

Fuels: Waste, Crops, Production, Harvest, Processing

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Outline

1. Biomass production for bioenergy:

- USDA / DOE Congressional study**
- Science Magazine**

2. C4 perennials and the European approach.

3. Pellets and briquettes: fabrication and durability tests

- **Biomass R&D Act of 2000 formed a Congressional Advisory Committee to build a vision to supply the US with:**

- **5% of its electricity**
- **20% of its transportation fuels**
- **25% of its chemicals**

..... all from biomass by the year 2030.



Equivalent to 30% of US petroleum consumption in year 2005.

Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply

April 2005



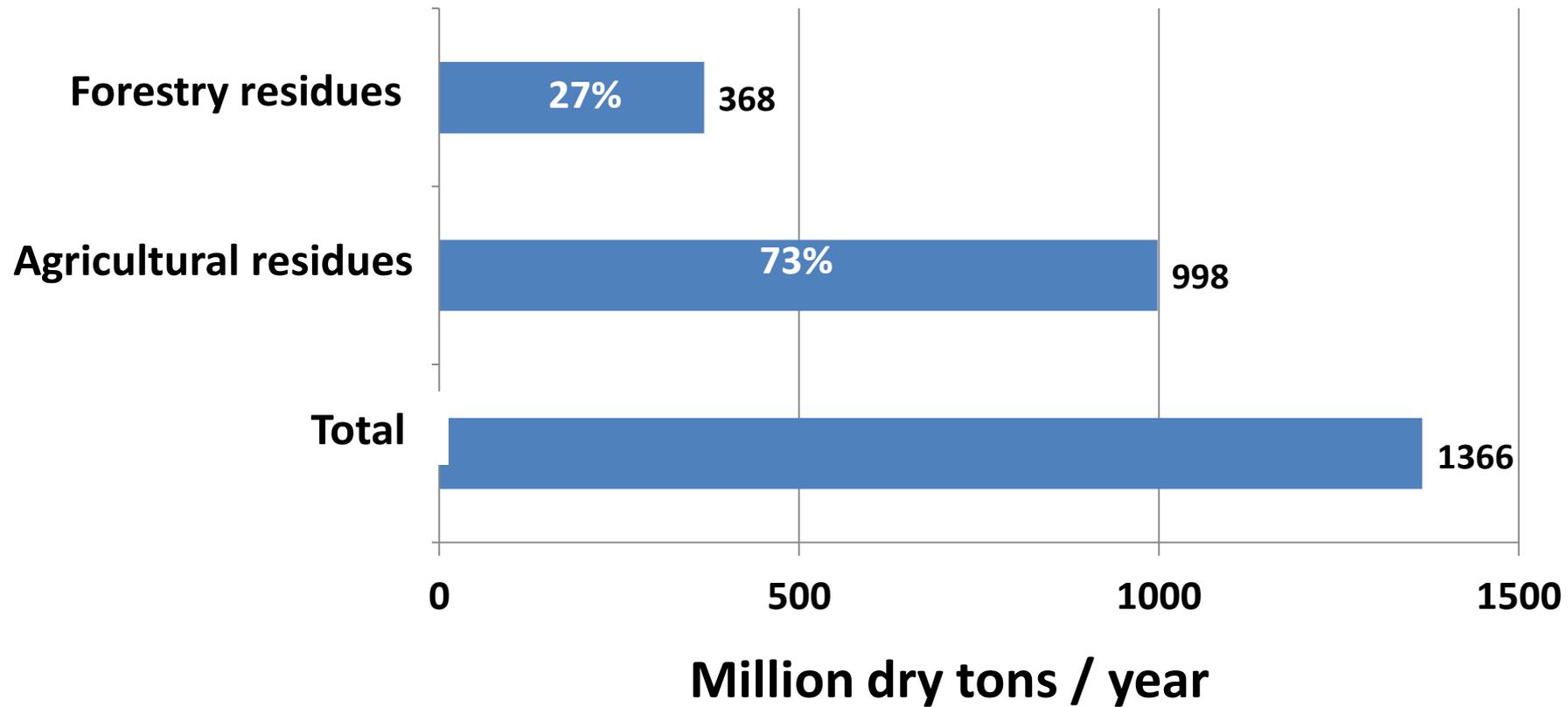
U.S. Department of Energy

USDA

U.S. Department of Agriculture

Main question: Is the US land base big enough to produce a billion tons annually?

Potential biomass supply



Source: Perlack et al. (2005)

- **Resource potential to make a billion tons per year isn't yet available.**
- **The report says this can be accomplished with relatively minor changes in land use and ag / forestry management practices.**
- **Result: seven-fold increase in biomass production above that currently consumed in bioenergy production and bio-based products.**

Assumptions

- **Forestland areas not currently accessible by roads are excluded.**
- **Environmentally sensitive areas are excluded.**

Assumptions

- **Yields of corn, wheat, and other grains would increase by 50 percent.**

Assumptions

- **Major improvements in residue harvesting equipment would become available.**



Assumptions

- **75 percent of annual crop residues would be recovered (only if this amount is sustainable for a given crop).**

Assumptions

- **Perennial crops (a combination of grasses and woody crops) would be grown on 55 million acres of cropland, idle cropland, and cropland pasture.**



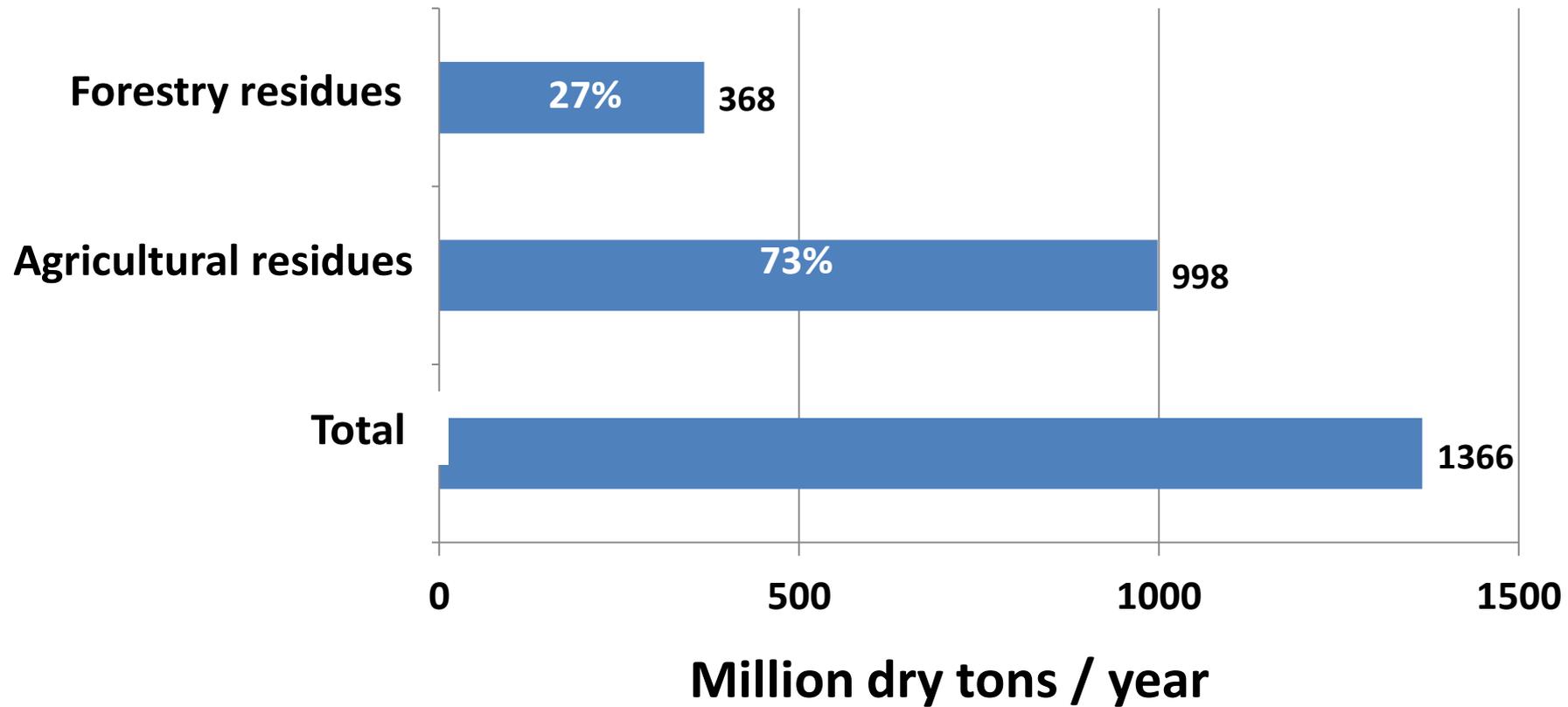
Assumptions

- All manure in excess of that which can be applied on-farm for soil improvement would be used for biofuel.



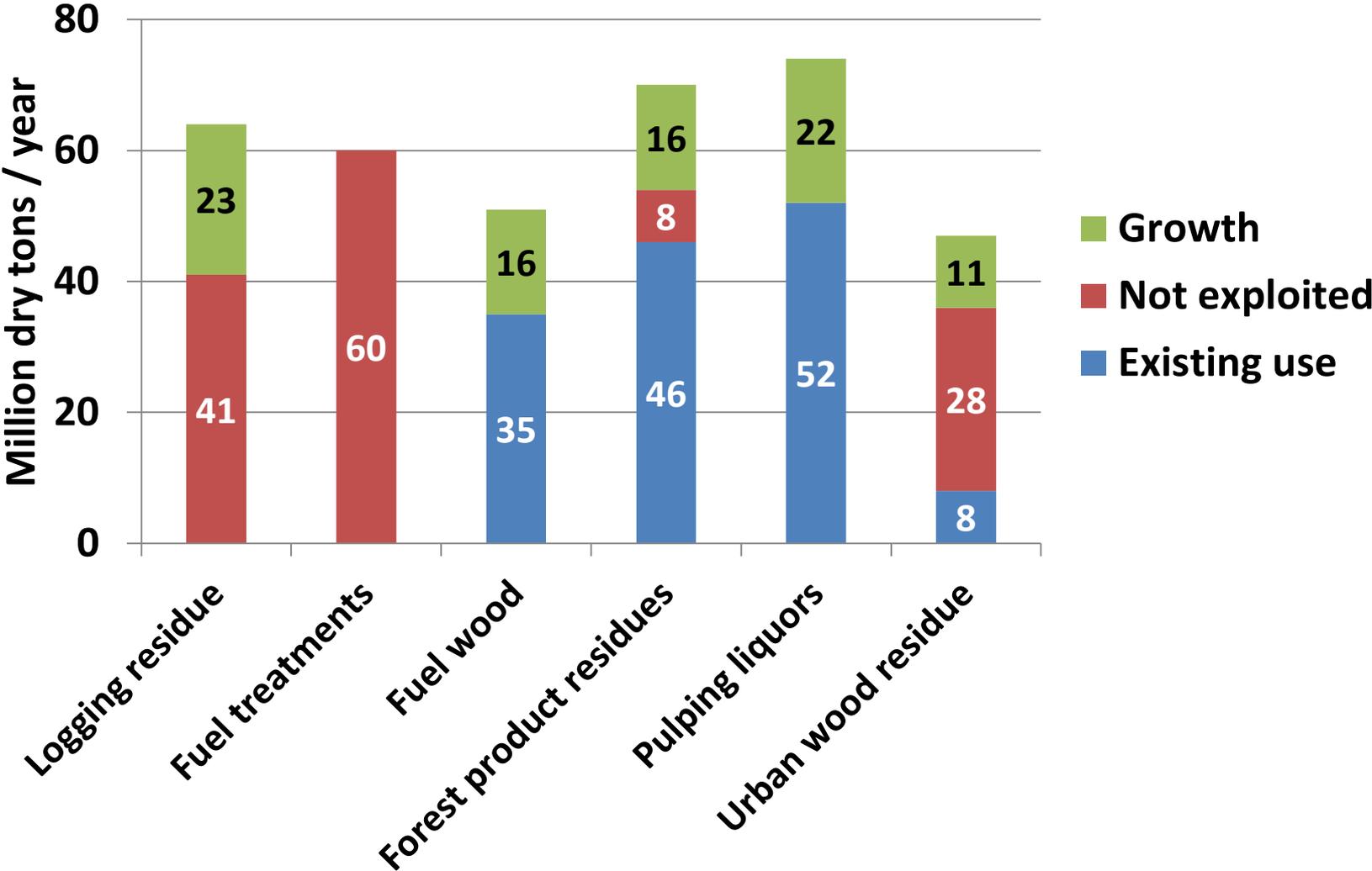
Biogas-fueled train in Sweden.

Potential biomass supply



Source: Perlack et al. (2005)

Distribution of forest resource potential



Source: Perlack et al. (2005)

Main Conclusion

- **Significant, currently available supplies:**
 - **Urban waste wood**
 - **Logging and land-clearing residues**
 - **Fuel treatments to abate forest fires**



We need the infrastructure to cheaply harvest and deliver biomass to powerplants and biorefineries.



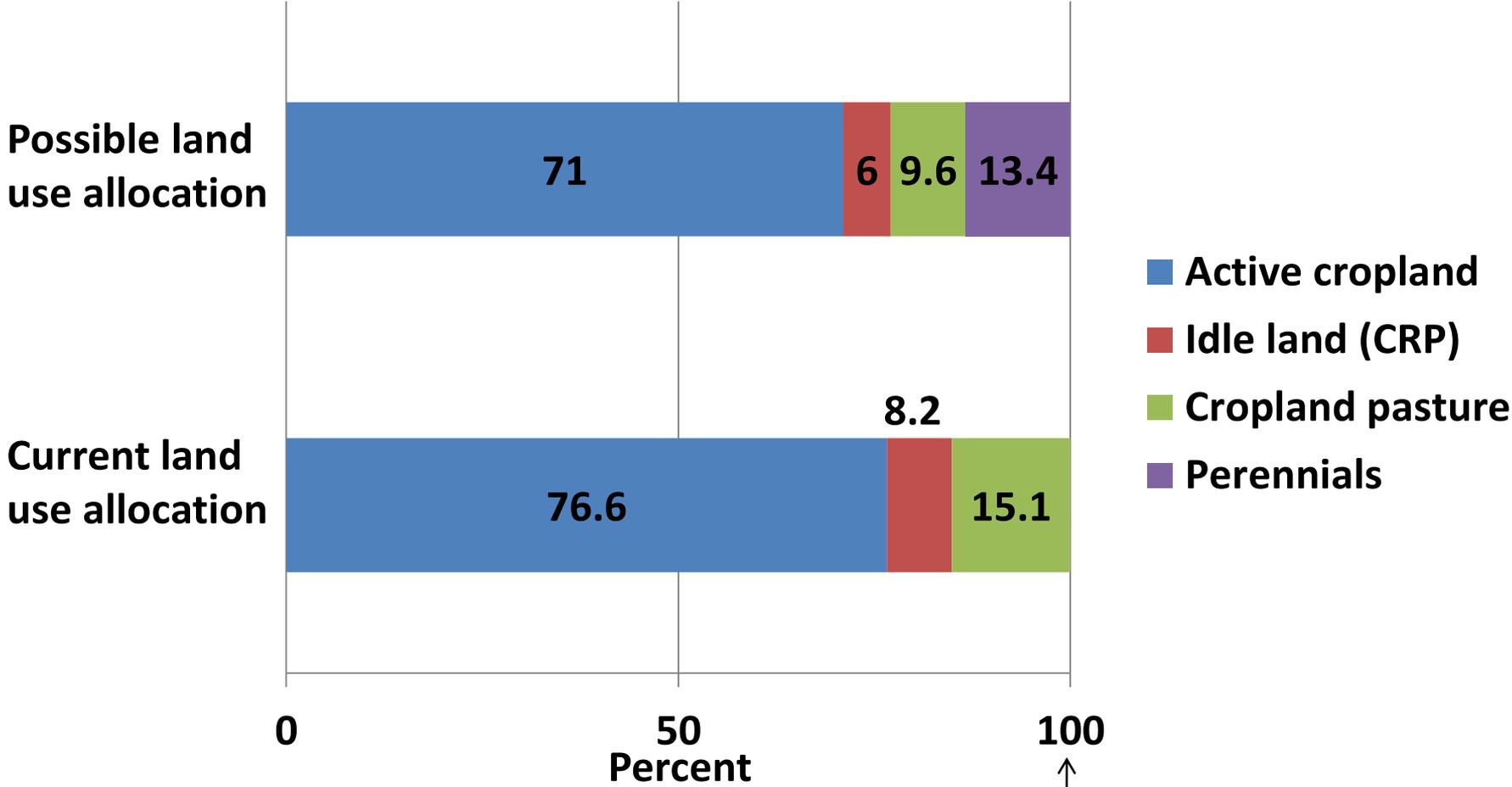


OU Chipper #2





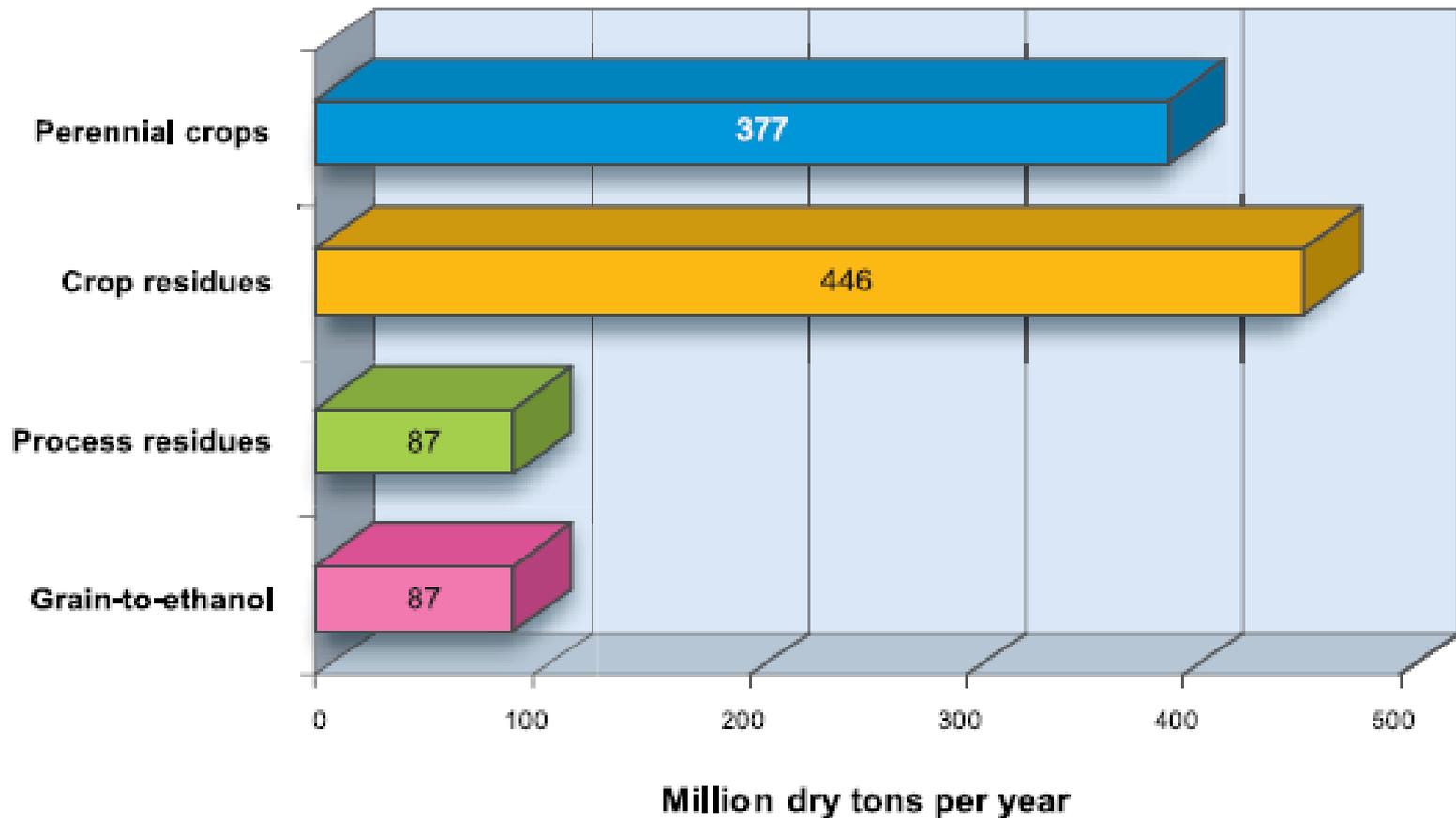
Potential allocation of ag land



Source: Perlack et al. (2005)

449 million acres

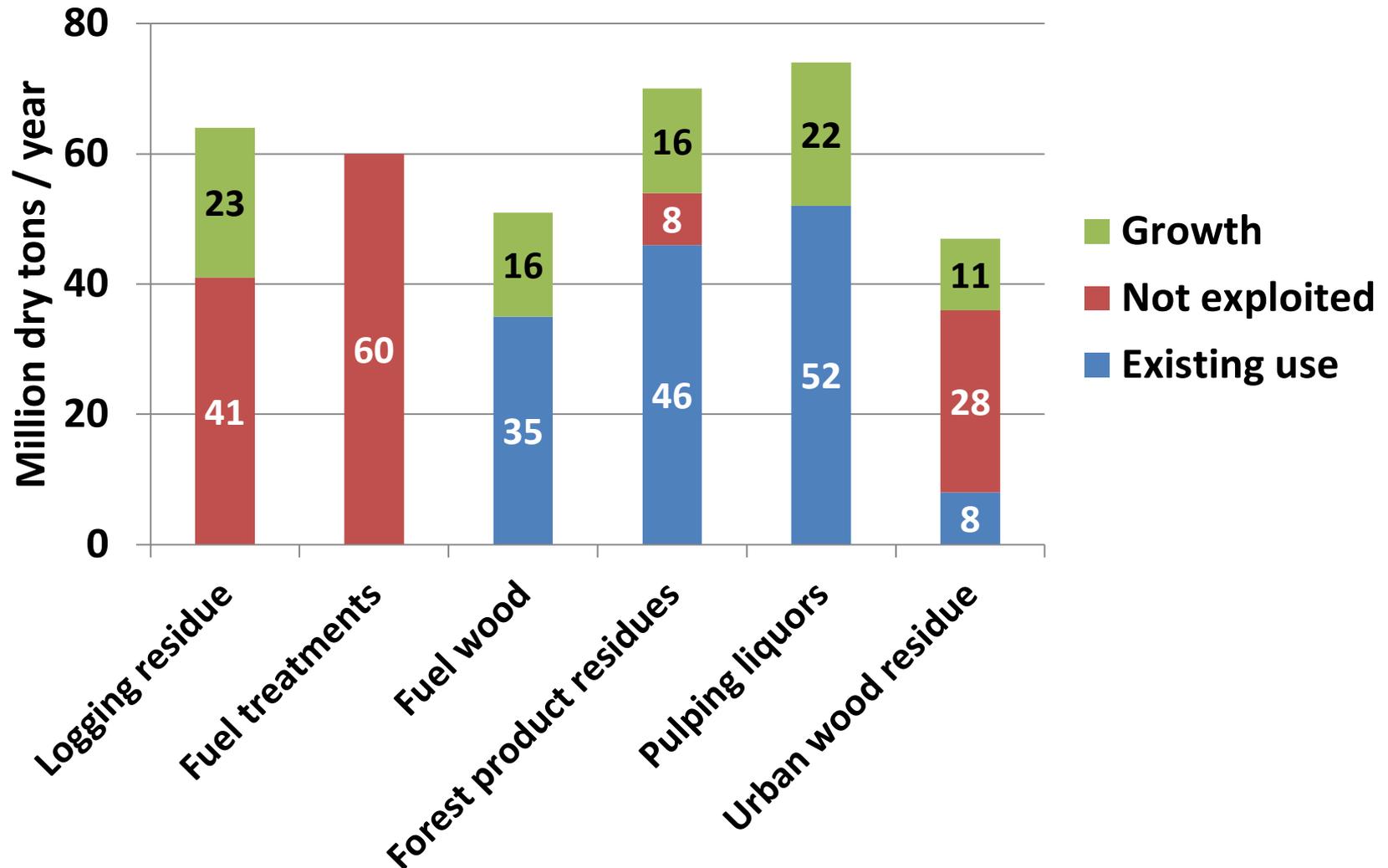
Main conclusion: Assuming a 50% increase in grain yields and a major introduction of perennial crops, ag lands can provide ~ 1 billion dry tons of sustainably collectable biomass and continue to meet food, feed and export demands.





We have the land base to **build** a billion ton supply, there are challenges.

A challenge: Supply growth is assumed in most sectors below.



Another challenge: 50% increased grain-harvest yields are assumed.



Crop residue as biofuel?



- **How to avoid erosion and loss of soil carbon?**
- **How much fertilizer to replace lost minerals?**

Another challenge: affordable, efficient equipment to harvest and process cropland residues



Cultivation, harvest, and transportation of perennials.



Shipping and storage infrastructure will need expanding.







August 13, 2010

**Special issue on
scaling up
renewable energy**

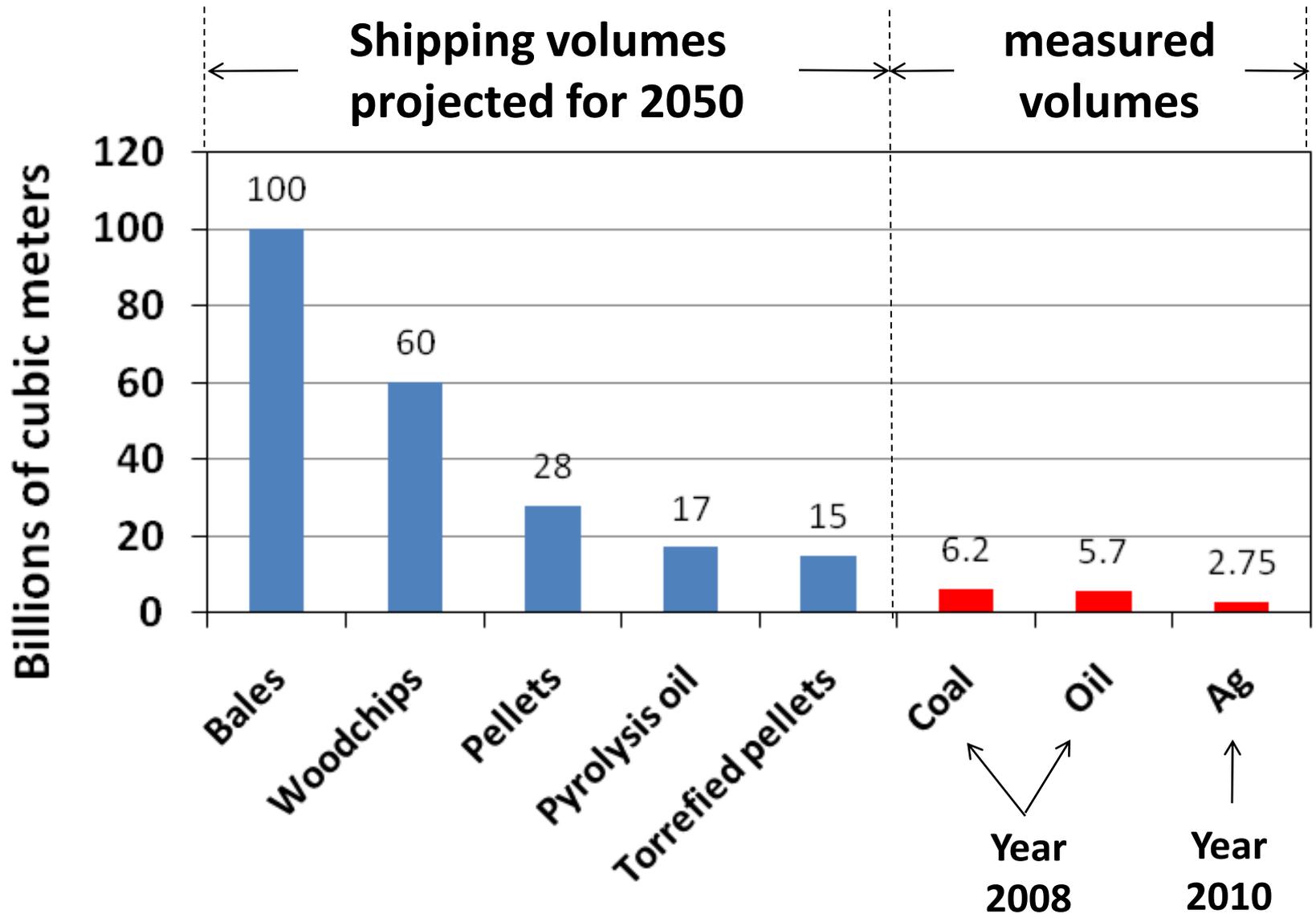
The energy density problem

- **1 kg of oil holds 3 times the energy as a kg of biomass.**
- **The picture looks worse when energy density is expressed per unit volume.**
- **Main implication: massive scale-up of the biofuel processing and transportation infrastructure.**

Source: R. A. Kerr, “Do we have the energy for the next transition?” *Science* Vol. 329, 13 Aug 2010, pp. 780-781.

Thought Experiment

- **Assume its possible to make 20% of the world's primary energy from biomass by 2050.**
- **This would require a factor of 4 increase above today's bioenergy production, to 150 EJ / yr ($E = 10^{18}$).**



T. L. Richard, "Challenges in Scaling Up Biofuels Infrastructure," *Science* Vol. 329, 13 August 2010, pp. 793-795



2 prime candidates



**Switchgrass
(*Panicum virgatum*)**



Miscanthus x giganteus



- **High efficiency of light, water, and nitrogen use.**
- **Reduced tillage and senescence add minerals to soil and protect against erosion.**
- **Low mineral content if harvested after senescence.**

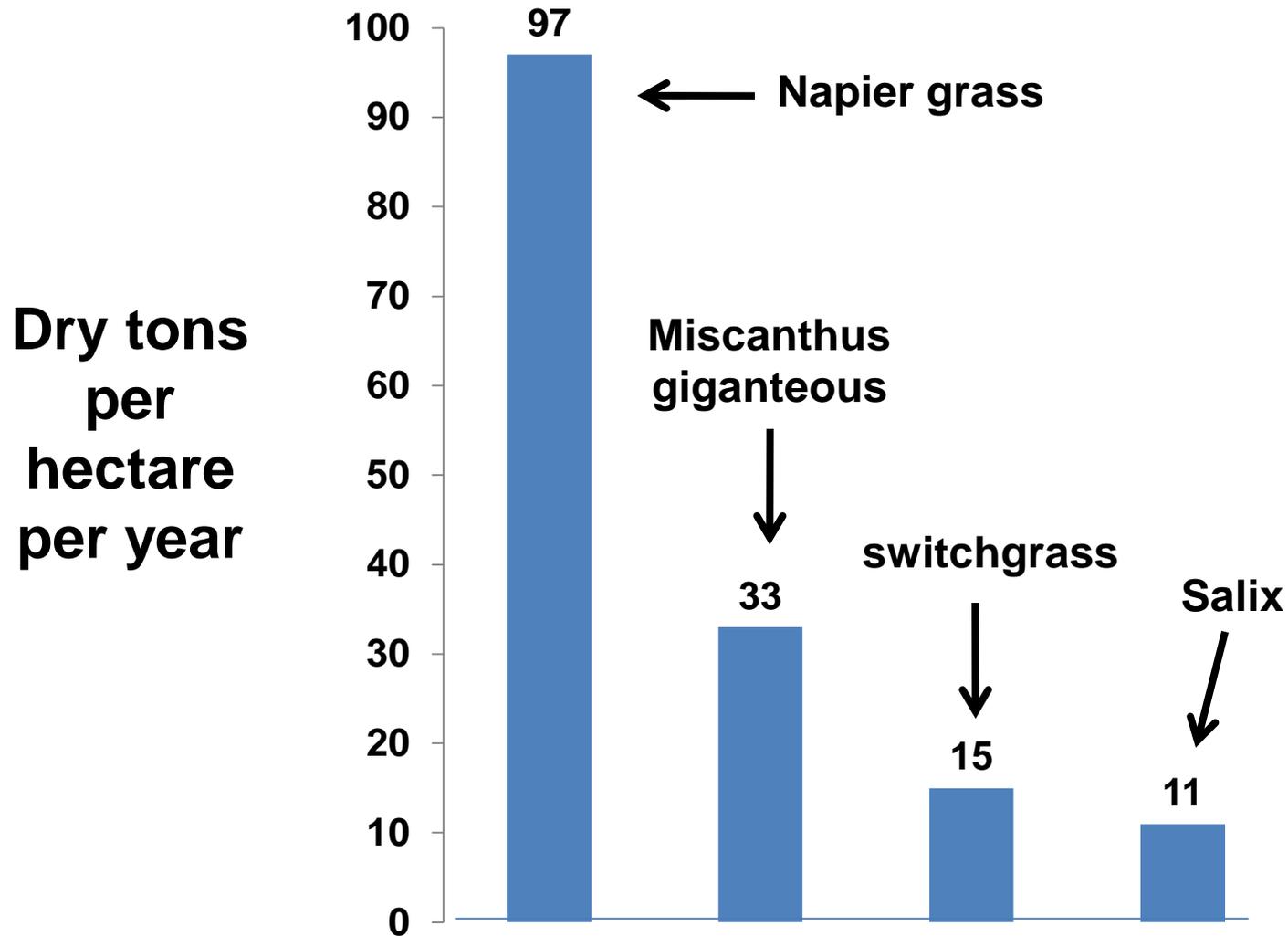


Miscanthus rhizomes

Other benefits

- **Carbon sequestration in soil.**
- **Excellent cover for wildlife.**
- **One planting and related tillage – this reduces costs, fossil fuel use, soil erosion.**
- **Respond well to irrigation, fertilization – thus valuable for wastewater remediation.**
- **Grow well in marginal soils unsuitable for food crop production.**

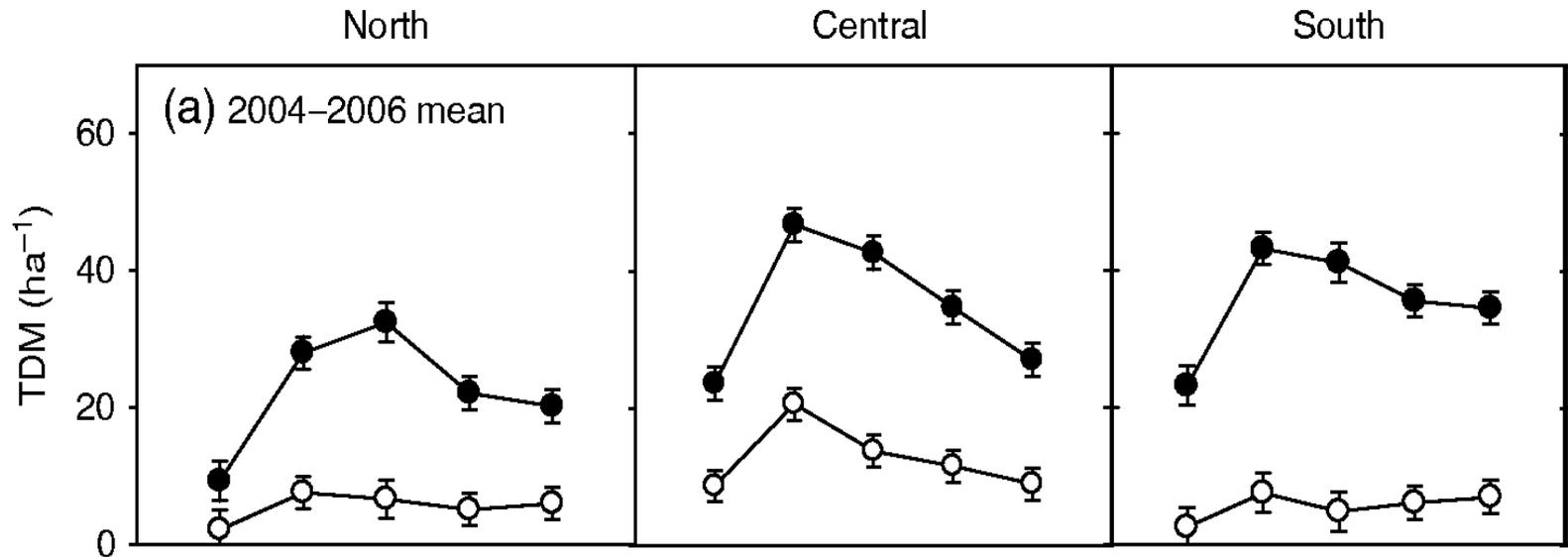
Average harvest yields



C. Somerville, H. Youngs, C. Taylor, S.C. Davis, and S. P. Long, "Feedstocks for Lignocellulosic Biofuels," *Science* Vol. 329, 790-92 (2010).

Seasonal dry matter accumulation over 4 years

Heaton et al. (2008)



Legend

- Miscanthus
- switchgrass

2004 was 3rd year after establishment.

Main differences

- ***P. virgatum*, a native species, is a fertile open-pollinating crop.**
- **Miscanthus is a sterile triploid hybrid - it can't produce viable pollen or spread by seed.**

Challenges with Miscanthus

- **Lack of affordable rootstock in US but not EU.**
- **Switchgrass is easily planted from readily available seeds; mechanized seed planting is well established and requires little labor.**

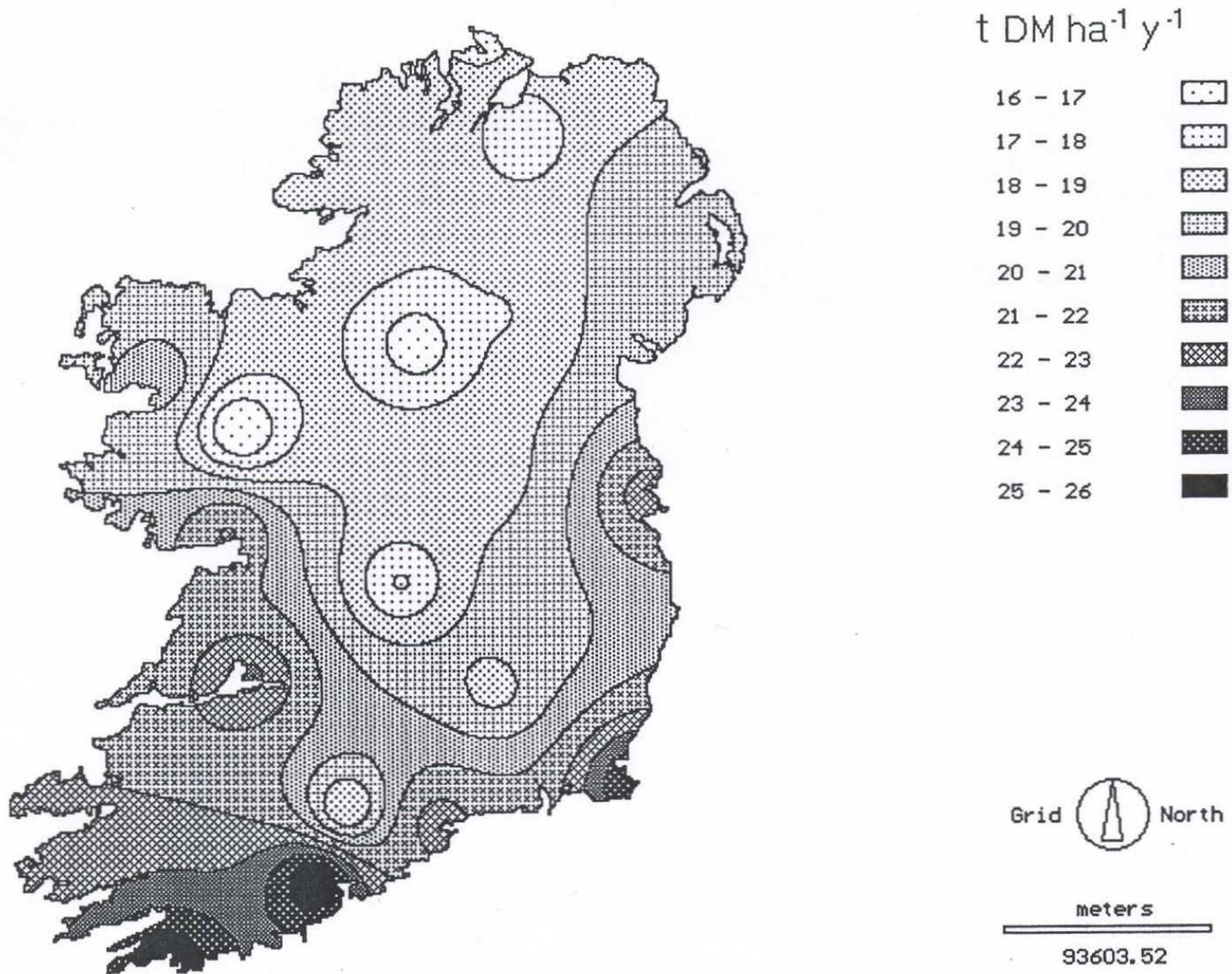
Challenges with Miscanthus

- **Significant labor is required to mechanically break up rhizomes into small fragments suitable for planting.**
- **Mechanized planting methods are under development.**

Resources

- **European yield trials have been performed since the 1970s.**
- **Heaton et al. (2004 and 2008) report exhaustive comparisons of worldwide production economic data for MG and switchgrass.**

Potential productivity in Ireland

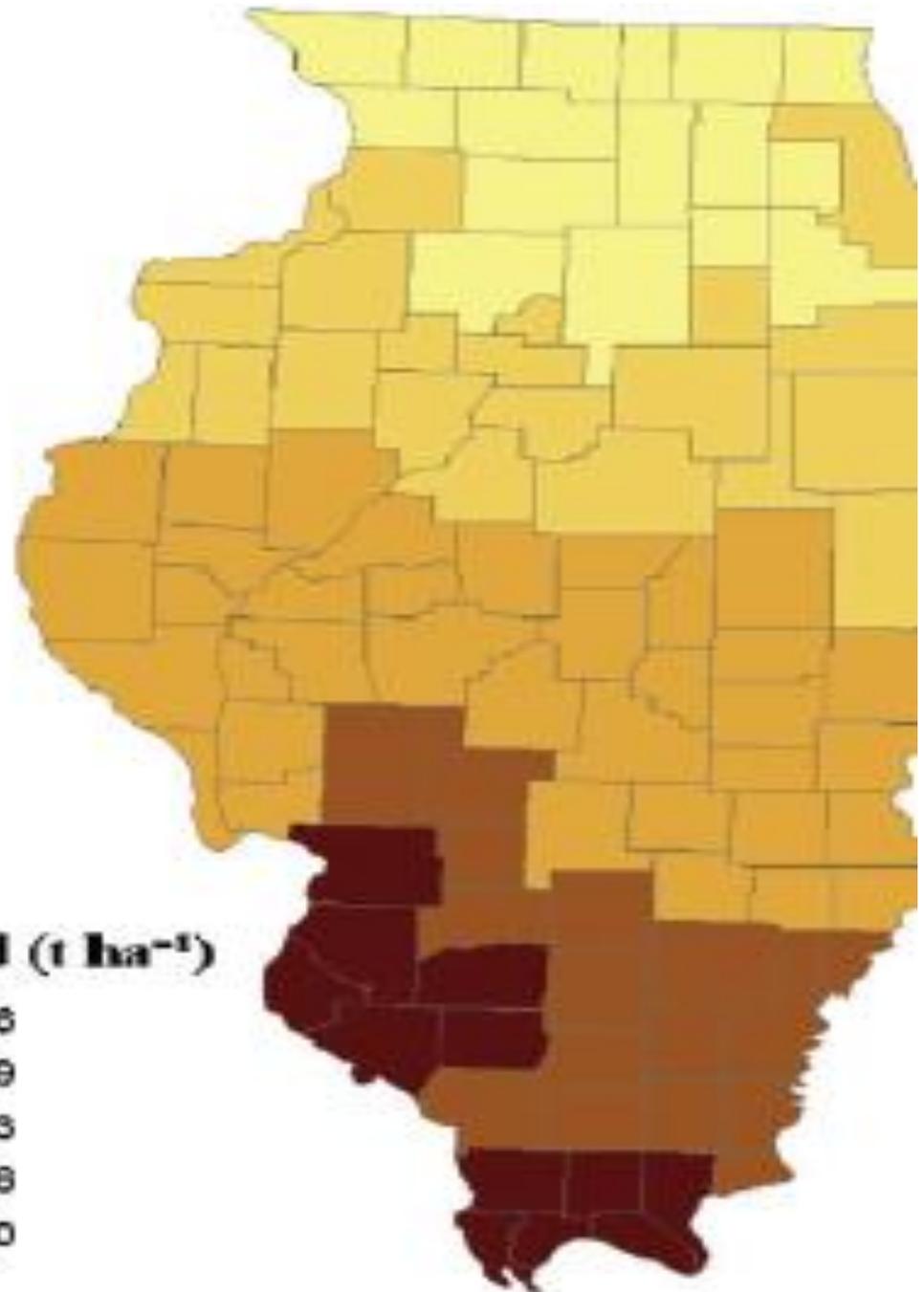


Source: Clifton-Brown et al. (2001)

Simulated yields in Illinois

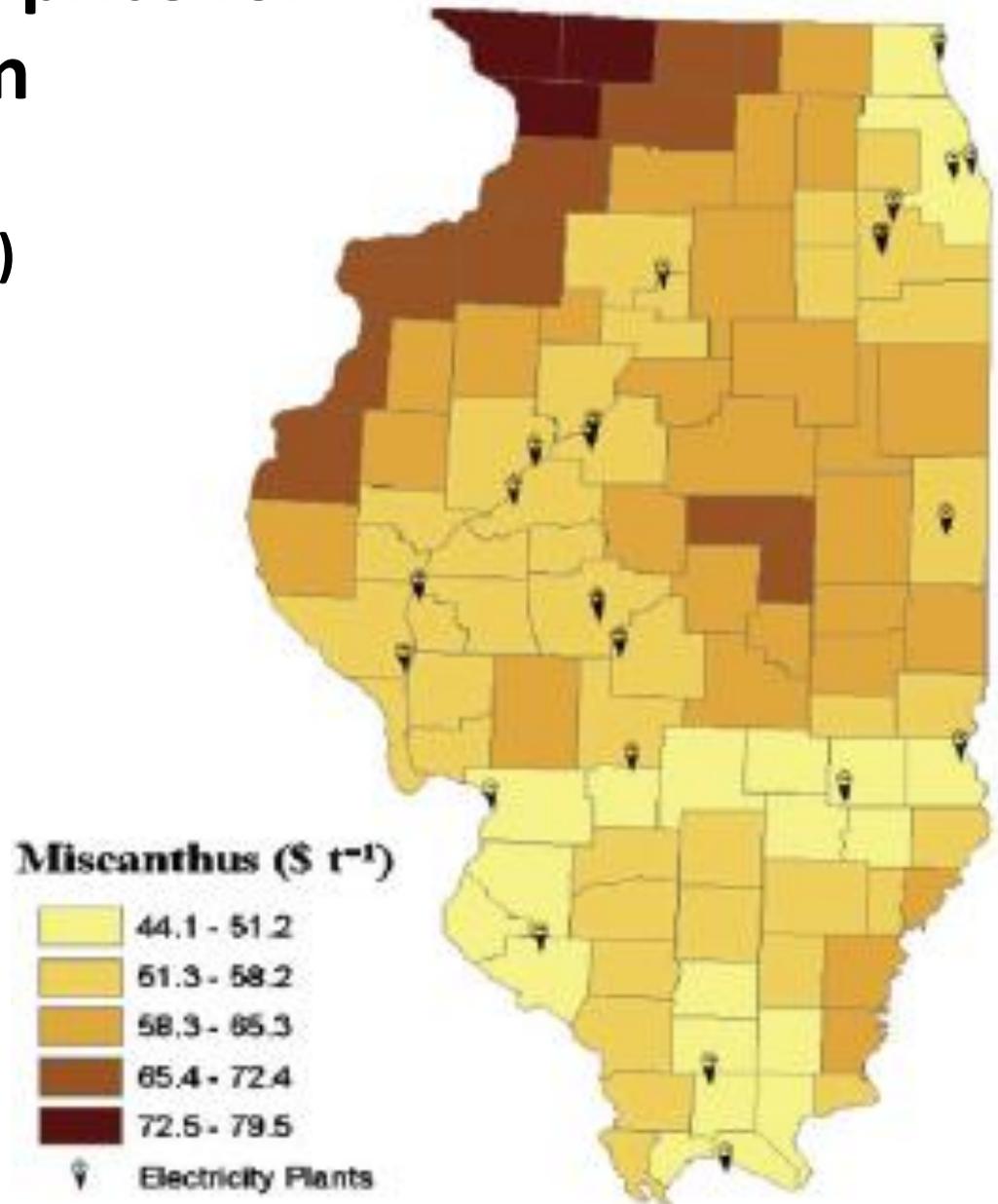
Source: Khanna et al. (2008)

Miscanthus Yield ($t\ ha^{-1}$)

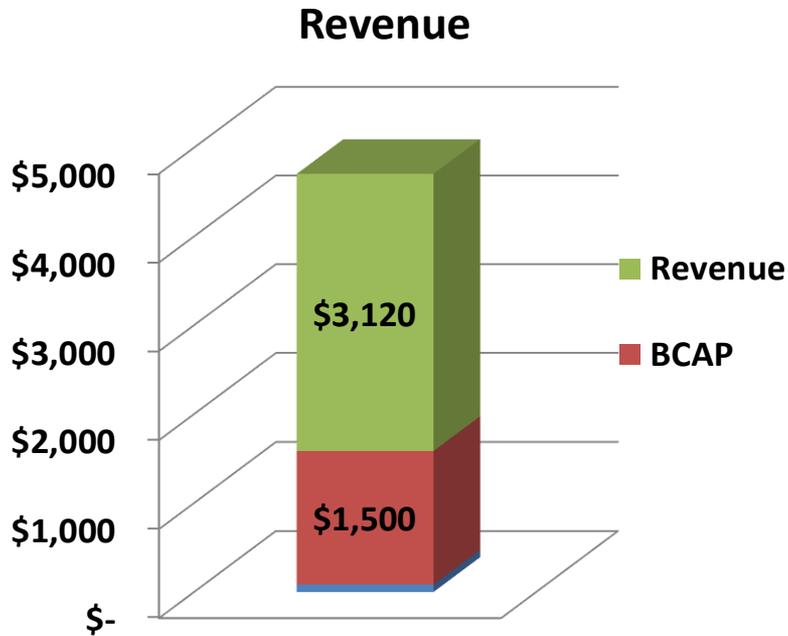


Breakeven delivered price for electricity generation

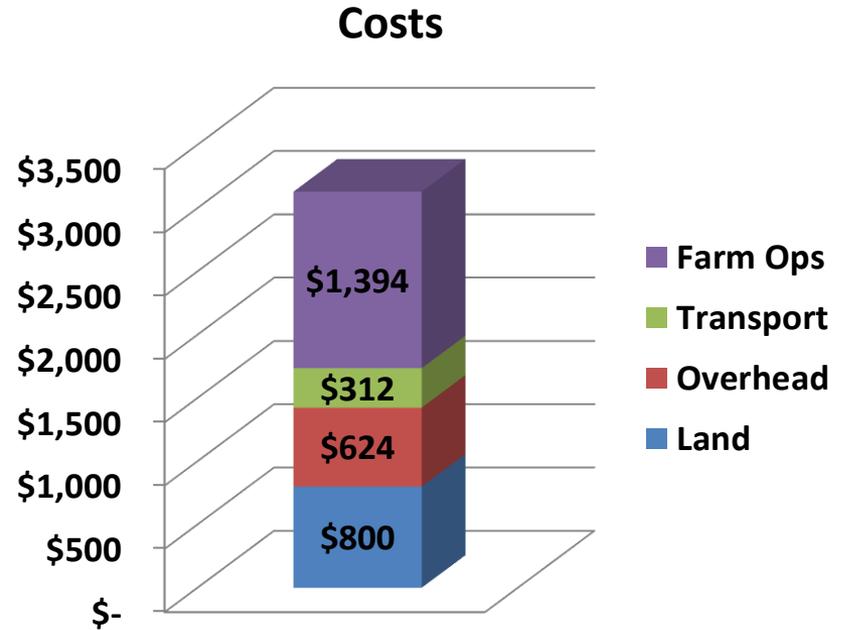
Source: Khanna et al. (2008)



Estimated 4 Year Revenue and Costs per acre (www.repreverenewables.com)



Total est. revenue = \$4,620



Total est. cost = \$ 3,130

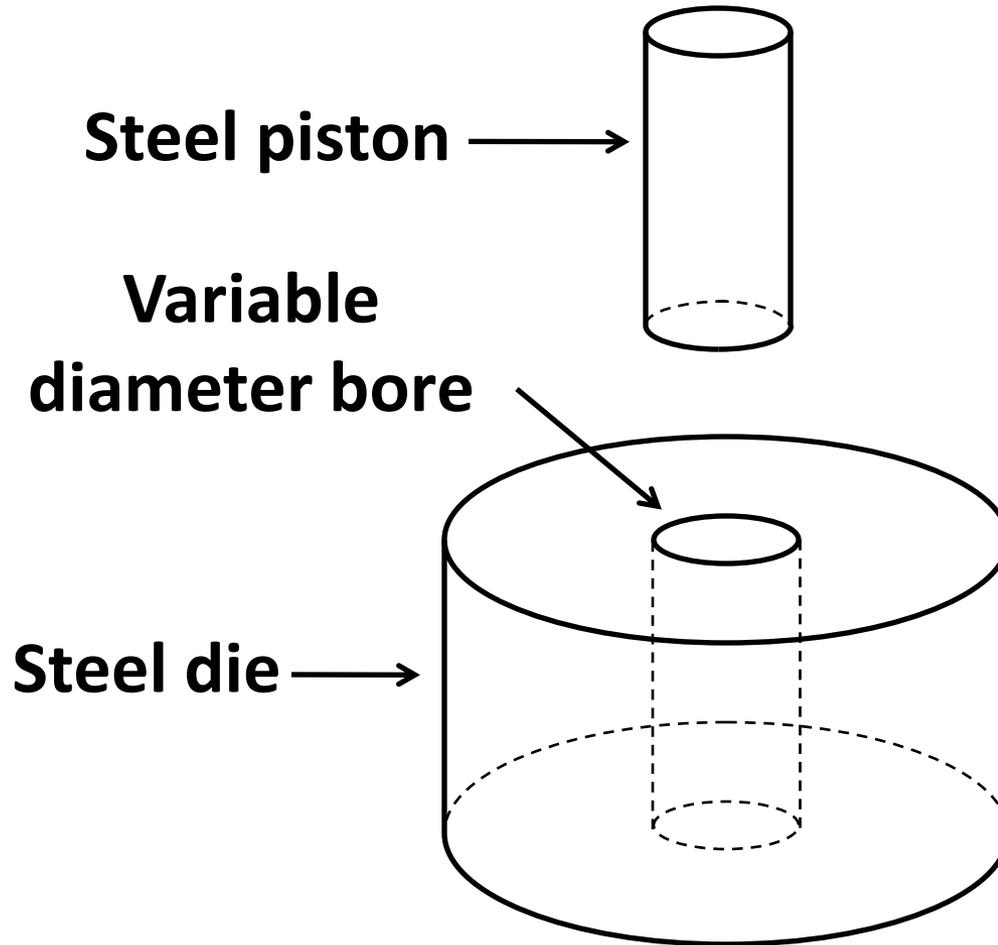




Lab tests optimize pellet & briquette fabrication

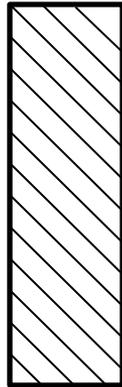
- Temperature**
- Pressure**
- Composition**
- Particle Size**
- Binder chemistry**
- Moisture**

Single Pellet Die

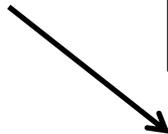


Section View

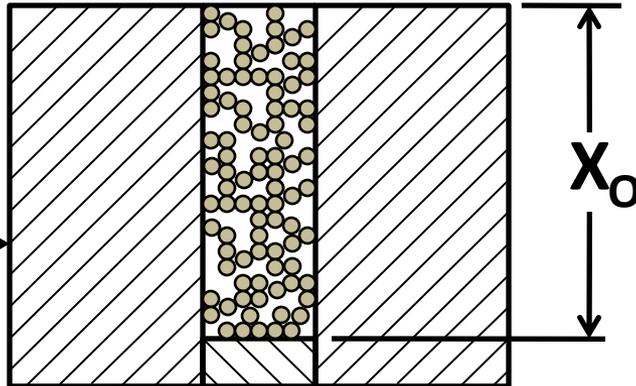
Piston



Loose fill powder

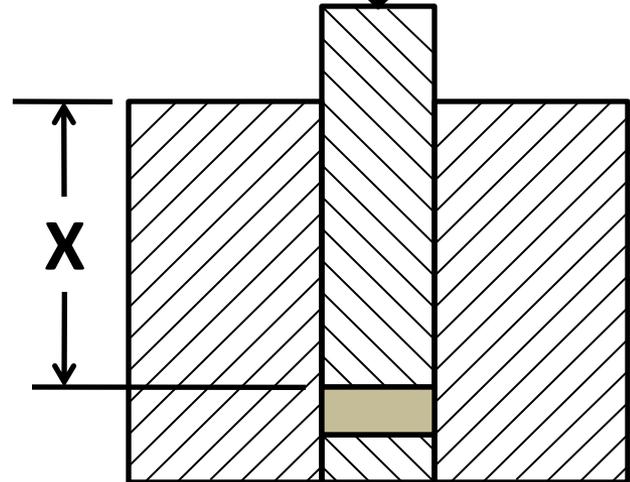


Cylindrical die



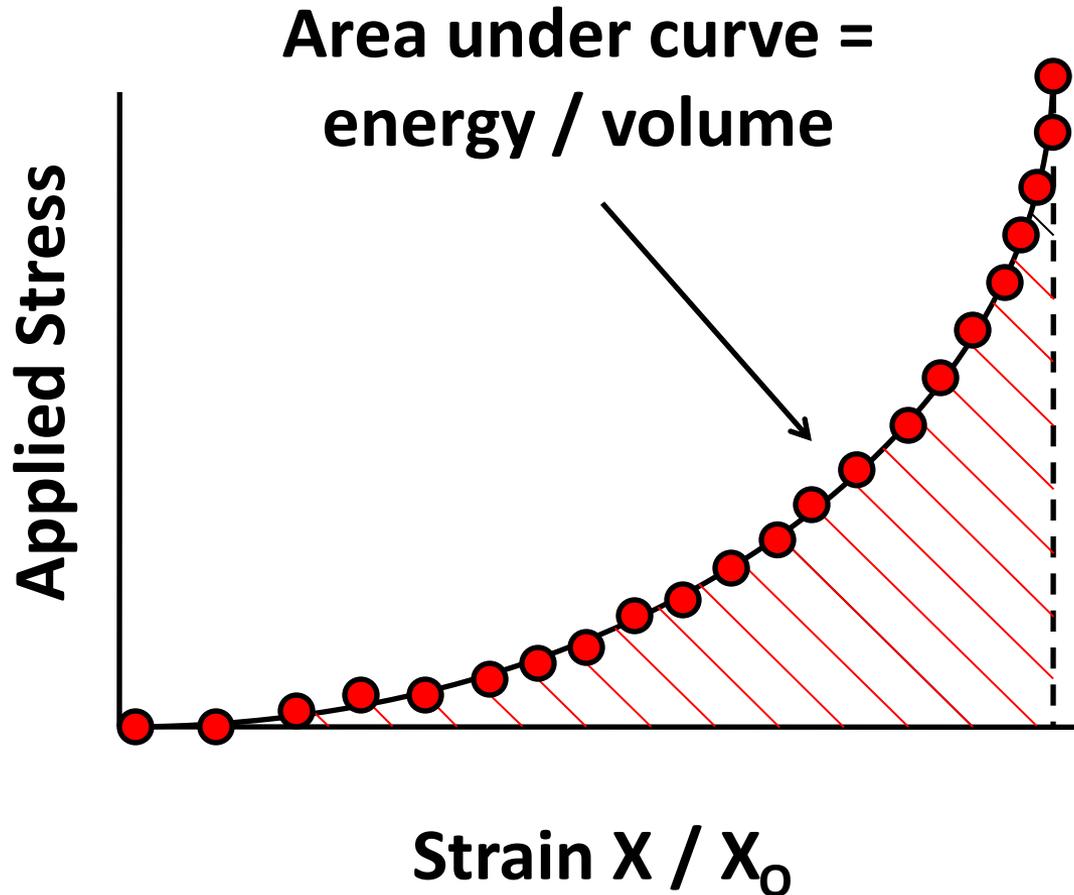
Before

Applied load



After

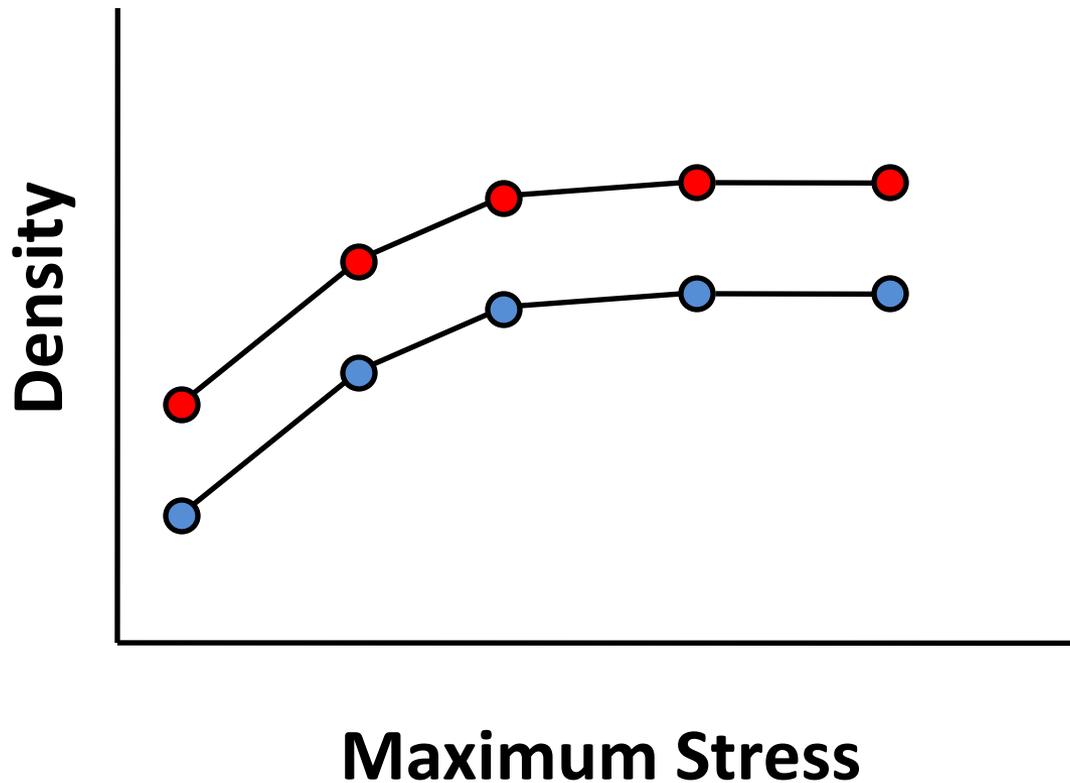
Single Pellet Fabrication



How to reduce area?

- T_g, T_{melt}
- Binder chemistry
- Particle size
- Moisture

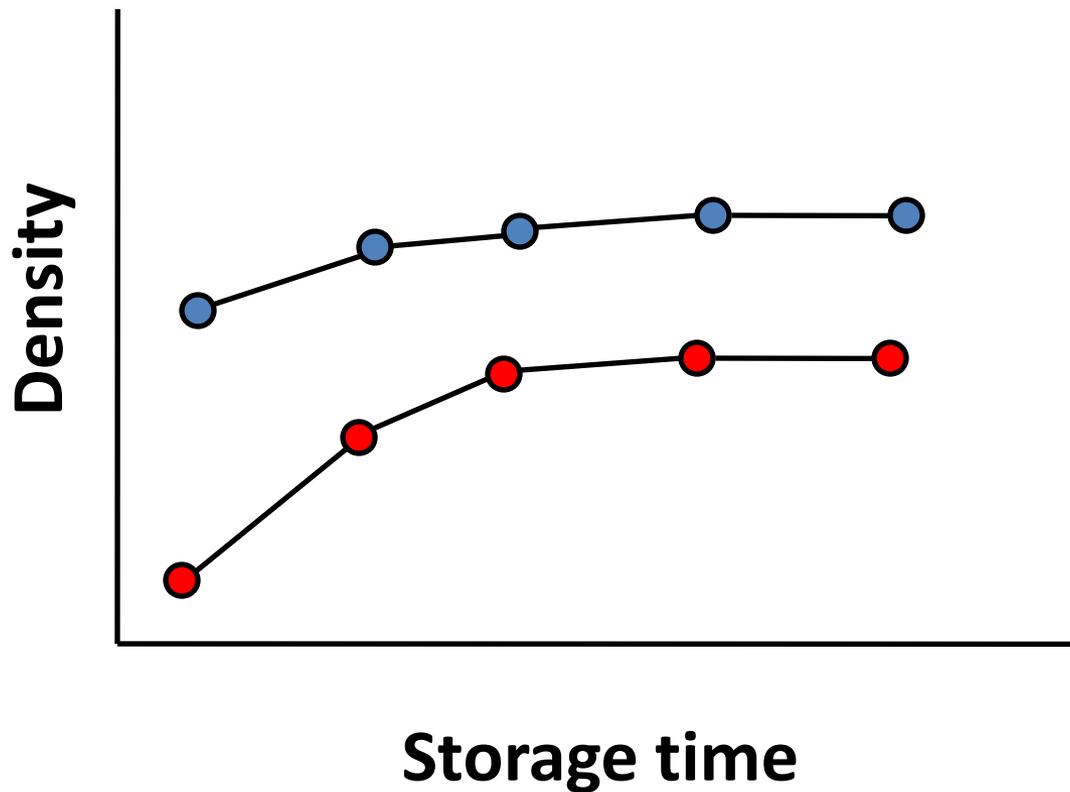
Compressibility Measurements



Critical variables:

- T_g , T_{melt}
- Binder chemistry
- Particle size
- Moisture

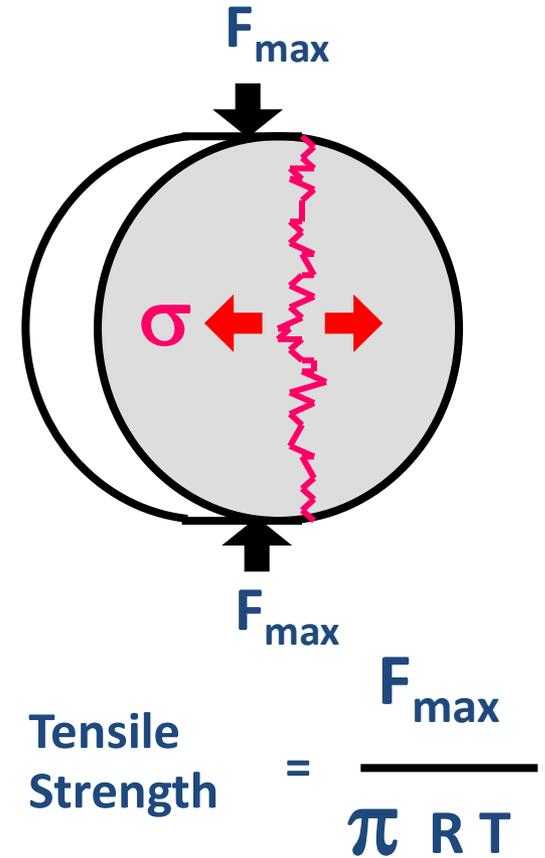
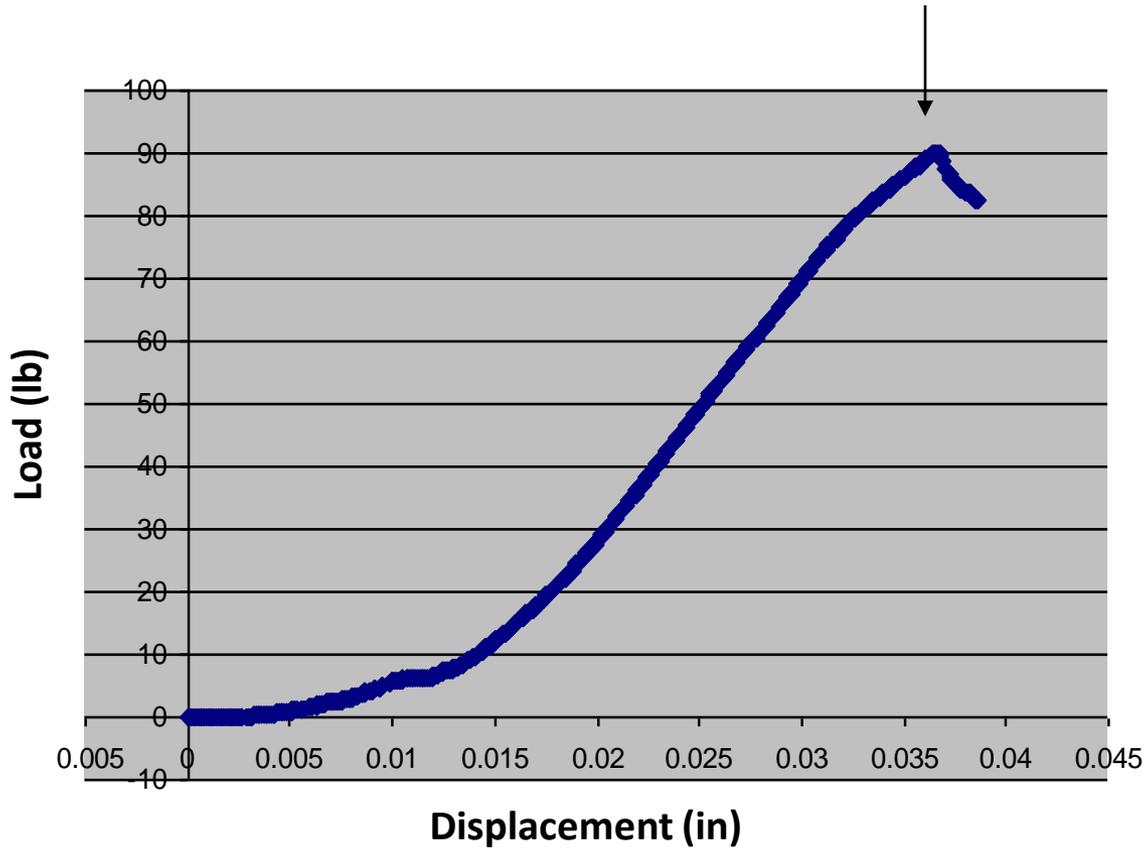
Storage Stability



Critical variables:

- T_g , T_{melt}
- Binder chemistry
- Particle size
- Moisture
- Max pressure
- Dwell time

F_{max} = maximum load

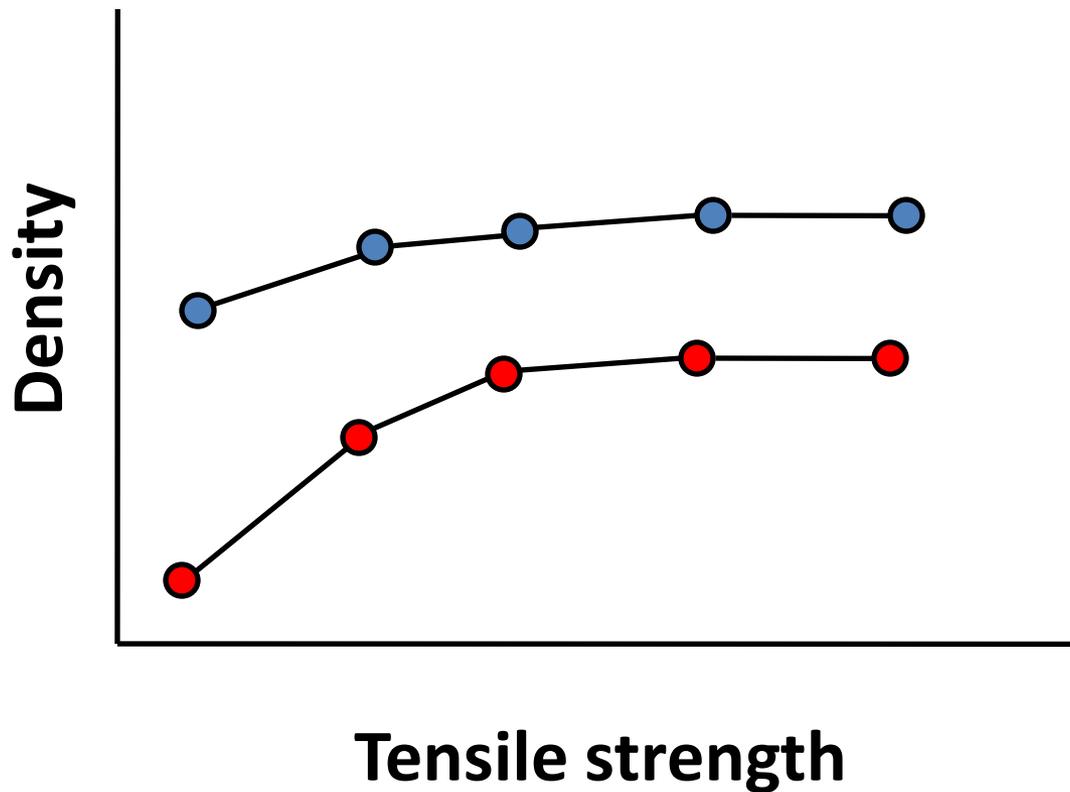


R = radius

T = thickness

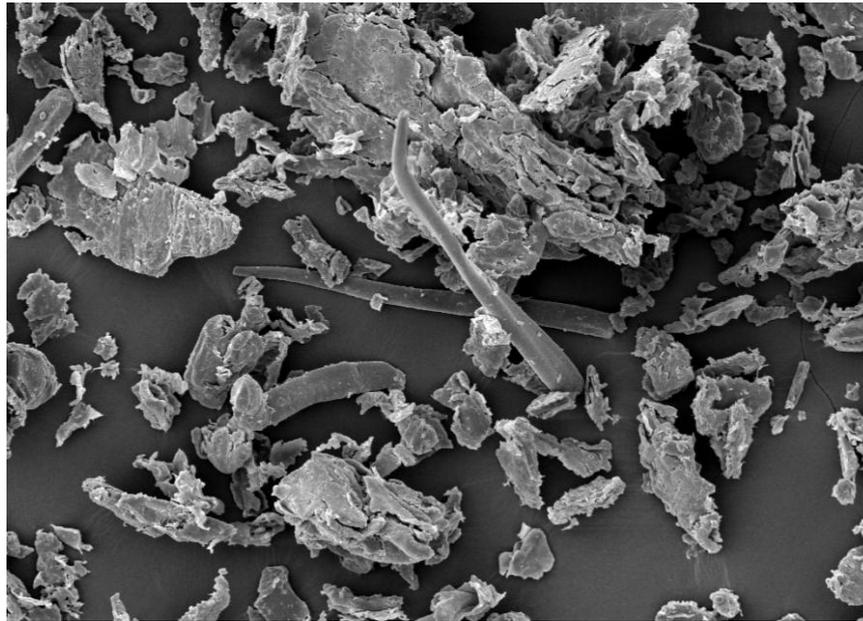
Diametric compression of a pellet made of soy meal + corncob powder.

Pellet Fracture

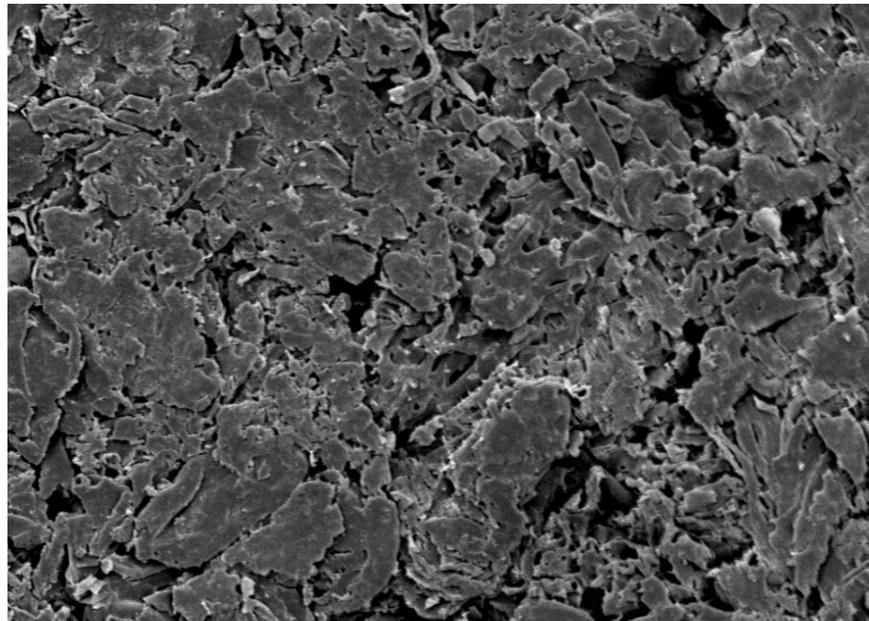


Critical variables:

- T_g , T_{melt}
- Binder chemistry
- Particle size
- Moisture
- Max pressure
- Dwell time



300µm



300µm



