Fuels: Waste, Crops, Production, Harvest, Processing

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Outline

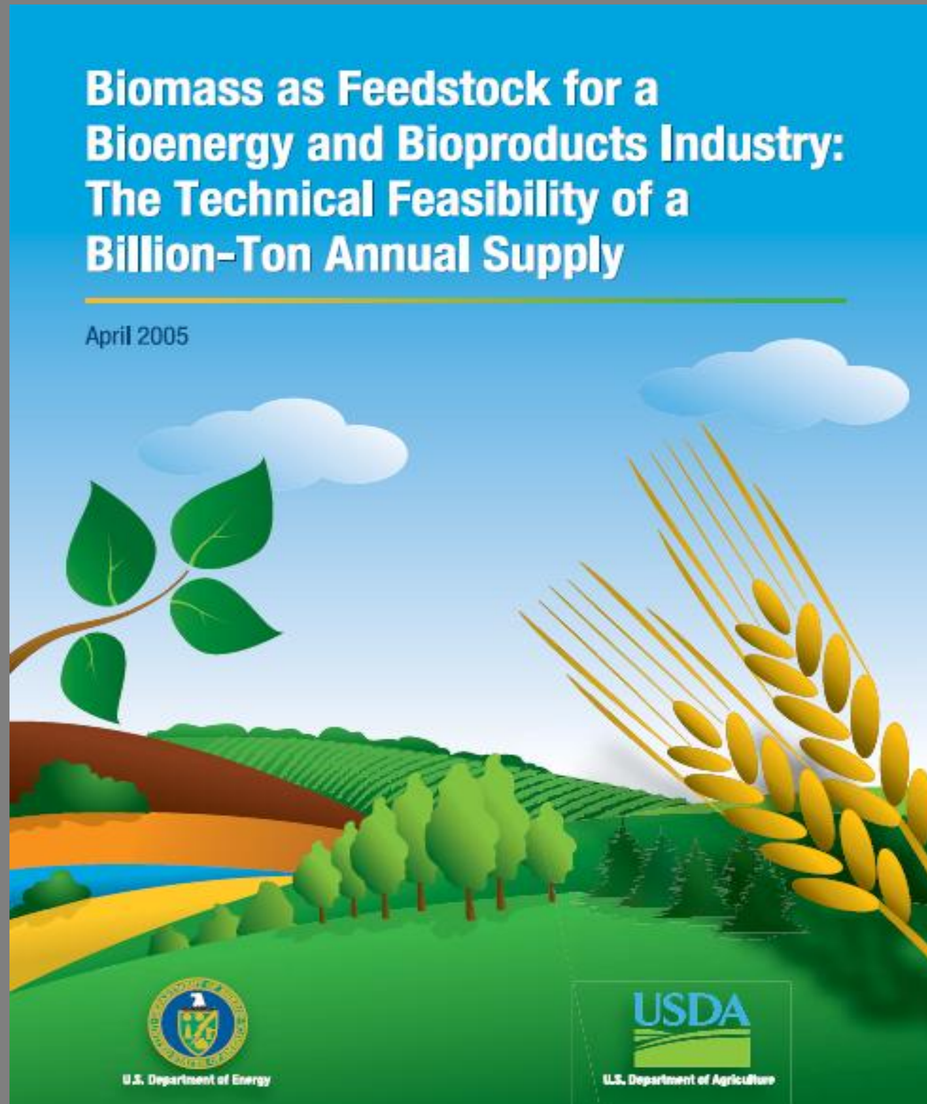
1. Biomass production for bioenergy:
   - USDA / DOE Congressional study
   - Science Magazine
2. C4 perennials and the European approach.
3. Pellets and briquettes: fabrication and durability tests

- 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

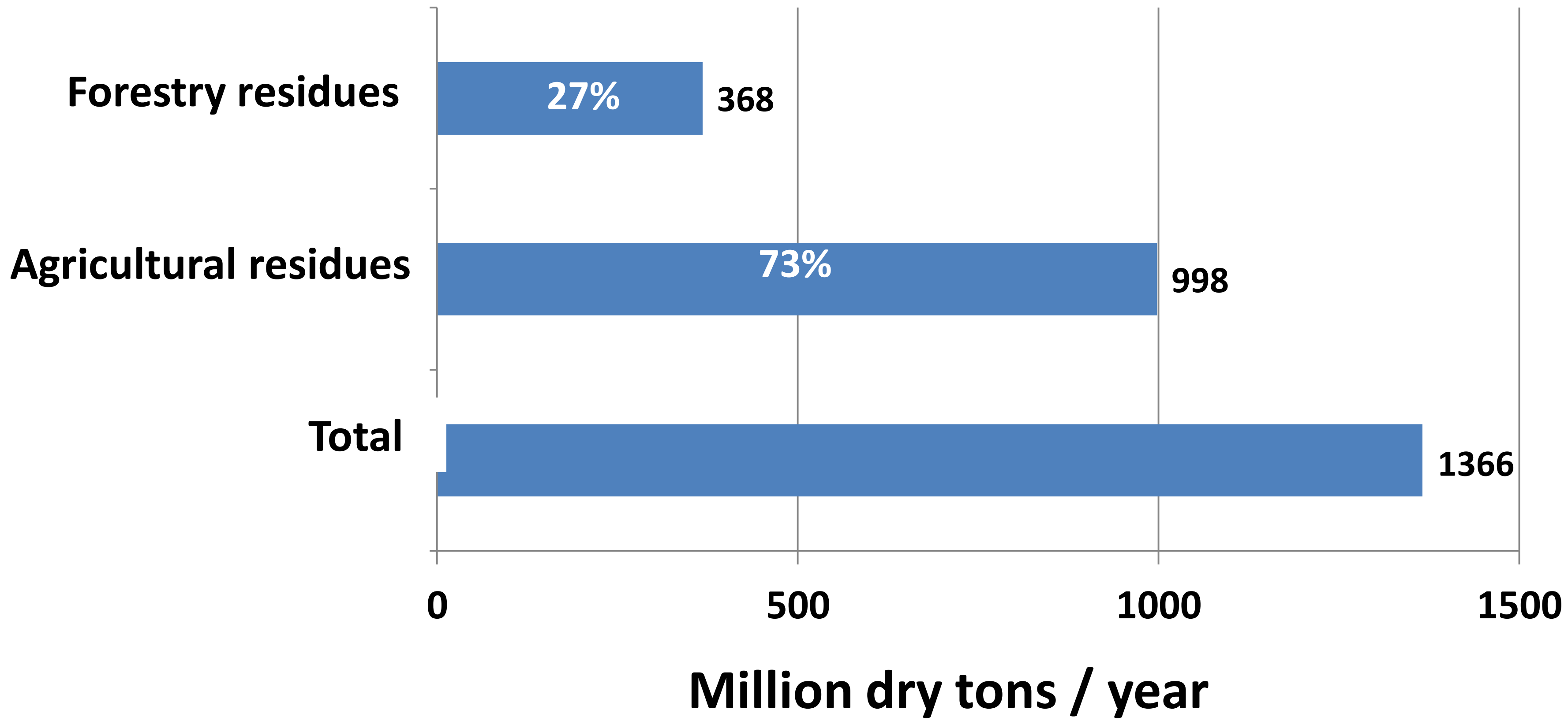
….. all from biomass by the year 2030.

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



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

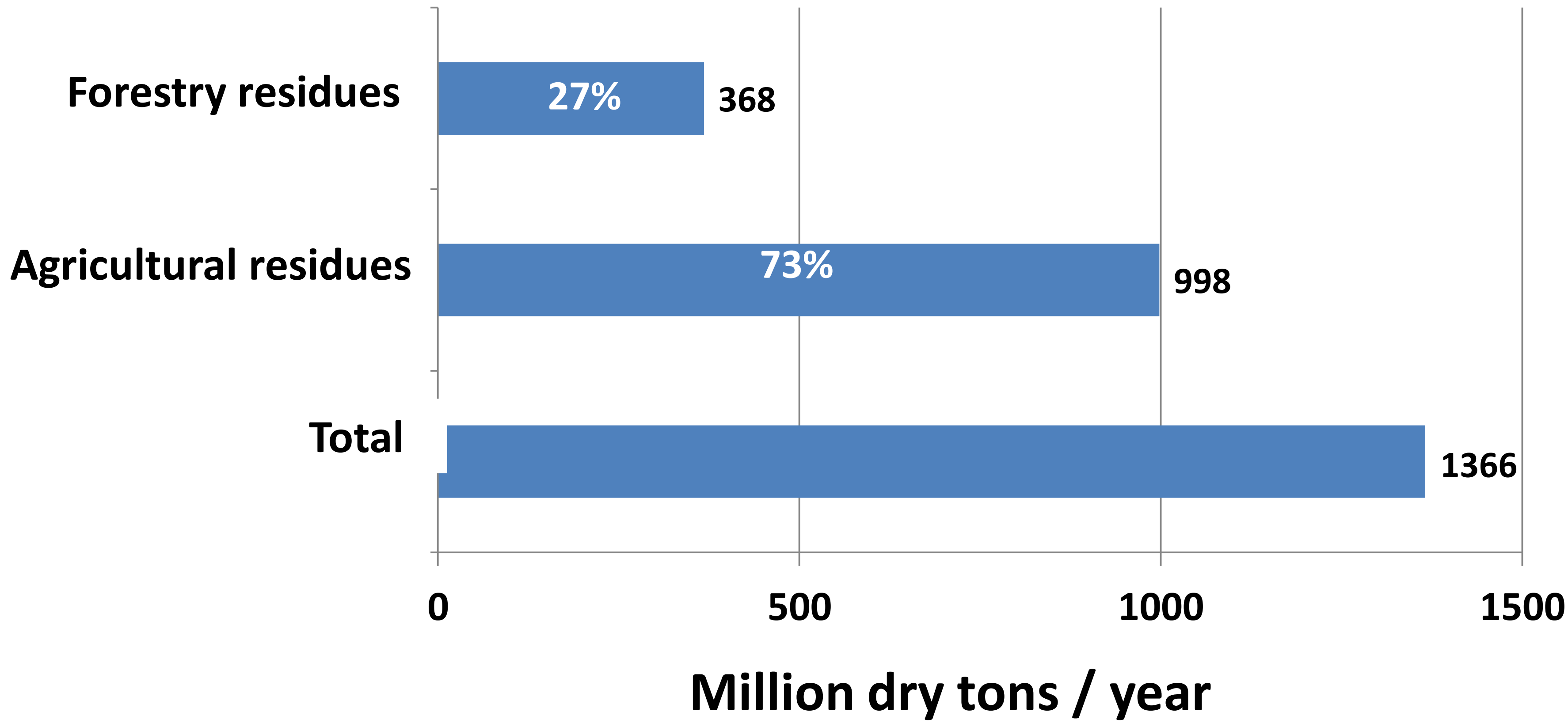
- **Perennial crops (a combination of grasses and woody crops) would be grown on 55 million acres of cropland, idle cropland, and cropland pasture.**

Assumptions

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

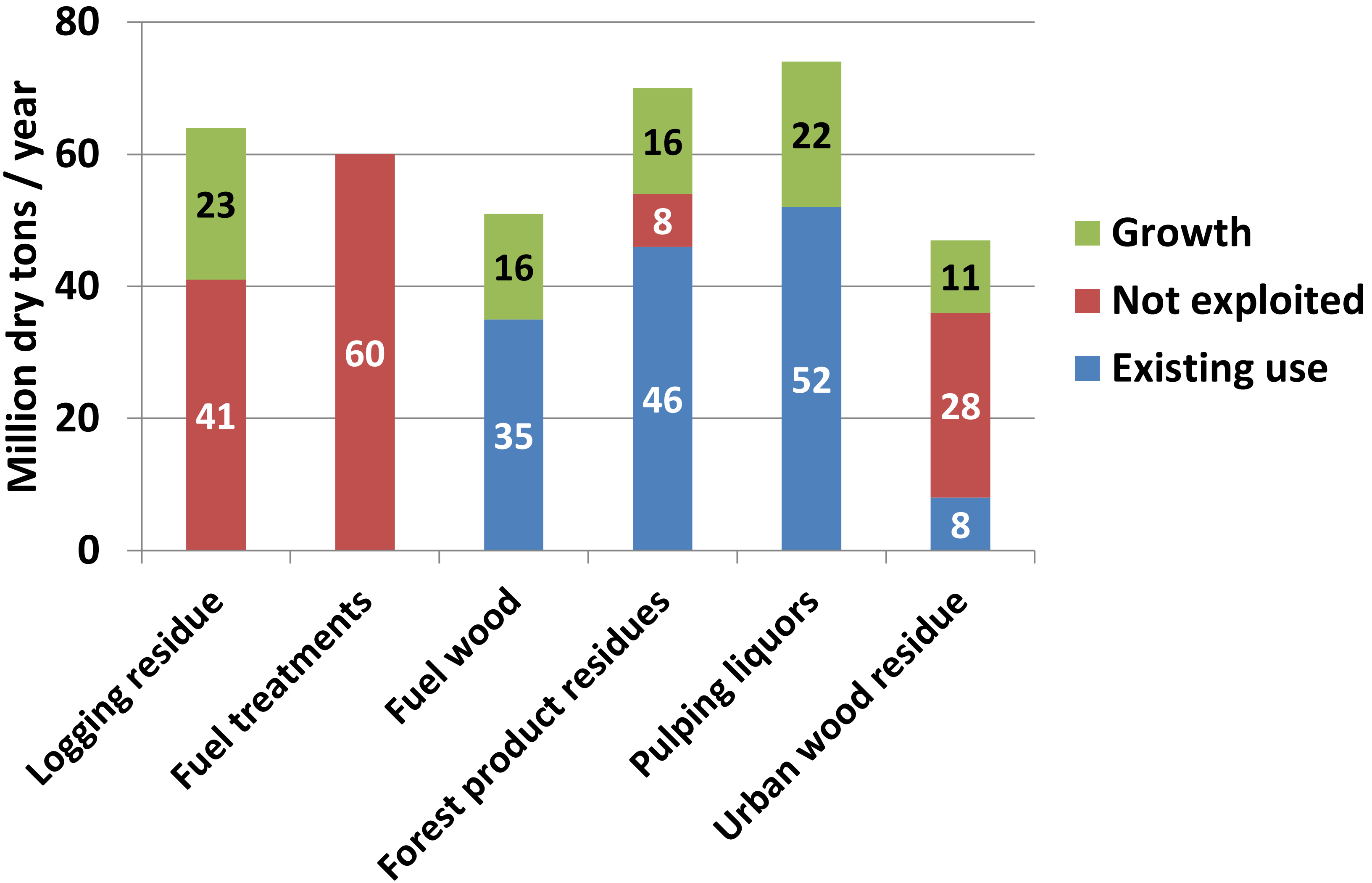
Biogas-fueled train in Sweden.

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.

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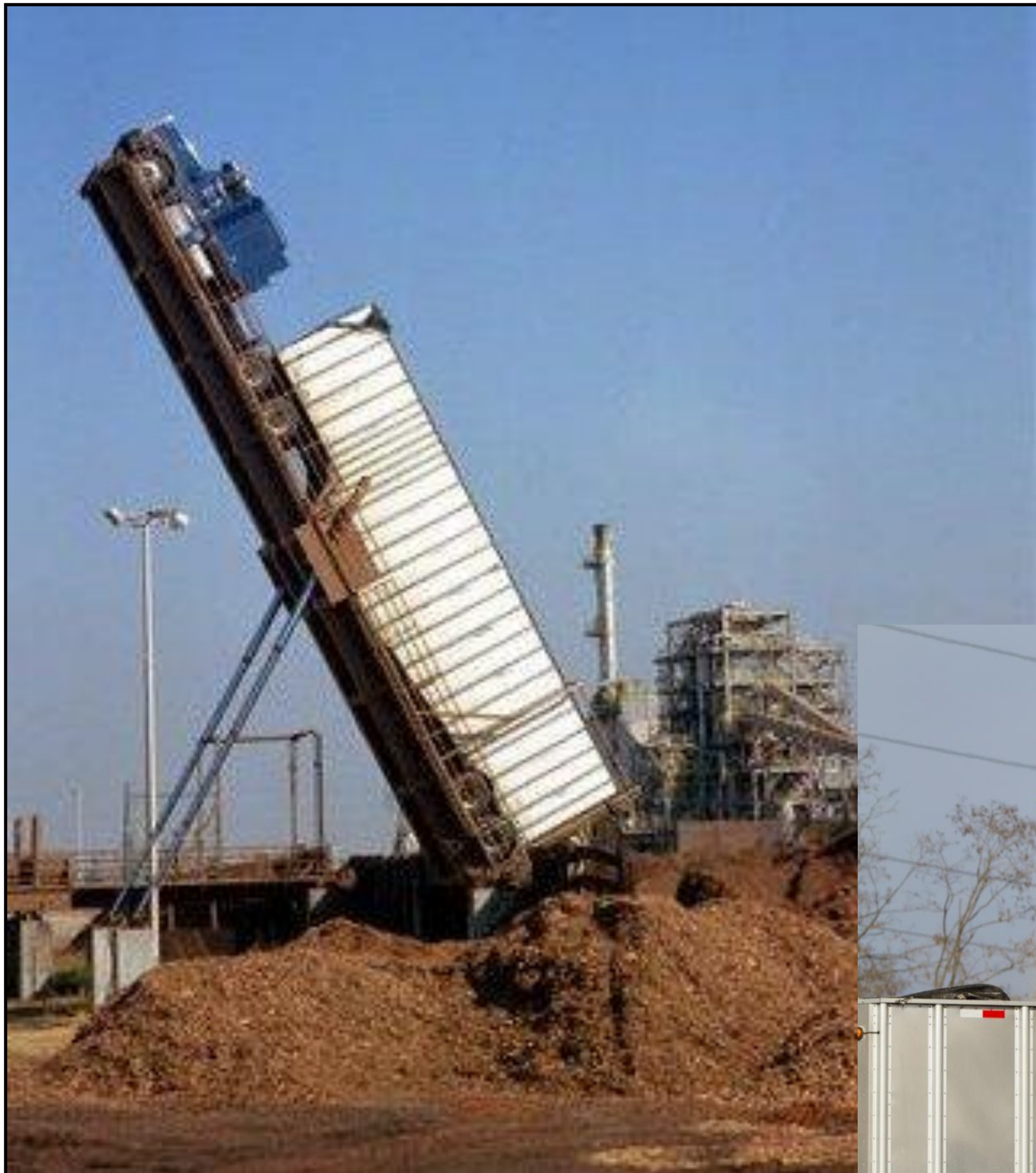

OU Chipper #2


ENVIRONMENTAL
Wood Solutions
Orion, MI
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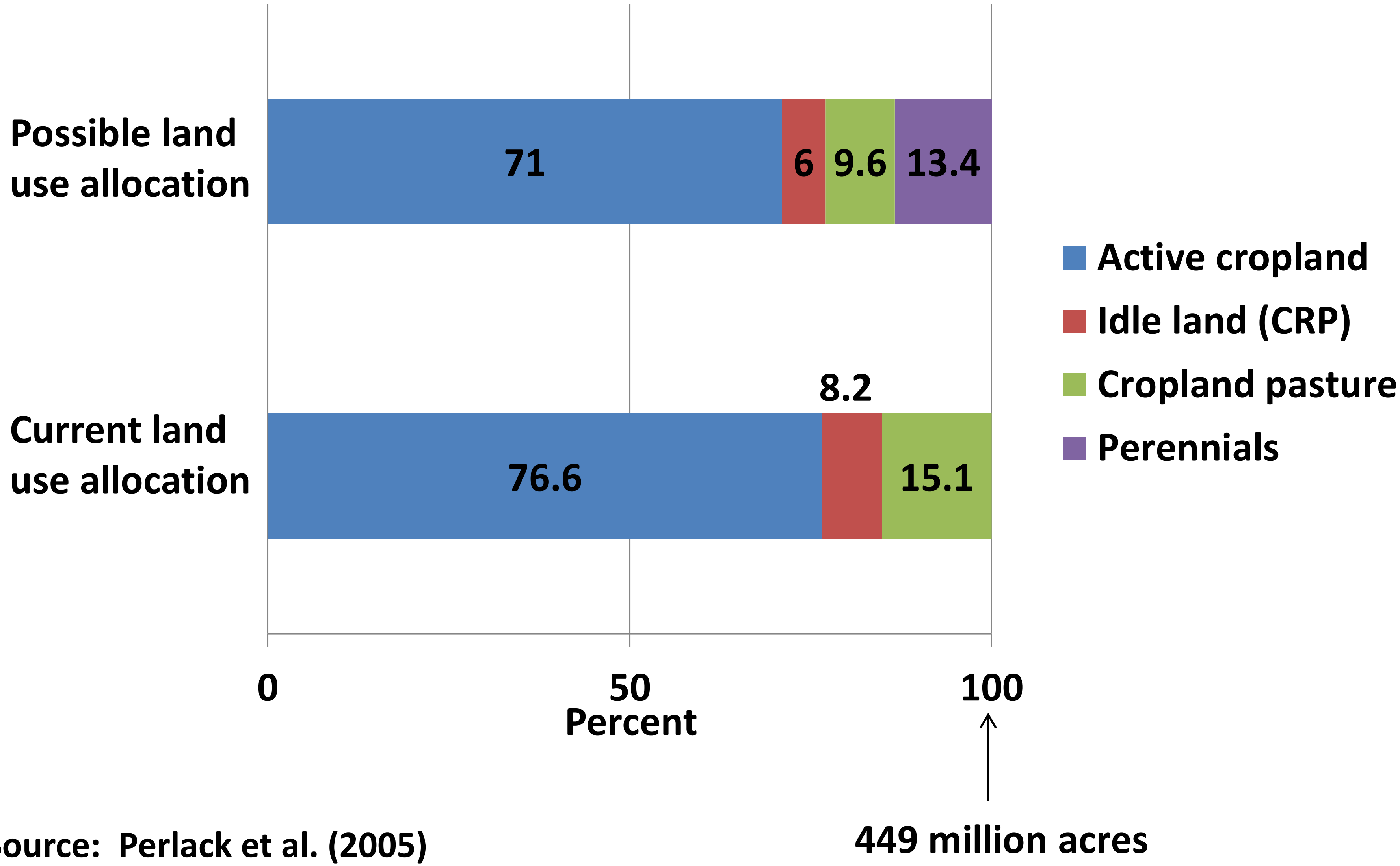
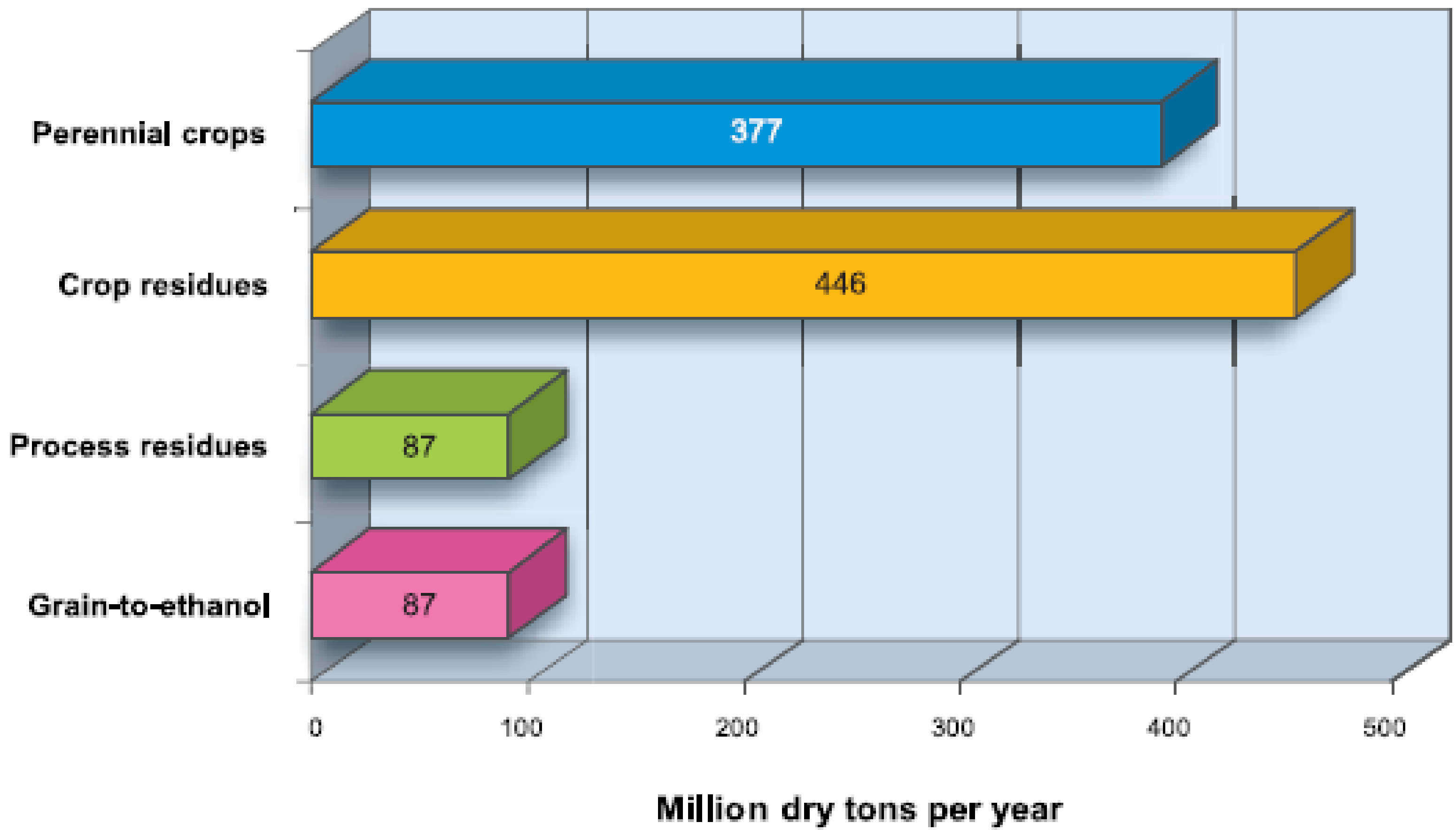
Potential allocation of ag land



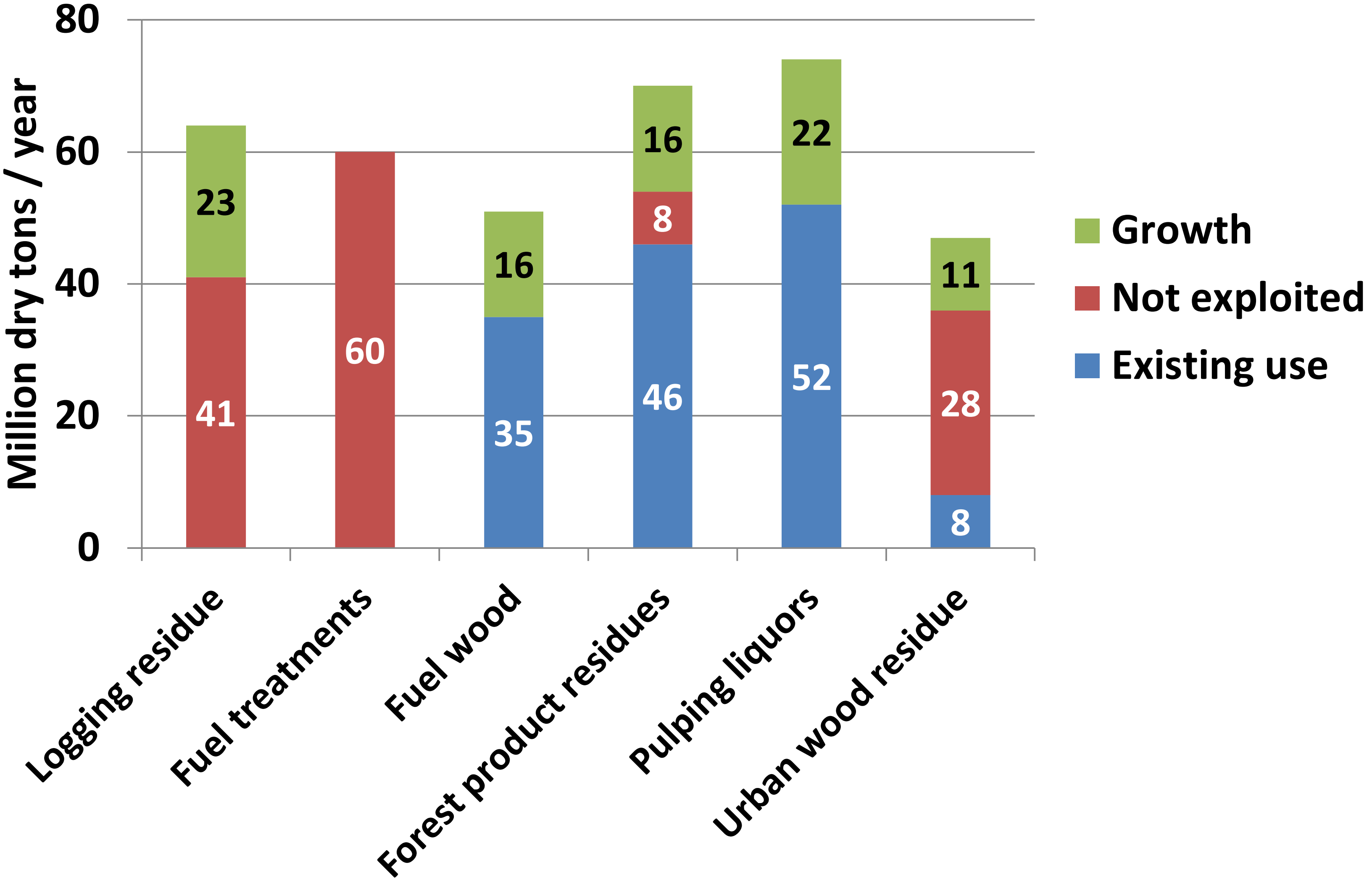
Source: Perlack et al. (2005)

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

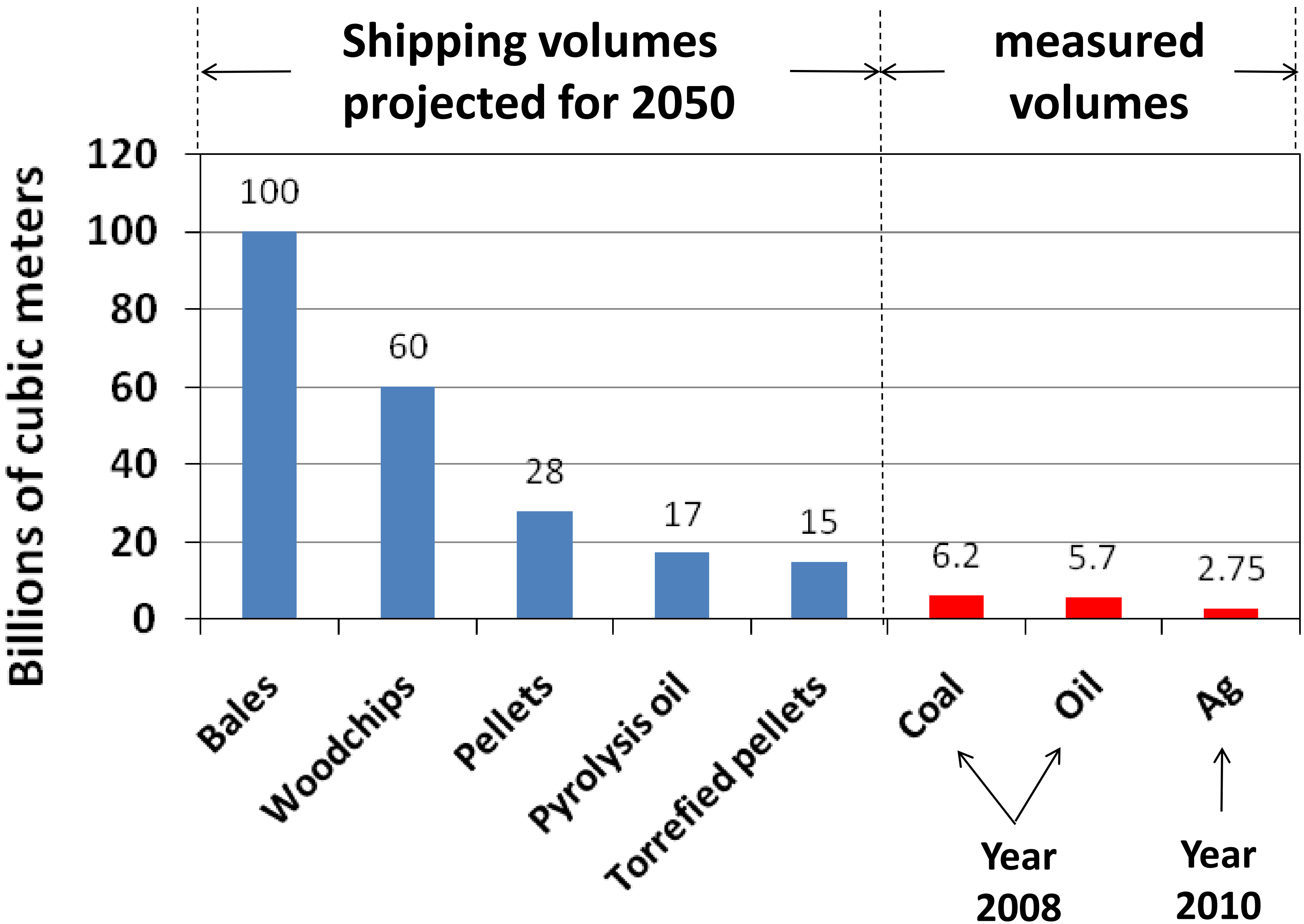
- 1 kg of oil holds 3 times the energy as a kg of biomass.
- The picture looks worse when energy density is expressed per unit volume.
- Main implication: massive scale-up of the biofuel processing and transportation infrastructure.

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 Aug 2010, pp. 793-795.



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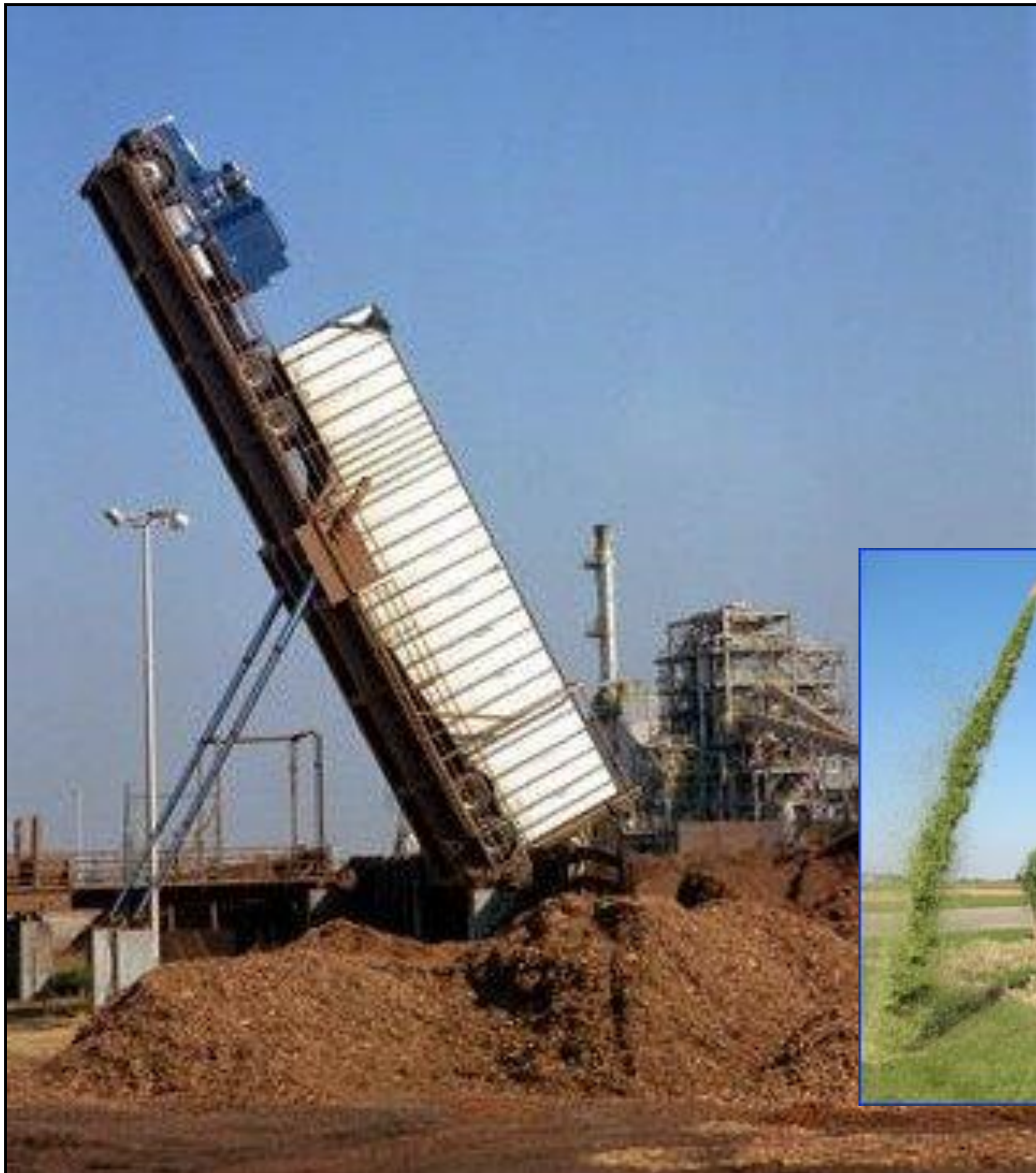

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2 prime candidates

Switchgrass

(Panicum virgatum)

Miscanthus x giganteous

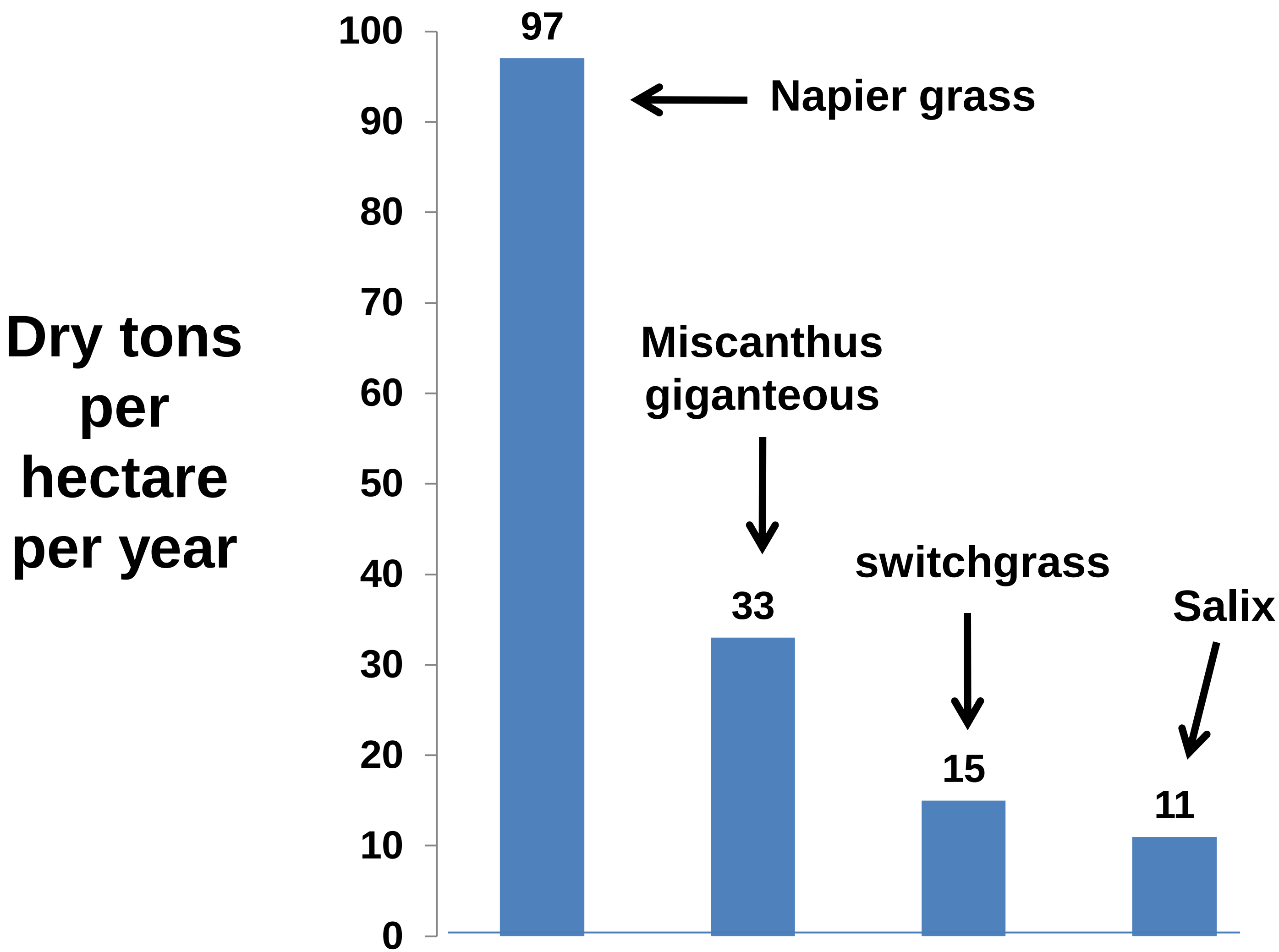
- **High efficiency of light, water, and nitrogen use.**
- **Reduced tillage and senescence add minerals to soil and protect against erosion.**
- **Low mineral content if harvested after senescence.**

Miscanthus rhizomes

Other benefits

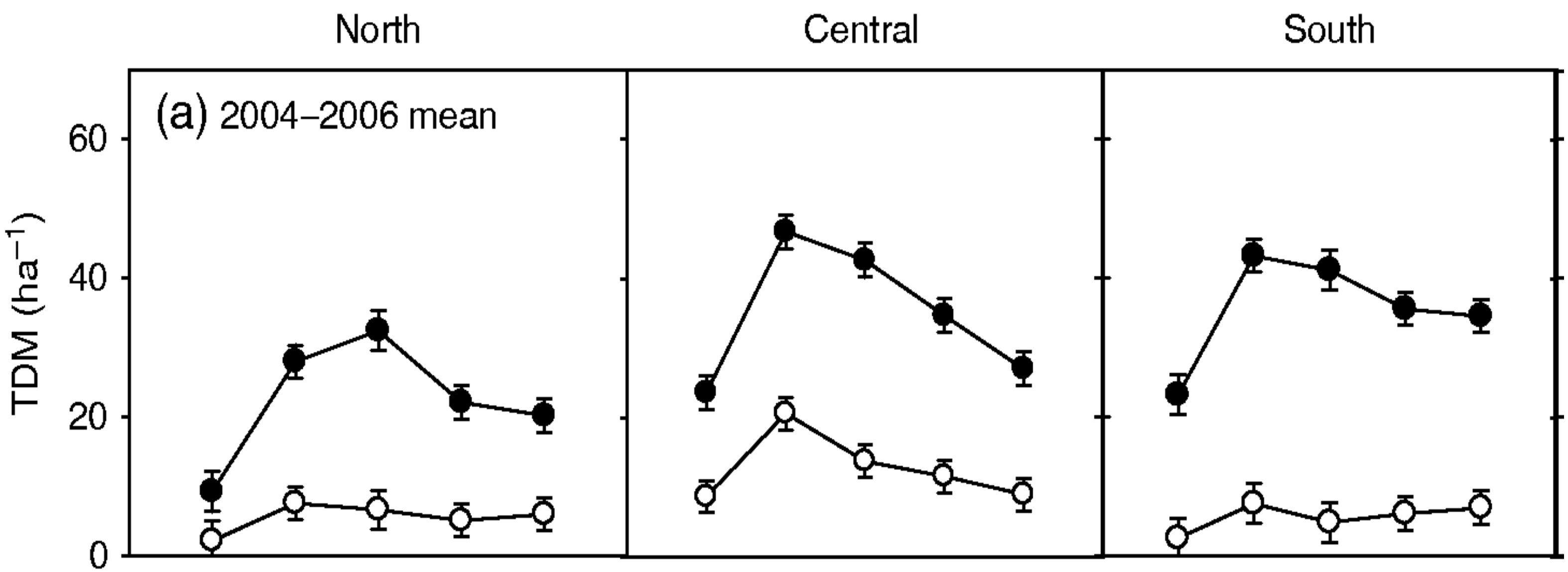
- Carbon sequestration in soil.
- Excellent cover for wildlife.
- One planting and related tillage – this reduces costs, fossil fuel use, soil erosion.
- Respond well to irrigation, fertilization – thus valuable for wastewater remediation.
- Grow well in marginal soils unsuitable for food crop production.

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**
o **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.

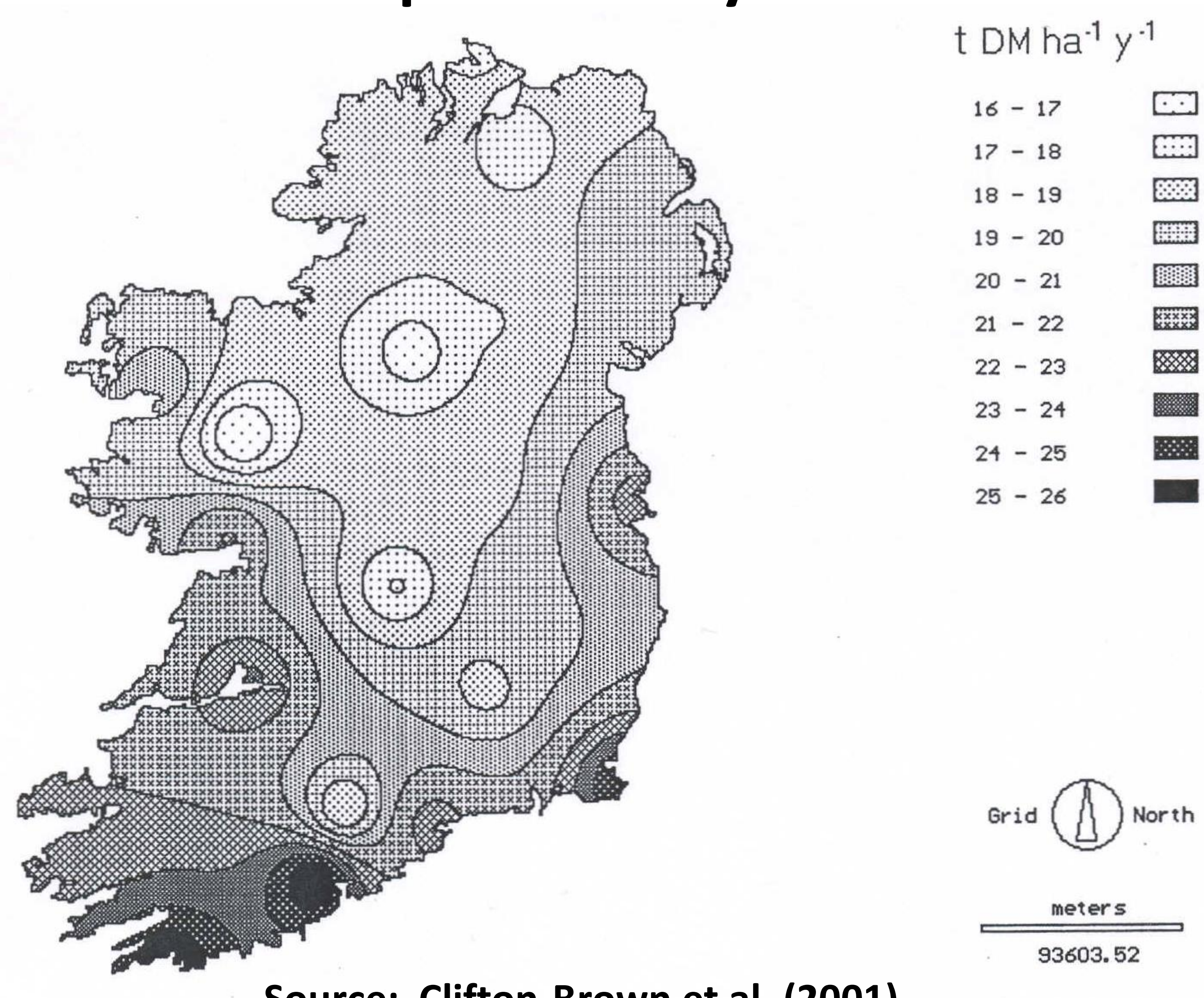
Challenges with Miscanthus

- 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.**

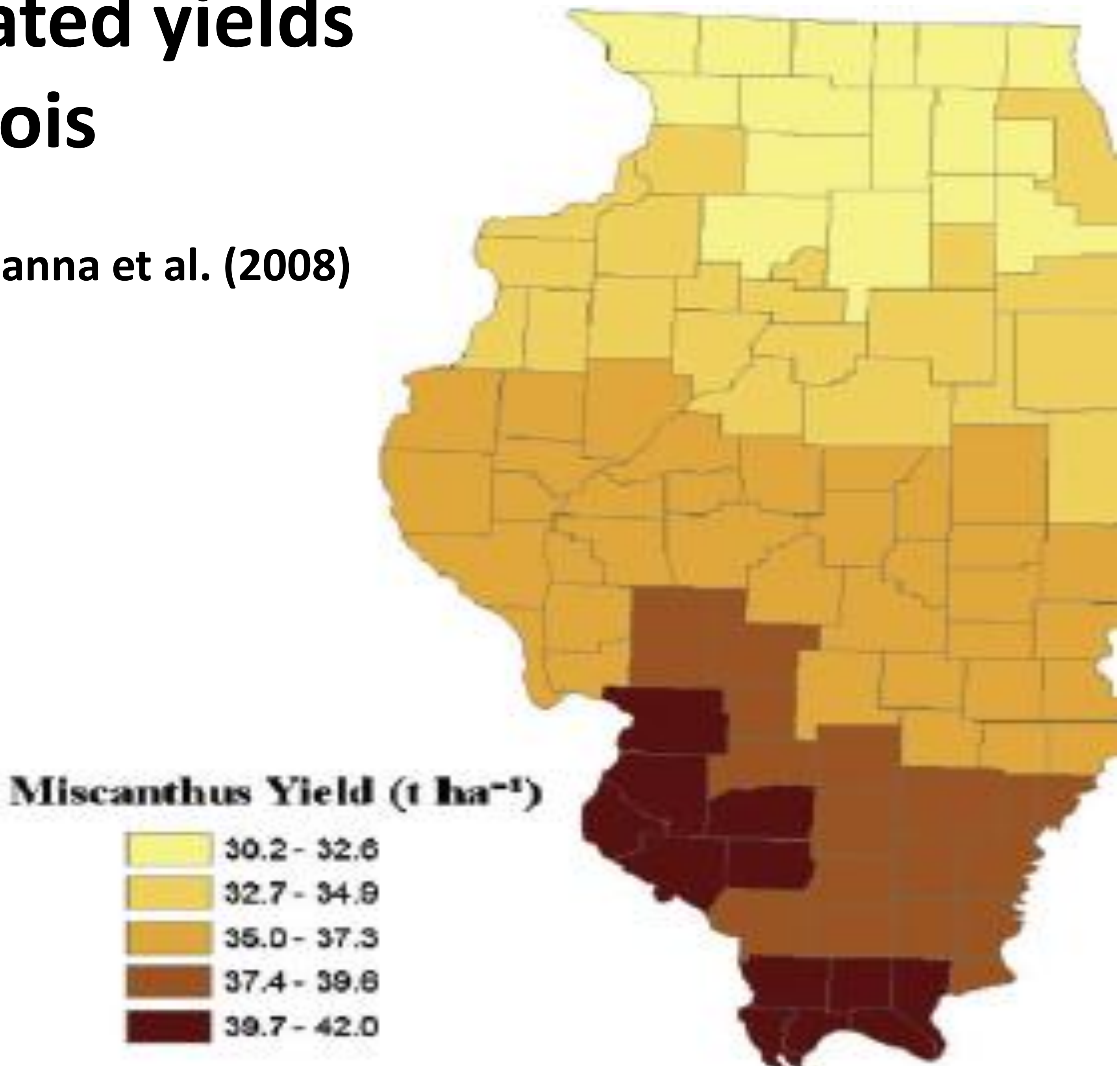
Potential productivity in Ireland



Source: Clifton-Brown et al. (2001)

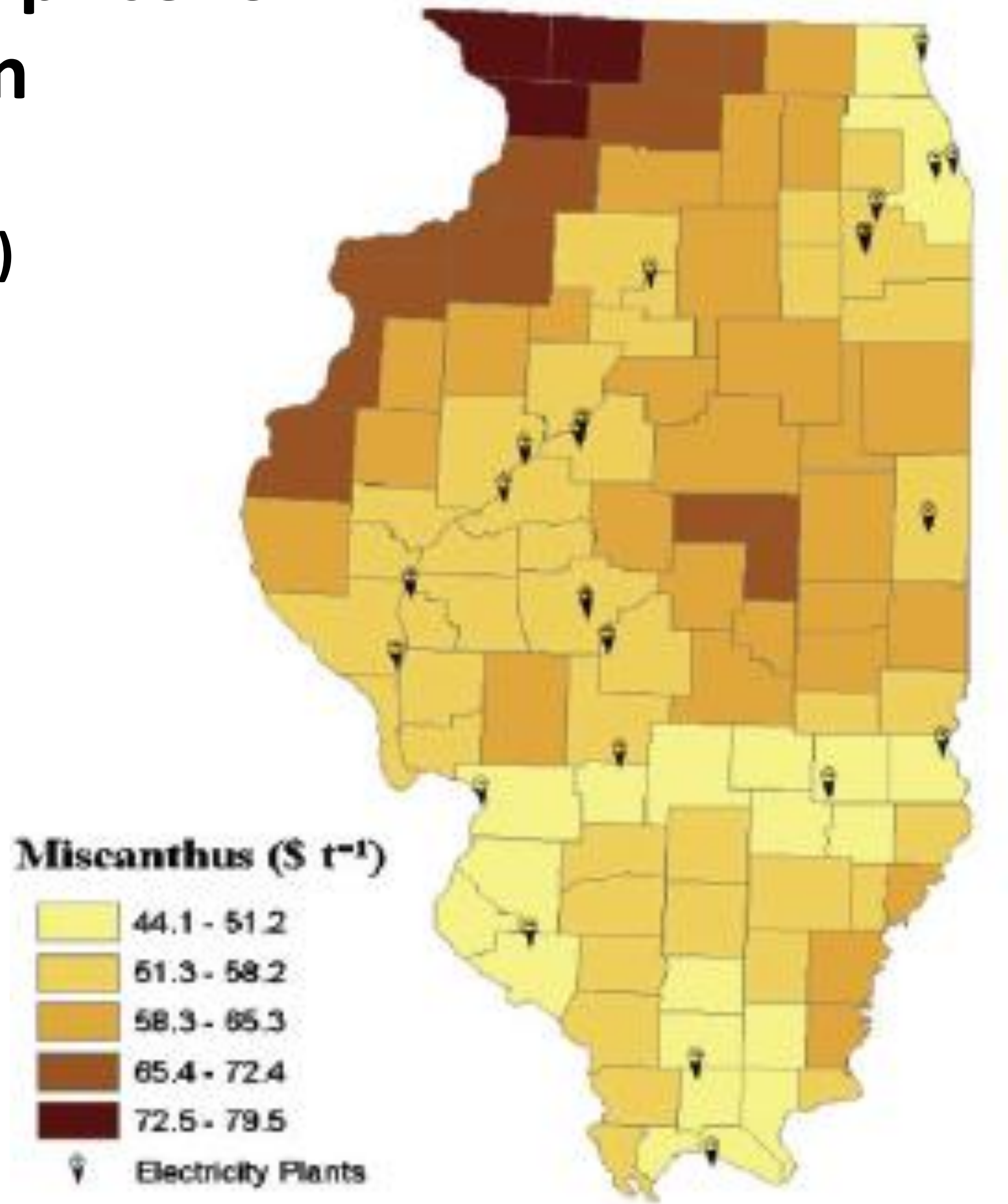
Simulated yields in Illinois

Source: Khanna et al. (2008)

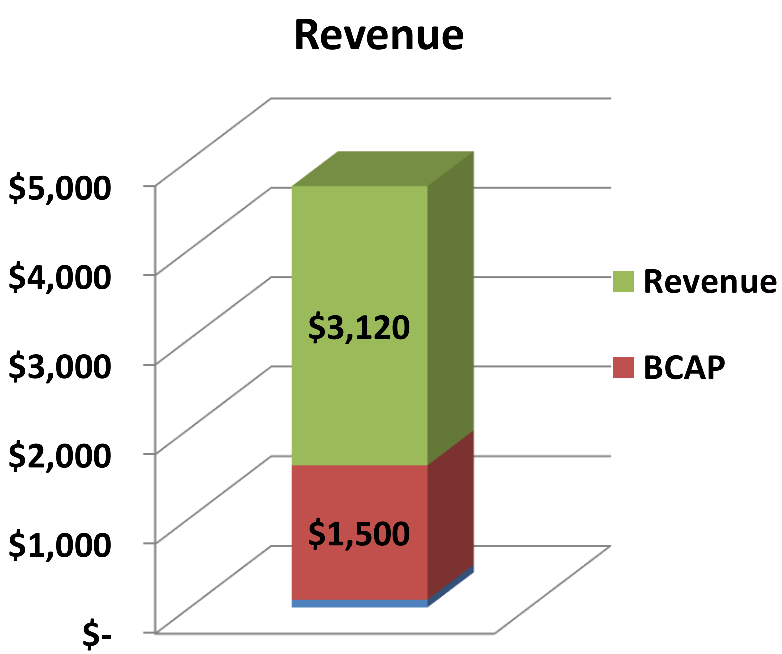


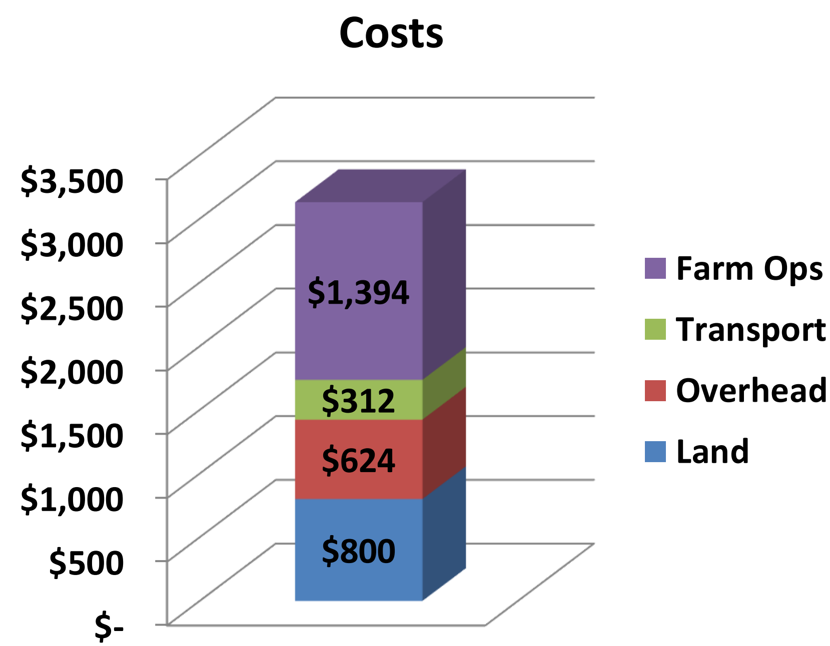
Breakeven delivered price for electricity generation

Source: Khanna et al. (2008)



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





Total est. revenue = $4,620

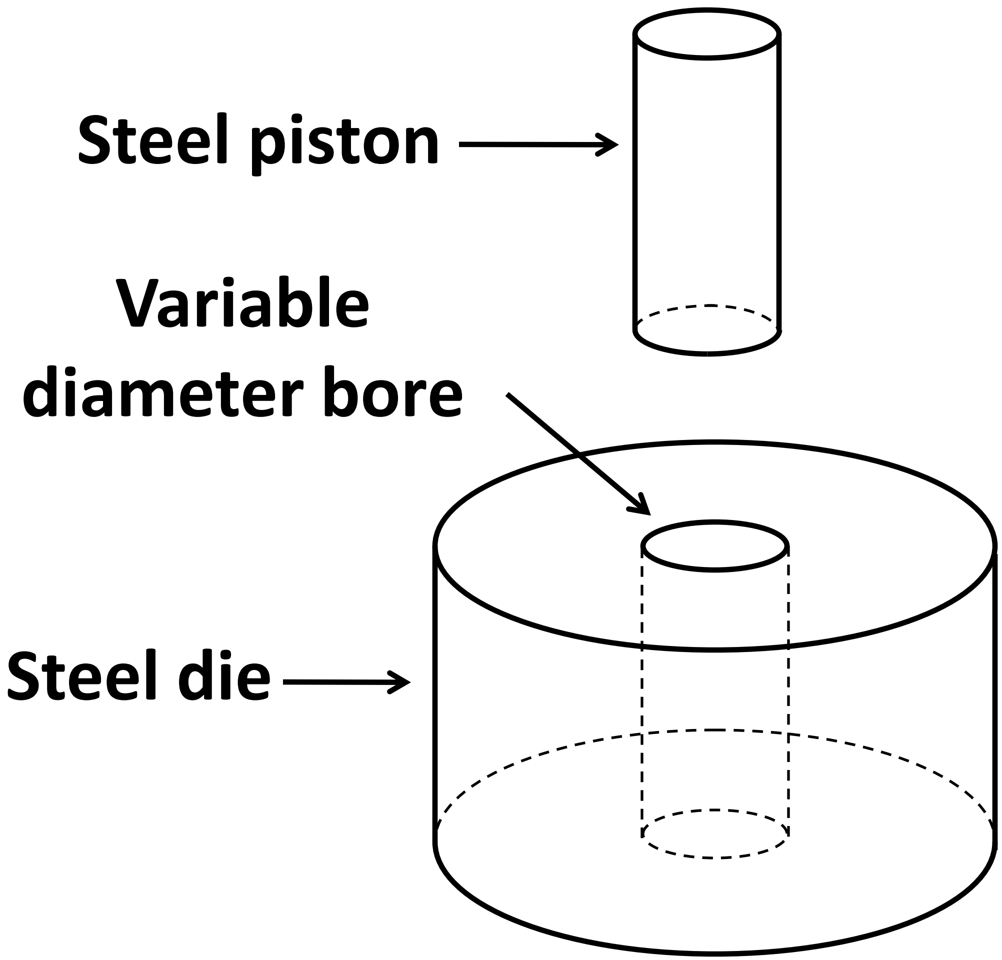
Total est. cost = $ 3,130

Freedom Giant Miscanthus

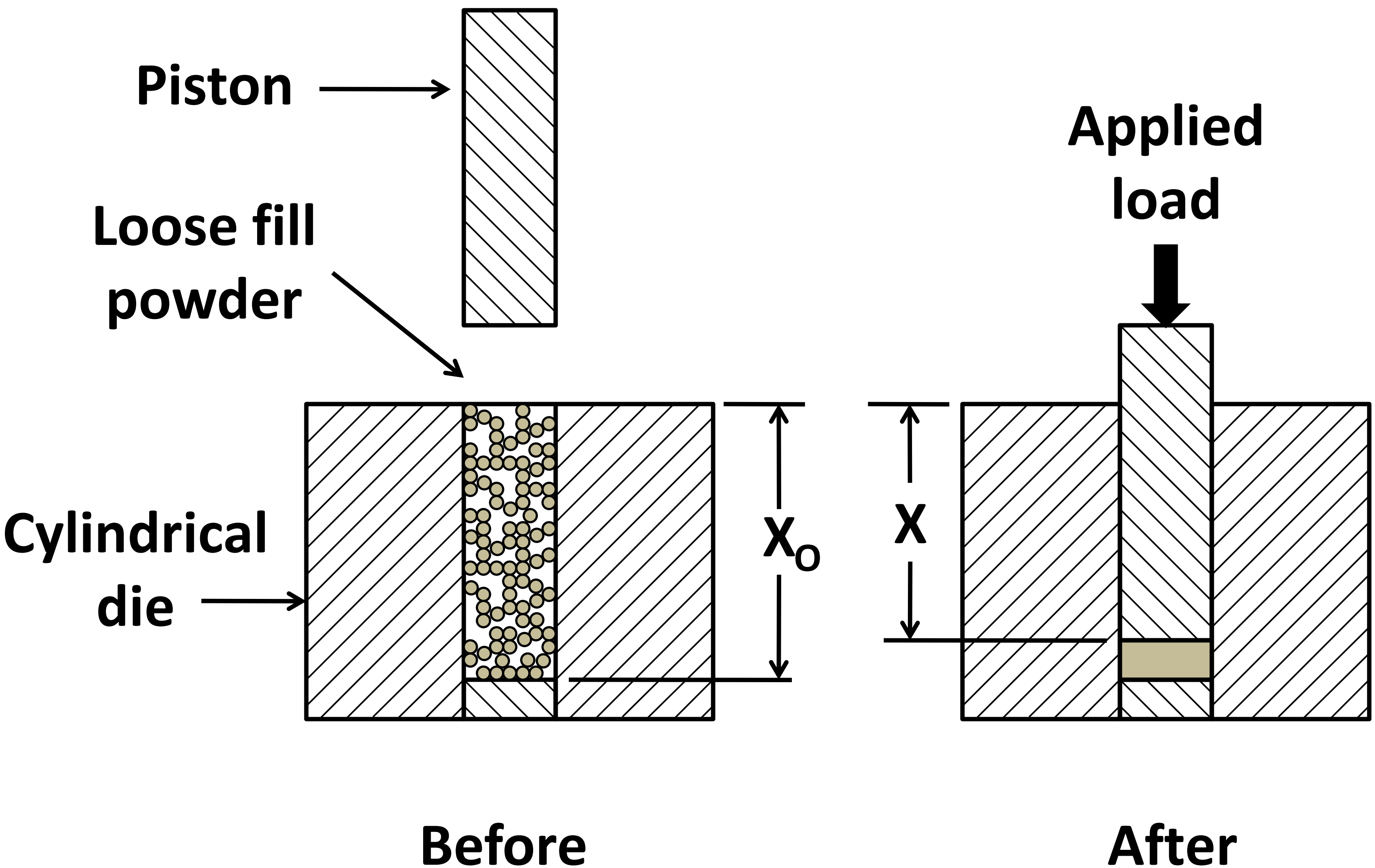
Lab tests optimize pellet & briquette fabrication

– Temperature
– Pressure
– Composition
– Particle Size
– Binder chemistry
– Moisture

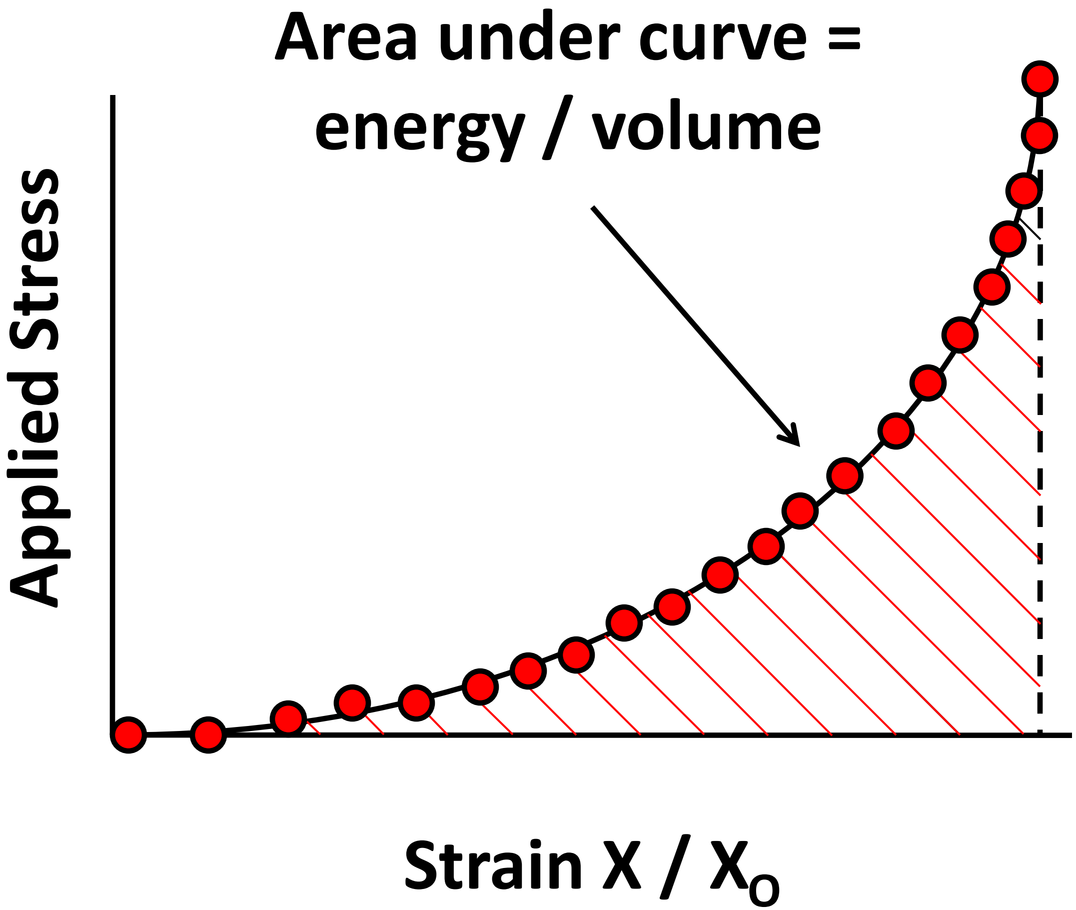
Single Pellet Die



Section View



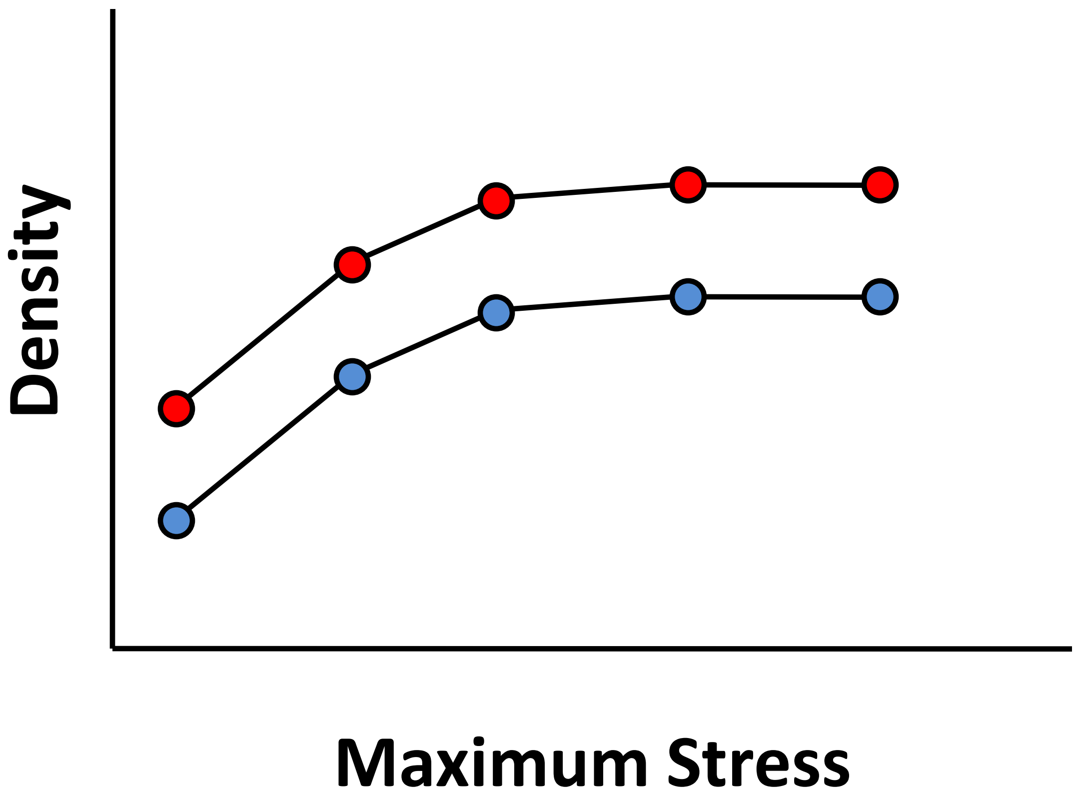
Single Pellet Fabrication



How to reduce area?

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

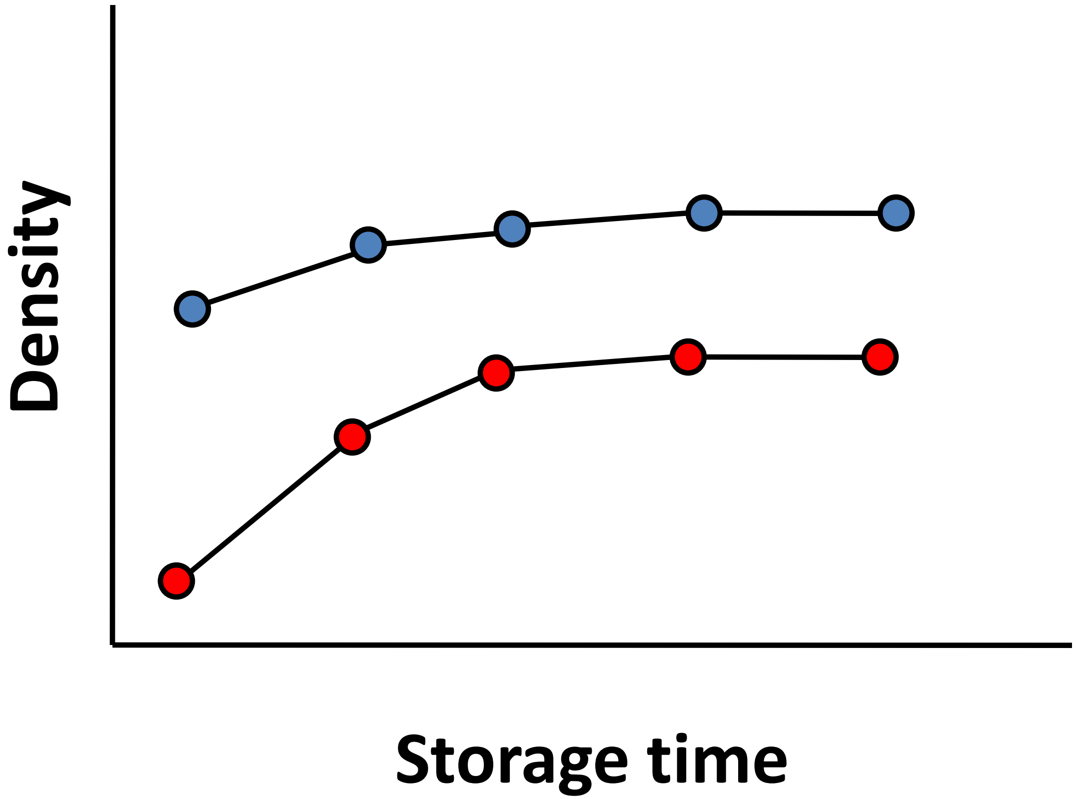
Compressibility Measurements



Critical variables:

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

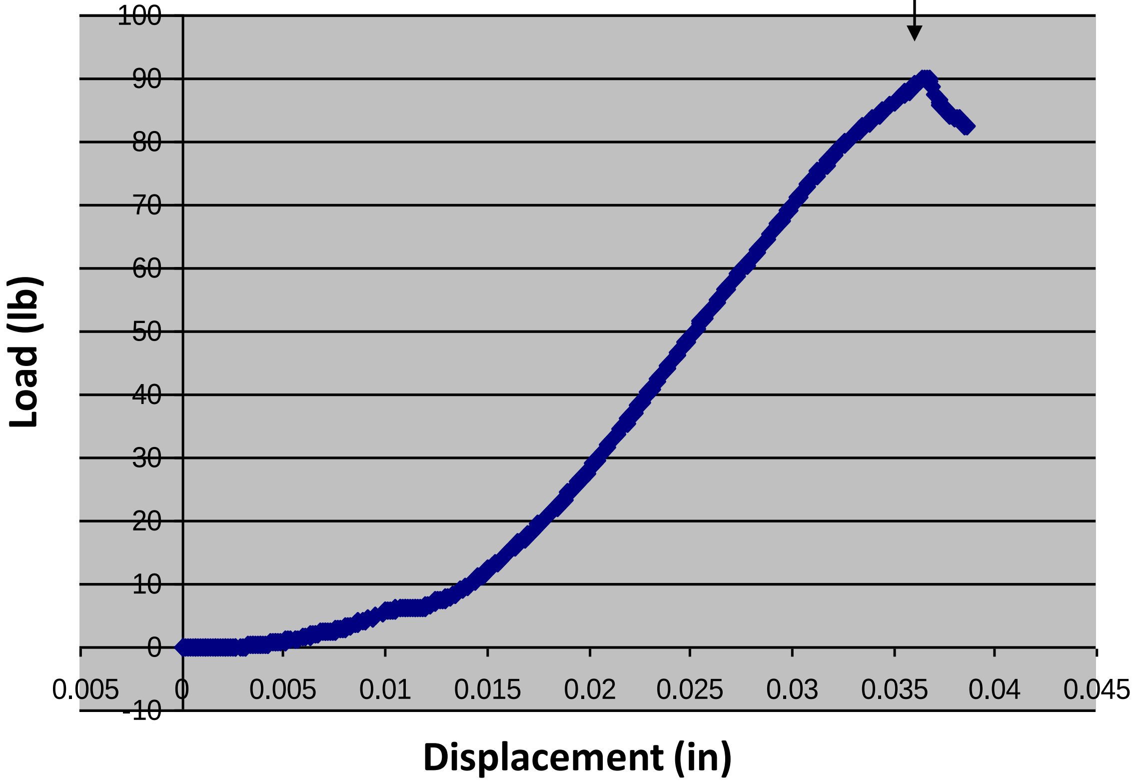
Storage Stability

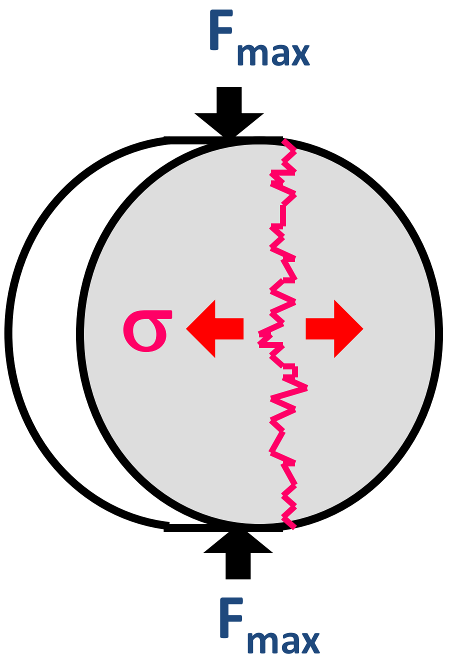


Critical variables:

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

F_{max} = maximum load



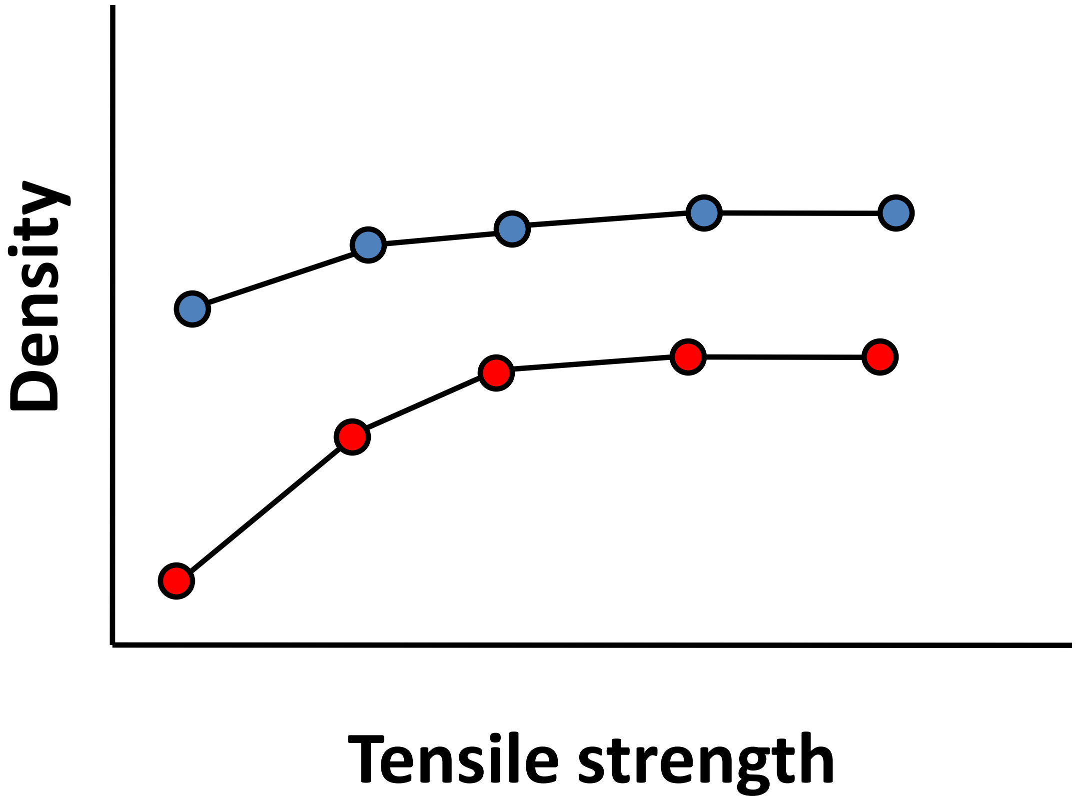


$$\text{Tensile Strength} = \frac{F_{max}}{\pi R T}$$

R = radius
T = thickness

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

Pellet Fracture



Critical variables:

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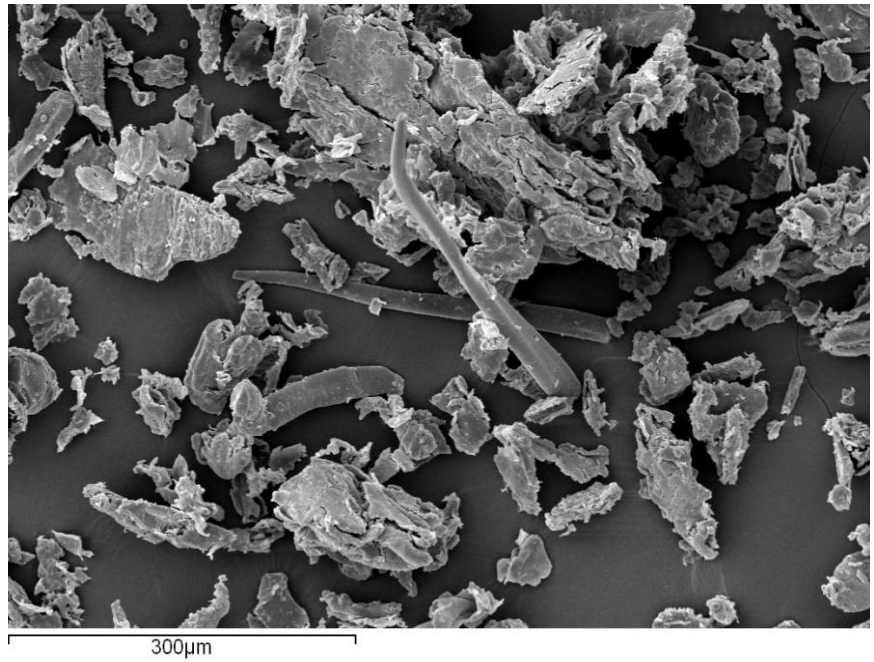
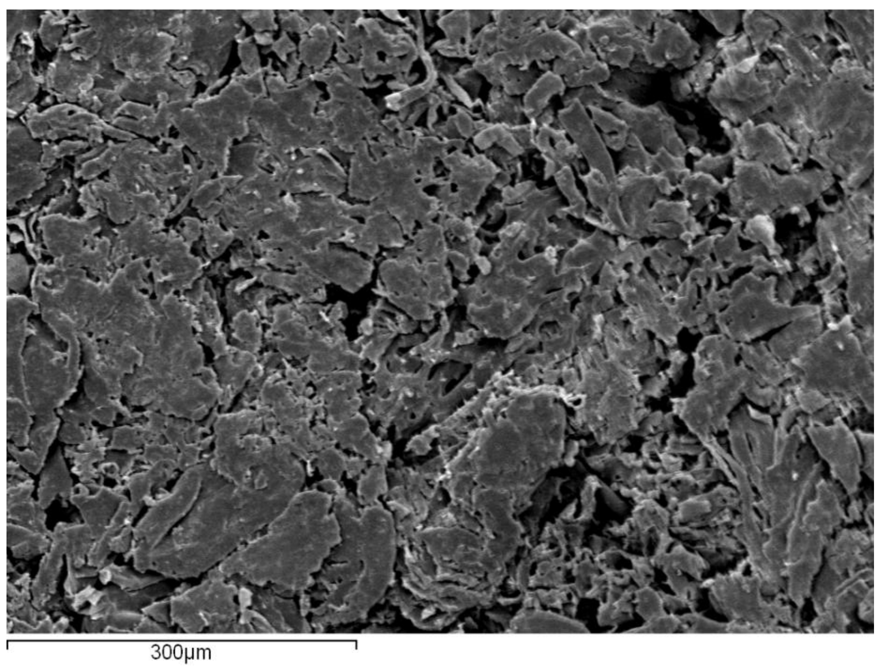

300µm


300µm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