Could biomass make a large contribution as an energy service provider?

Resource availability a central issue, often seen as a key constraint.

Today

- **Addressed in terms of physical considerations (production, conversion, demand)**
- **Positive answer a necessary but not sufficient condition to establish desirability**

Subsequently during the project

- **Addressed in terms of environmental & economic considerations**

Illustrates impact of the context within which questions are framed

Outlines approach to be taken in Task 5, Resource Sufficiency

Big or little potatoes?

How big a contribution could biomass make?

Radically different conclusions have been reached

- **Biomass becomes the largest energy source supporting humankind in the (Renewables-Intensive Global Energy Scenario, Johanssen et al., 1993).**
- **Biomass share of world energy supply will equal that of oil in 2050 and be as large as any other resource (Kassler, Shell Petroleum Ltd, 1994).**
- **Biomass will eventually provide over 90% of U.S. chemical and over 50% of U.S. fuel production (Biobased Industrial Products, NRC, 1999).**
- **To provide ethanol to replace all gasoline used in the [U.S] light-duty fleet, we estimate it would be necessary to process the biomass growing on 300 to 500 million acres. (Lave et al., 2002).**
- **Large scale biofuel production is not an alternative to the current use of oil and is not even an advisable option to cover a significant fraction of it (Giampetro et al., '97).**

Key variables impacting availability of biomass for non-food uses

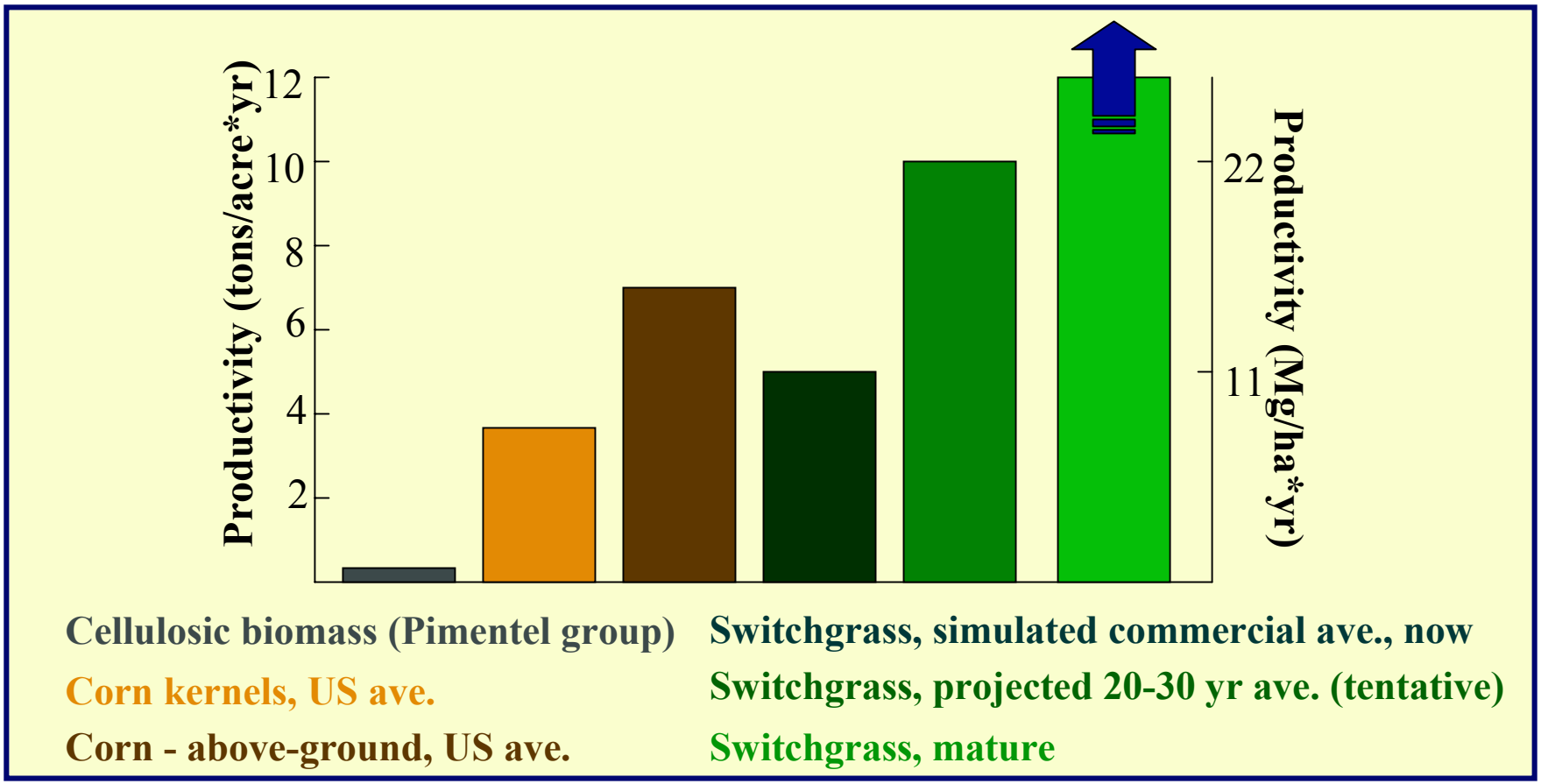
Biomass productivity (tons/acre*yr)

Vehicle efficiency (miles/gallon)

Land use

- **Food production efficiency (calories, protein/acre)**
- **Integrated production of feed and feedstocks**

Biomass Productivity

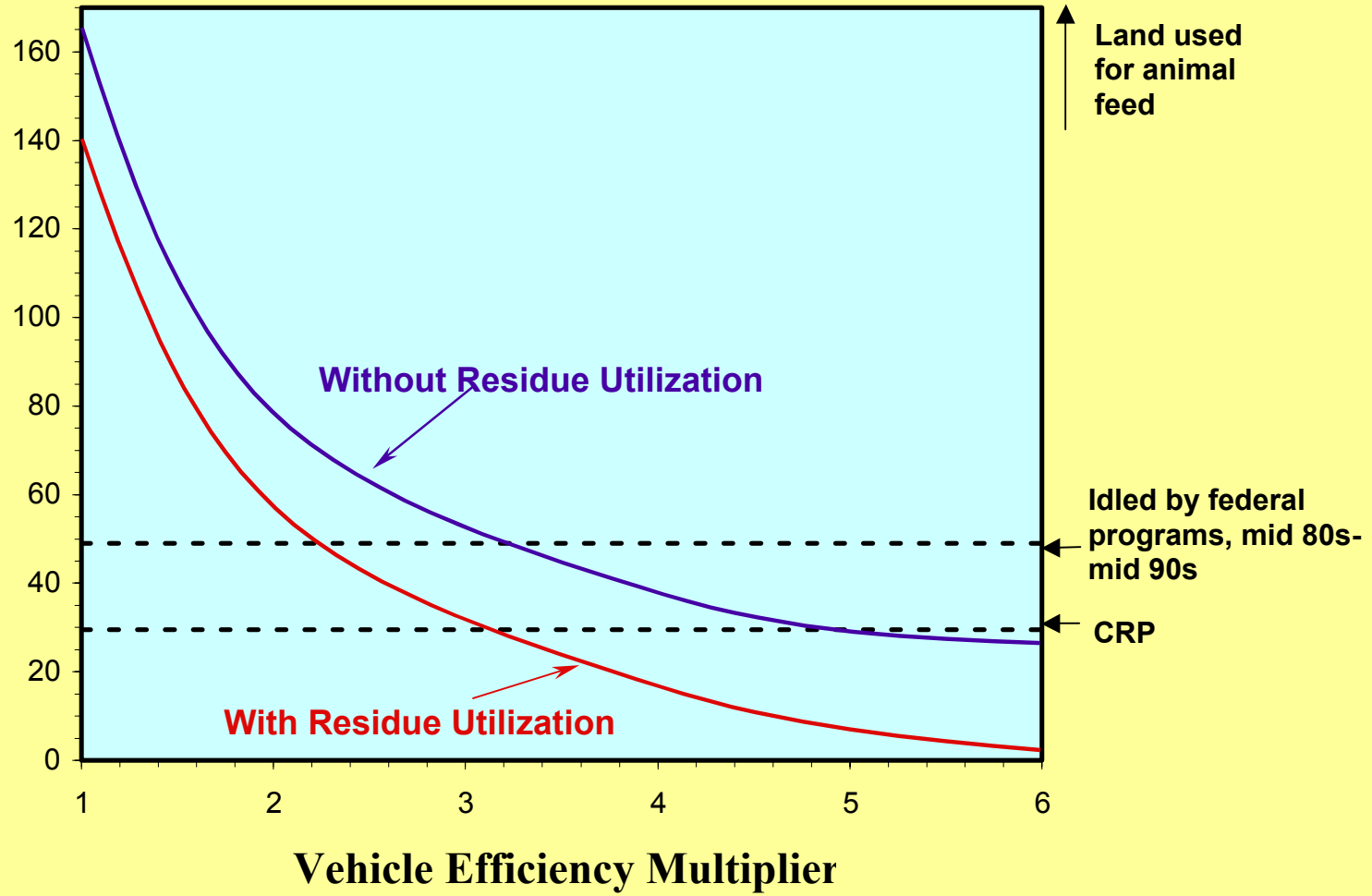


<u>Future</u> productivity important for evaluating feasibility of large-scale bioenergy

Relatively little effort put into development of high-productivity crops, cropping systems for cellulosic biomass

If increasing the BTU productivity of perennial grass received an effort comparable to that invested in increasing the productivity of corn kernels, what would be reasonable to expect?

Land Area Required for Current U.S. Light Duty Mobility in Relation to Vehicle Efficiency



- LDV VMT = 2.5 trillion vehicle miles traveled
- Waste availability: 200 million dry tons
- Switchgrass productivity: 10 dry tons/acre/year (20 to 30 year projected average, tentative)
- Fuel yield: 100 gallons/dry ton

High Vehicle Efficiency

Possible *(2020 estimates from Friedman, 2003)*

Today: '04 Prius (mid-size), 56 mpg

By 2020, fuel savings > added vehicle cost (hybrids + advanced technology)

Fleet average: 50 to 60 mpg.

A fleet made up only of pickups, minivans, and SUVs could still reach 50 mpg.

Desirable

Direct: Reduces GHG emissions, oil imports & depletion rate.

Indirect: Increases the feasibility of alternatives to petroleum

Difficult to imagine a sustainable transportation sector without it

Scenario	High efficiency vehicles compensate for…
Renewable power/H_2	Otherwise low travel radius
Renewable power/batteries	Otherwise low travel radius
Biomass/ethanol	Otherwise large land requirement

Implicit in transportation scenarios featuring energy storage as H_2

Food Production Efficiency: Some Observations

Strongly impacted by dietary trends - the amount and kind of meat consumed in particular.

Tremendous potential elasticity

Land to feed U.S. population in the most land-efficient way possible: ~ 20 million acres

Land currently used: > 400 million acres

Food production is usually assumed to remain static in analyses of the role of biomass as an energy source.

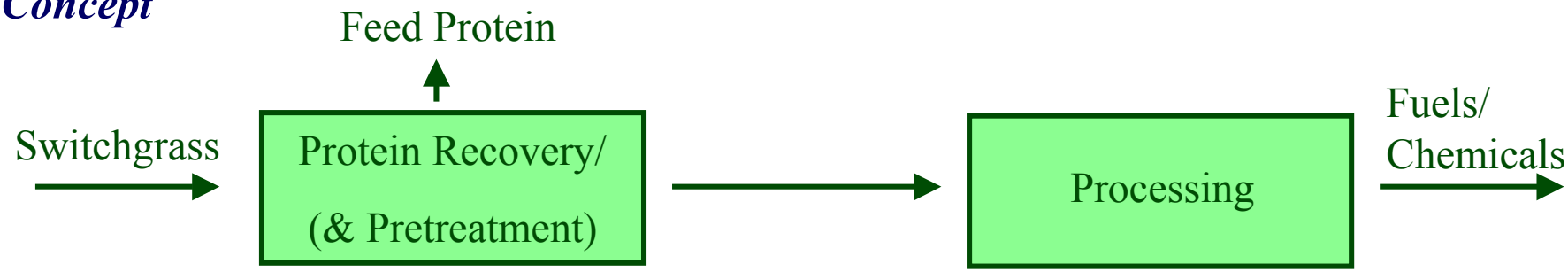
However, demand for cellulosic feedstocks due to cost-competitive processing technology would very likely result in large changes in food production.

Farmers would rethink what they plant.

Coproduction of processing feedstock and animal feed is one likely change.

Integrated Production of Processing Feedstocks and Feed Protein

Concept



Composition & productivity comparison

Crop	Mass Productivity (tons/acre/year)	Protein (Mass Fraction)	Protein Productivity (tons/acre/year)
Switchgrass	5.0 – 10	.08 -0.12 (early cut)	0.4 – 1.2
Soybeans	1.1 – 1.3	0.36 (bean only)	0.40 – 0.45

- **Consumption of calories and protein by livestock 10x that by humans in the U.S.**
- **Currently the U.S. devotes 74 million acres to production of soybeans, used primarily as a protein supplement for animal feed**
- **Production of perennial grass could potentially produce the same amount of feed protein per acre while producing a large amount of feedstock for energy production**
- **Requires readily foreseeable processing technology to recover feed protein**

The Availability of Biomass for Non-Food Uses is a Much More Elastic Quantity Than Usually Assumed

***Would like to know*:** $\dfrac{\text{Land Required to Meet a Specified Need (e.g. Transportation)}}{\text{Land Available}}$

Driving habits, demography

$\dfrac{1}{\text{Vehicle Efficiency}}$

$\dfrac{1}{\text{Conversion Efficiency}}$

Allowance for residues

$\dfrac{1}{\text{Ag. Productivity}}$

$$= \frac{\text{Population x mi/person x energy/mile x ton biomass/energy x (1 - } f_{residues}\text{) x acres/ton}}{\text{Available land - Population x } 1/\eta_{distribution} \text{ x nutrition/person x acres/nutrition}}$$

Sustainable land base, w/ allowance for nature

Distributional losses

Calories, protein per person

$\dfrac{1}{\text{Ag. Productivity \& diet}}$

***Considering the range of values these largely independent parameters might be assumed to take in a future scenario (e.g. several decades hence)*:**

$$= \frac{\text{1.5-fold x 3-fold x 4-fold x 2-fold x 2-fold x 5-fold}}{\text{3-fold - 2-fold x 1.5-fold x 1.5-fold} \geq \text{5-fold}} = \frac{\text{320-fold}}{\text{3-fold - 20-fold}}$$

Some Illustrative Scenarios

Calibration points

Total U.S. cropland: ~400 million acres (162 million ha)

Land planted in soybeans: ~74 million acres (30 million ha)

Idled cropland in conservation reserve program: ~30 million acres (12 million ha)

Land required to satisfy current U.S. LDV mobility (~2/3 of total transport energy)

Scenario	Biomass Productivity tons/acre*year [Mg/ha*yr]	Fleet mpg	Integrated Feed/Feedstock Coproduction	Additional Land* Million Acres [ha]
a. Status quo	5 [11]	20	No	360** [146]
b. High productivity	10 [22]	20	No	180 [73]
c. (b + high mileage)	10 [22]	55	No	72 [29]
d. "Motivated"	10 [22]	55	Yes	Near zero

* Land in addition to current cropland.

**$(2.5 \times 10^{12}$ mi/yr)*(1 gal gas/20 mi)*(0.0144 ton biomass/gal gas equiv.)*(1 acre*yr/5 ton) = 360×10^{6} acres

Sample calculation for ton biomass/gal gas equivalent:
(1.55 gal EtOH/gal gas)*(1 ton biomass/108 gal EtOH) = 0.0144 ton/gal gas equiv.
Similar values are obtained for other biomass-derived fuels

Land required to satisfy current U.S. LDV mobility (~2/3 of total transport energy)

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Additional considerations

- **Increase in VMT (vehicle miles traveled)**
  - "Extrapolate the present scenario": *Expected*
  - "Innovate & change", motivated by sustainability, security: *Reduced or eliminated*
- **Oil as well as protein from land currently in soybeans would have to be provided.**
- **Continued growth in energy crop productivity beyond the 2025 timeframe.**
- **Sustainable utilization of biomass residues.**
- **Other strategies to integrate feedstock production into agriculture and/or increase the land efficiency of food production.**
- **Coproduction of HDV fuels or power along with LDV fuels.**

Large contributions to LDV (& HDV) fuel supply less than 100% are still important!

We do not need to wait for full maturation of technology to realize significant benefits while providing the foundation for more to come.

Coproduction & Integration Synergies

In the field

Coproduction of feed & feedstock

Recycle of fertilizer from processing

To keep land requirements reasonable

High productivity crops

High efficiency vehicles

Integrating feedstock production, agriculture

Processing

LDV Liquid Fuels

HDV Fuels

Hydrogen

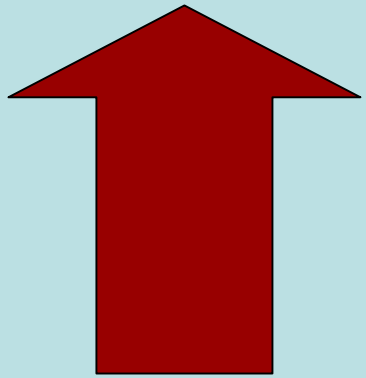
Electricity

Chemicals

Animal feed

Fertilizer

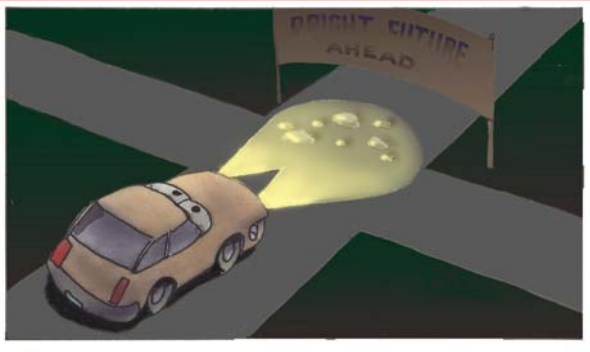
- Greater resource efficiency
- Better economics



More output per input

Coproducts can increase energy yields significantly in some mature technology scenarios

e.g. power and/or HDV fuels @ $\geq$ 30 % LDV fuel yields



Low-beam perspective

- *Current technology*
- *Few if any integration benefits*
- *Demand, efficiency extrapolated*

Resource availability presents a major barrier to biomass playing a large role in supplying energy services

High-beam perspective

- *Mature technology (innovation)*
- *Extensive integration*
- *Assume change is possible*

Available information supports the working hypothesis that biomass can play a large energy service supply role on little or no new land

Required changes are large, but not necessarily larger than other paths to a sustainable & secure energy future, most if not all of which require a "high beam" approach featuring innovation & change.