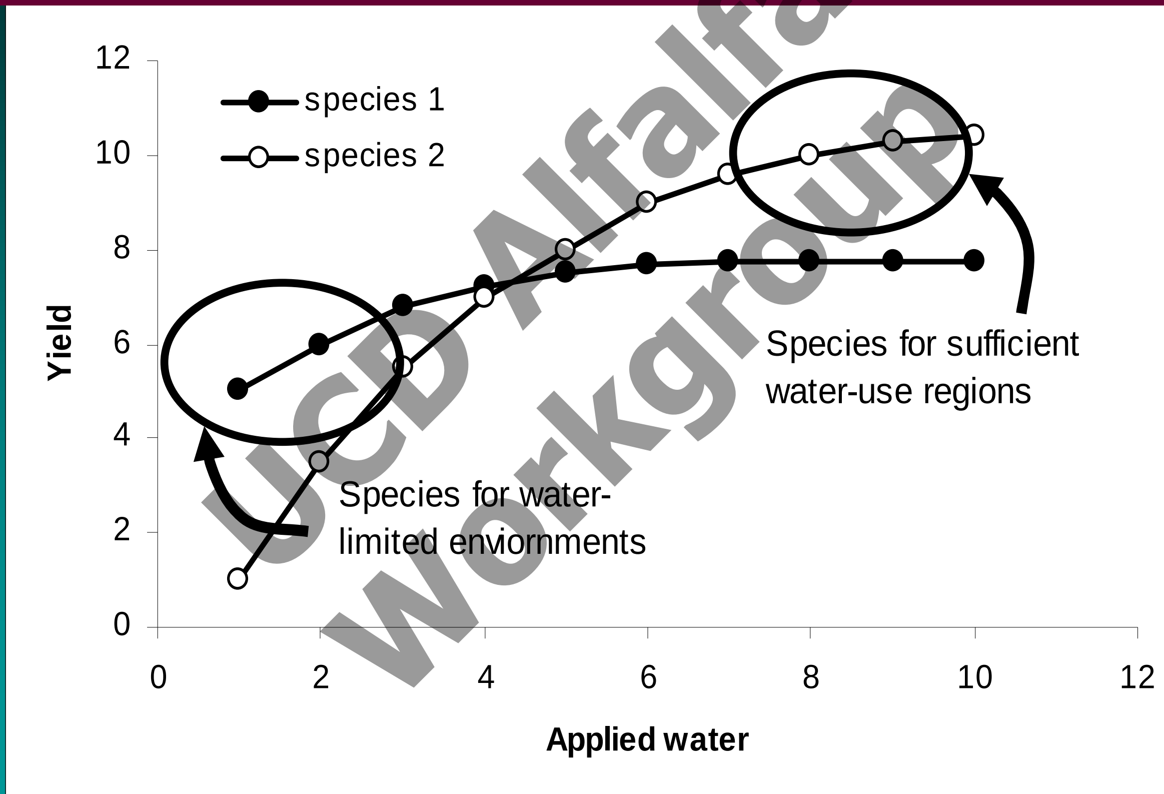
Criteria to choose Feedstocks

- **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 → Anhydrous Ammonia

Approx 32 mcf Natural gas → 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 otherwised 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 mulitple 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

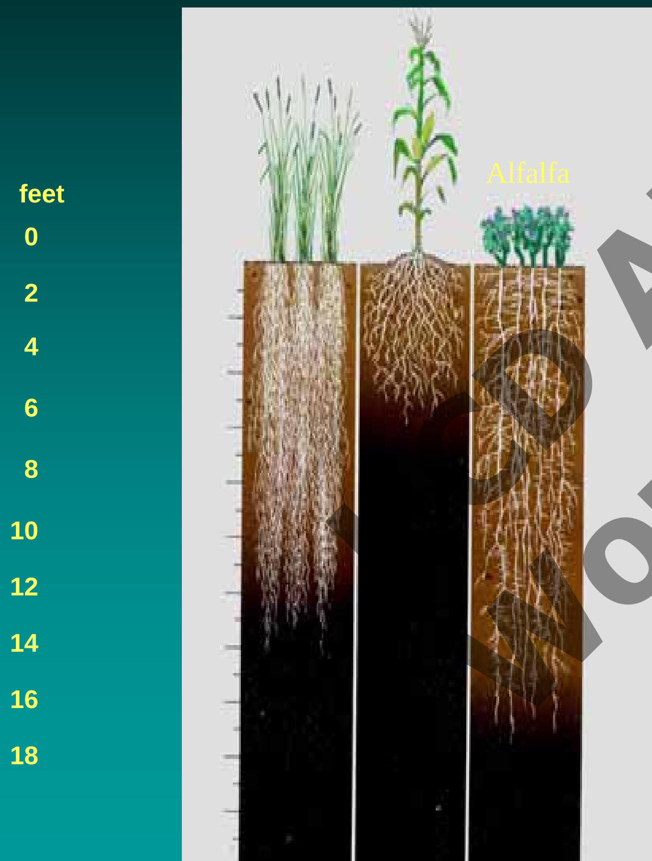
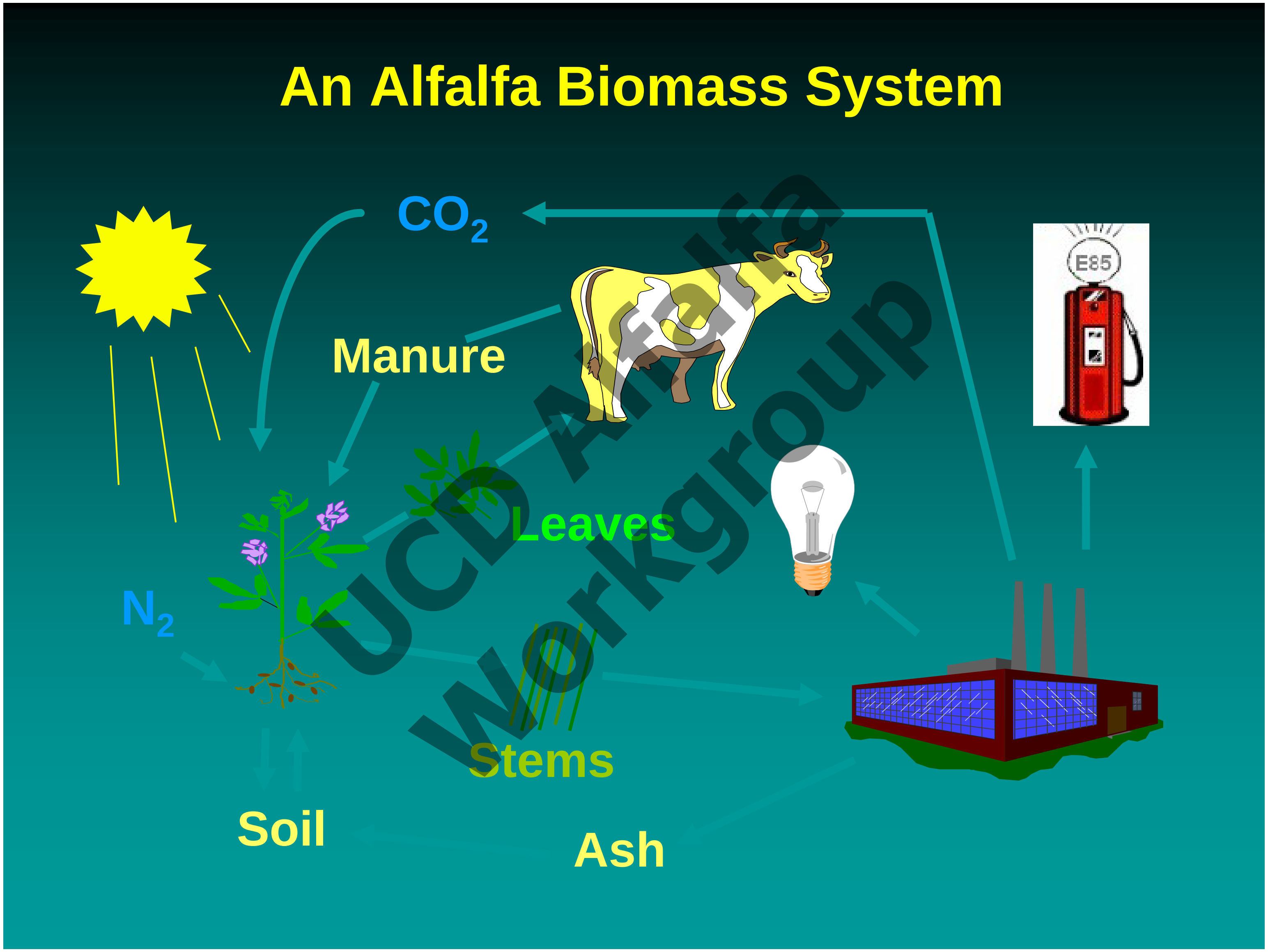


Image courtesy of Mike Russelle

- **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

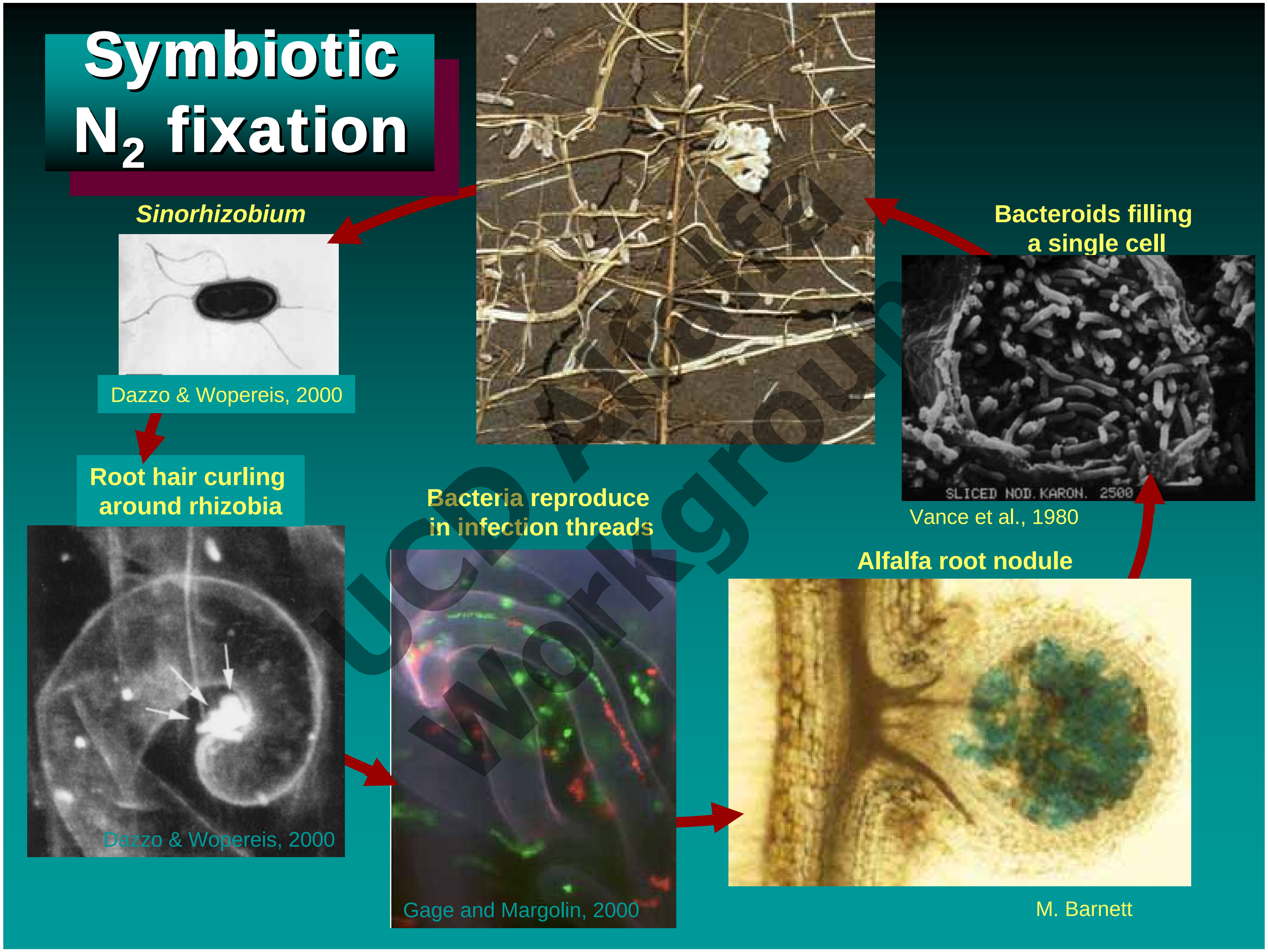

An Alfalfa Biomass System
CO_2
Manure
E85
Leaves
N_2
Stems
Soil
Ash
UCD Alfalfa Workgroup

N – Advantage of Alfalfa

- Estimate that to replace the protein produced each year by 1 million acreas 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

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


Symbiotic
N_2 fixation
Sinorhizobium
Dazzo & Wopereis, 2000
Root hair curling
around rhizobia
Dazzo & Wopereis, 2000
Bacteria reproduce
in infection threads
Gage and Margolin, 2000
Alfalfa root nodule
M. Barnett
Bacteroids filling
a single cell
SLICED NOD. KARON. 2500
Vance et al., 1980
UCD Alfalfa Workgroup

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:

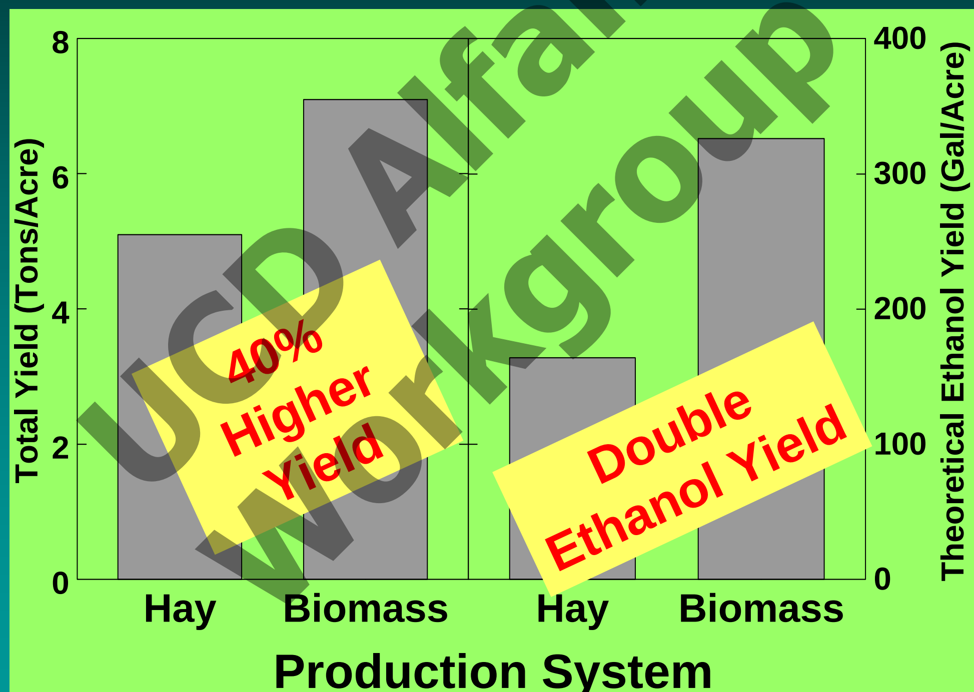
- Genetic advances
  - Breakdown of cellulose
  - Downregulated lignin

New alfalfa biomass management system (MN w

> Biomass type alfalfa (reduce lodging, increase yield)

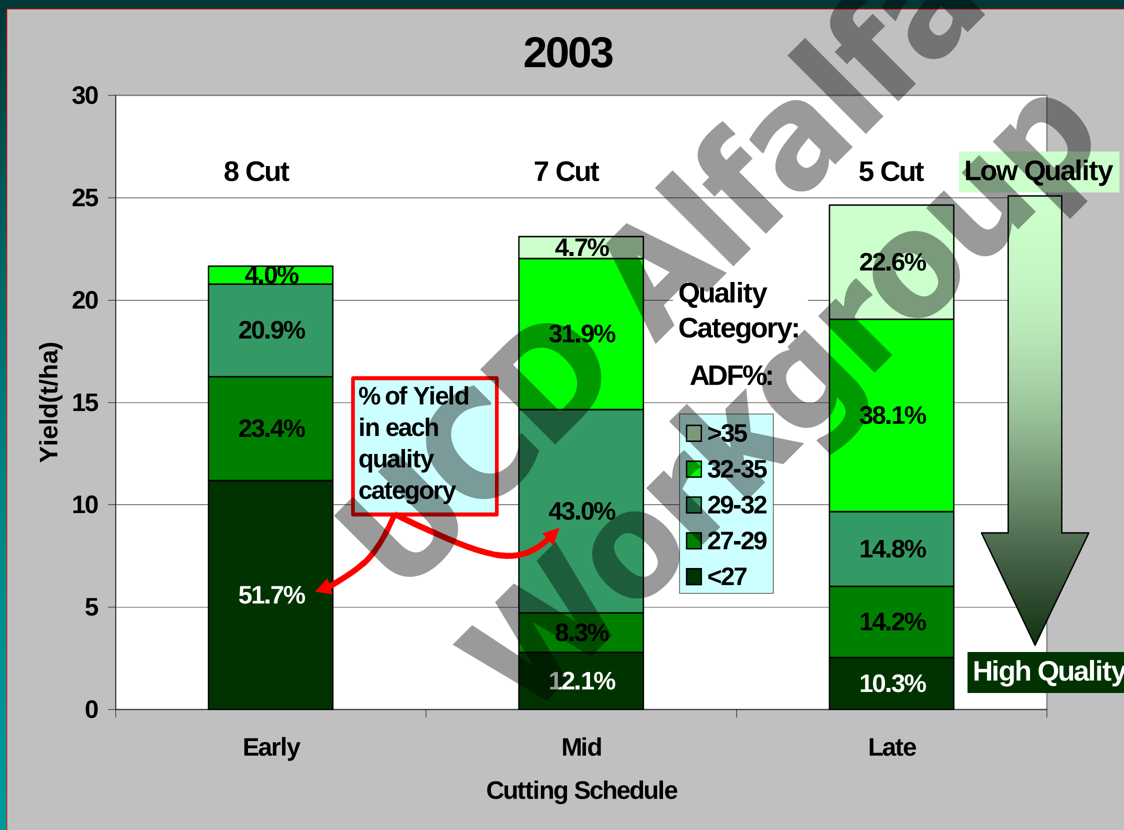
> Thinner stand (60% less seed, save $ and energy)

> 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	Ethanol: Corn	Ethanol: Alternate	Ethanol: Total	Protein
	Gal/Acre			Tons/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

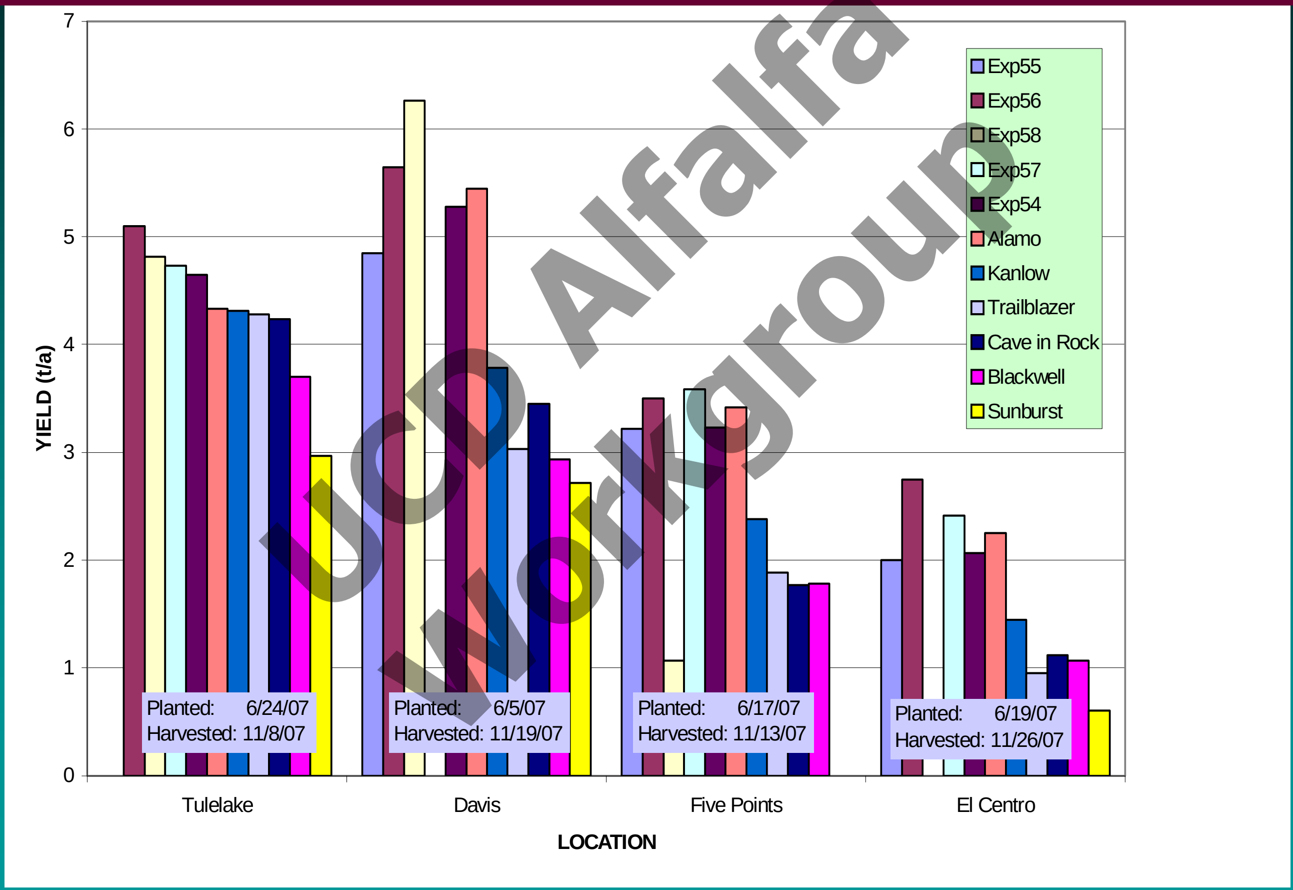
- 10-12 ton irrigated yields
  - Late cutting schedules
  - Improved Varieties
  - Low densities, other techniques
- 4-5 tons/acre – high value leafy product
- 5-6 tons/acre – stemmy cellulosic product

Switchgrass

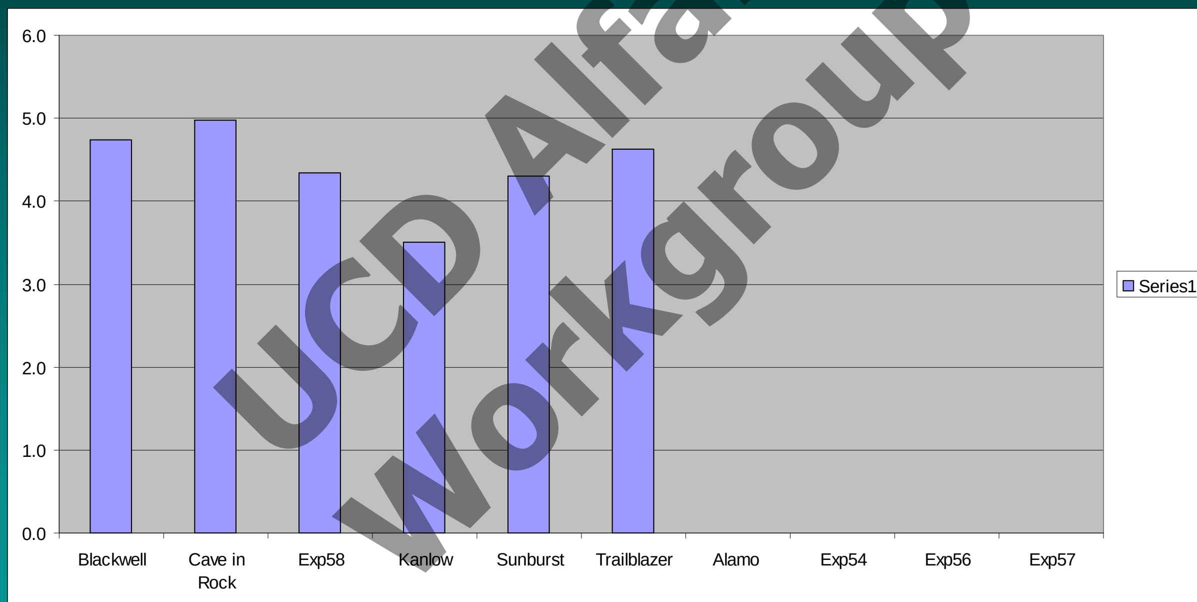
Switchgrass Trials:

- 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

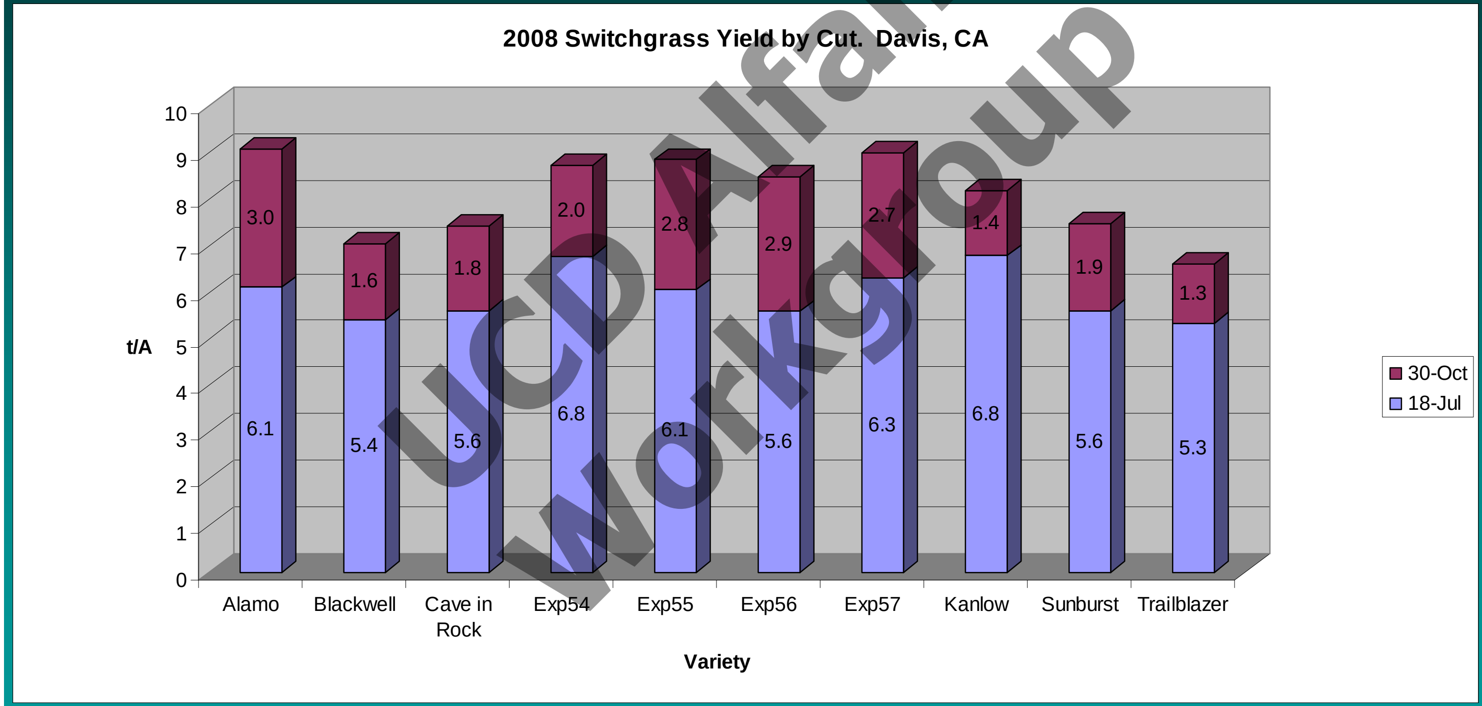
Switchgrass – Year 1 yields



Switchgrass - Tulelake 2008

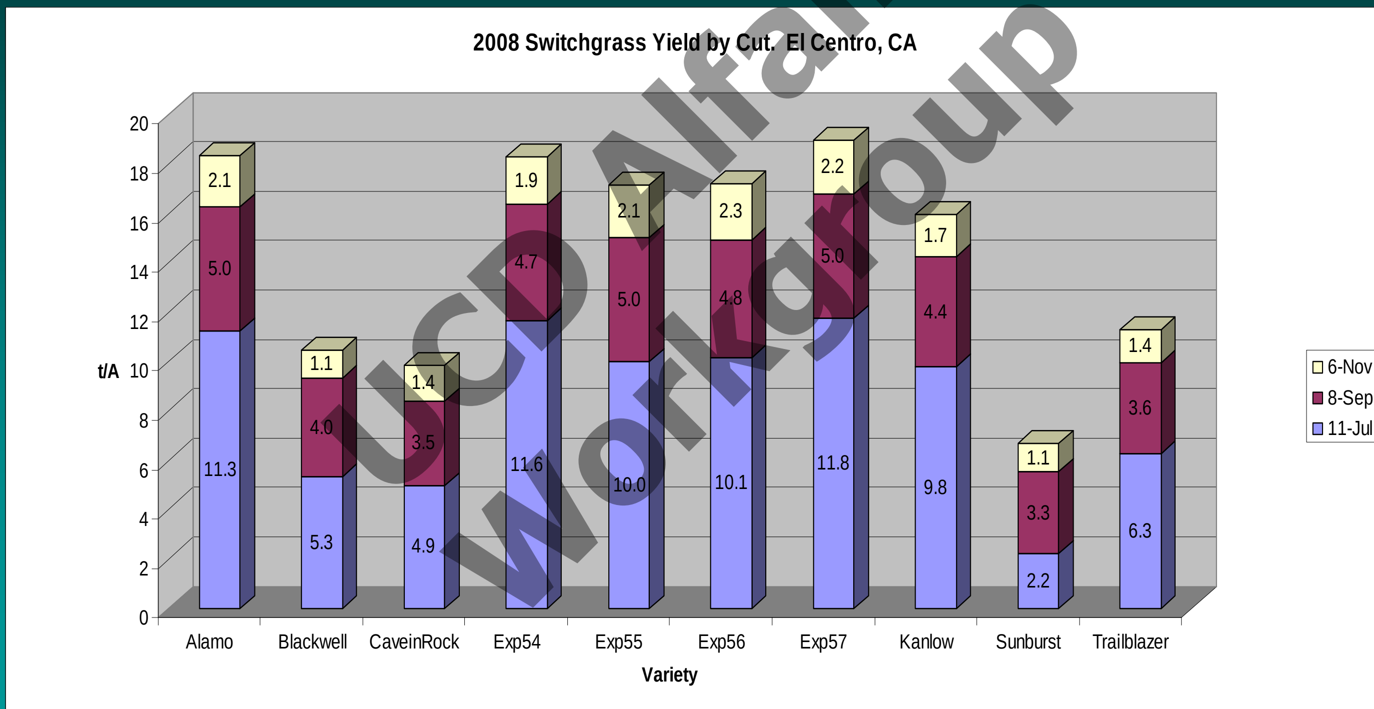


Switchgrass – Davis 2008

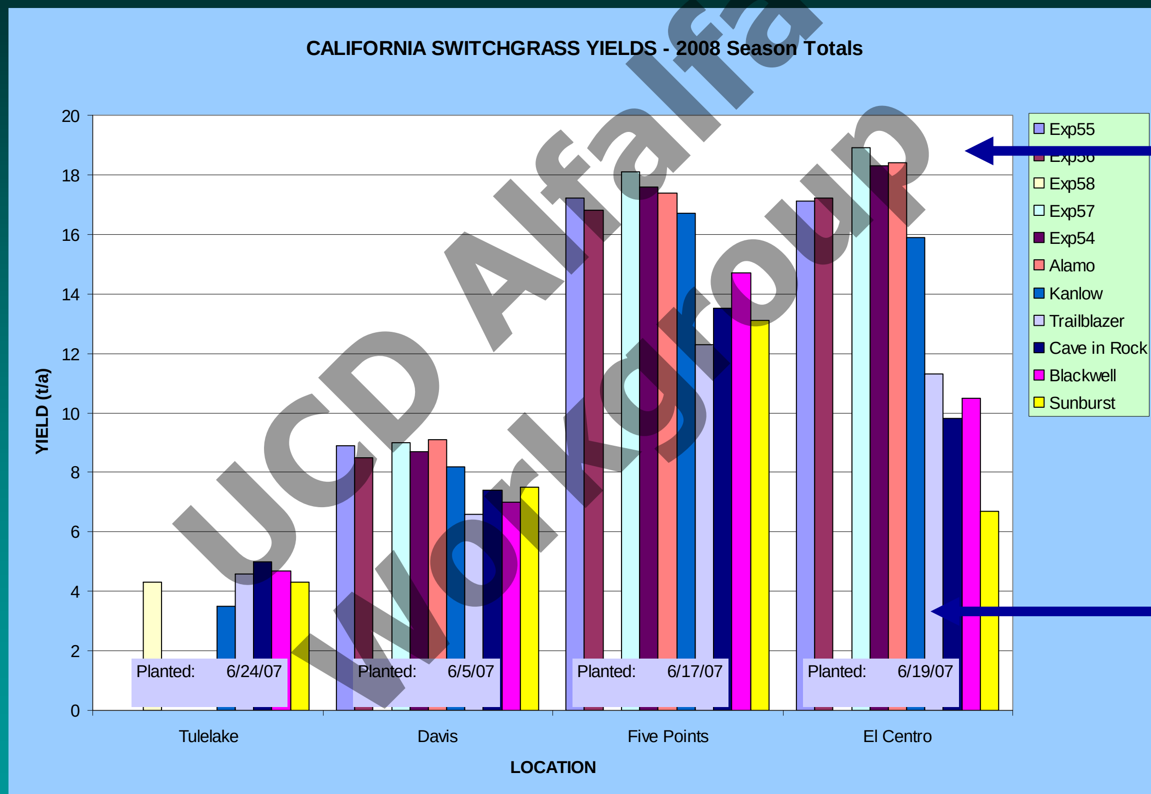


Switchgrass – Fresno Co. 2008

2008 Switchgrass – El Centro



2008 CA Switchgrass Yields



18 t/a

4 t/a

Scenarios:

- Low Input Scenario: Average 3-6 t/a 'low imput' 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