A review of energy crop yields

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CRC LCA 2015

THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Energy crops for biofuel and power

- Energy crops are non-food crops for biomass
- Receive government support: e.g. cellulosic sub-mandate in U.S. (RFS); double counted in EU (RED)
- Energy crops may have less impact on indirect land use change and food prices than food crops:
  - Grown on non-prime or non-agricultural land
  - Potentially higher areal biomass yields
  - Grown in rotation or in complementary systems
- May have higher yields than food crops
- Potential environmental benefits, but also risks

Outline

Energy crops

- Miscanthus
- Switchgrass
- Willow
- Poplar
- Eucalyptus

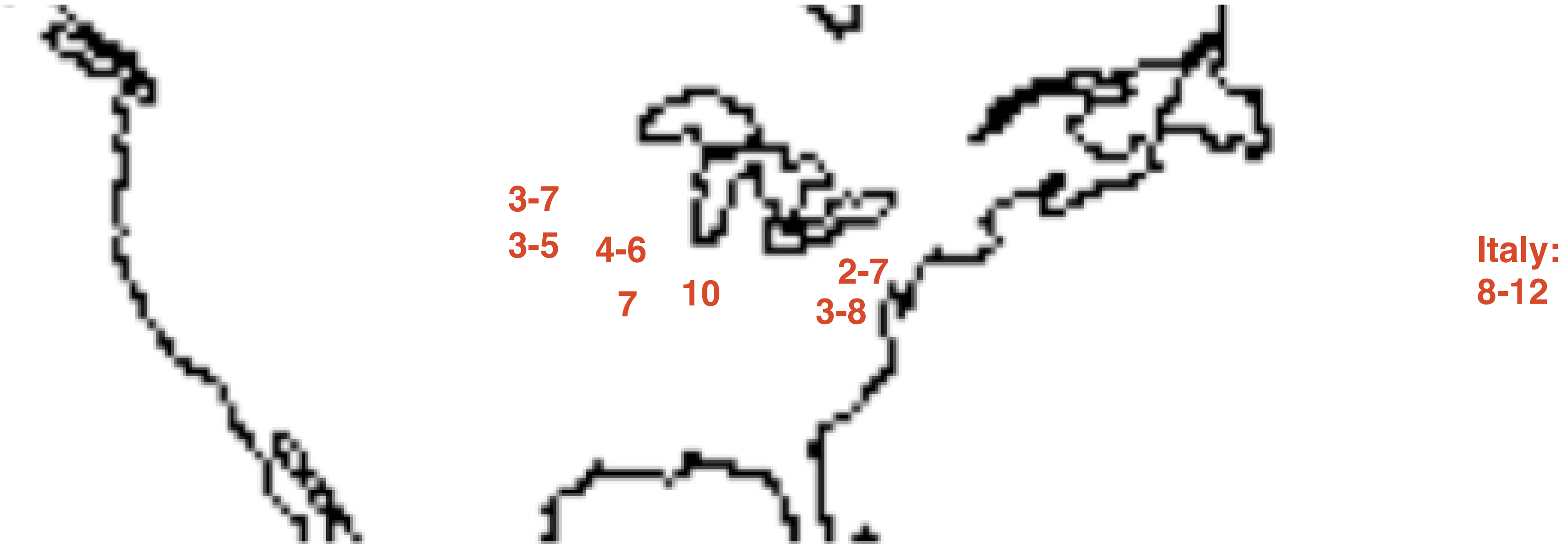
Topics

- Current yields
- Improvement potential
- Environmental concerns

Miscanthus yields (t ha^{-1})

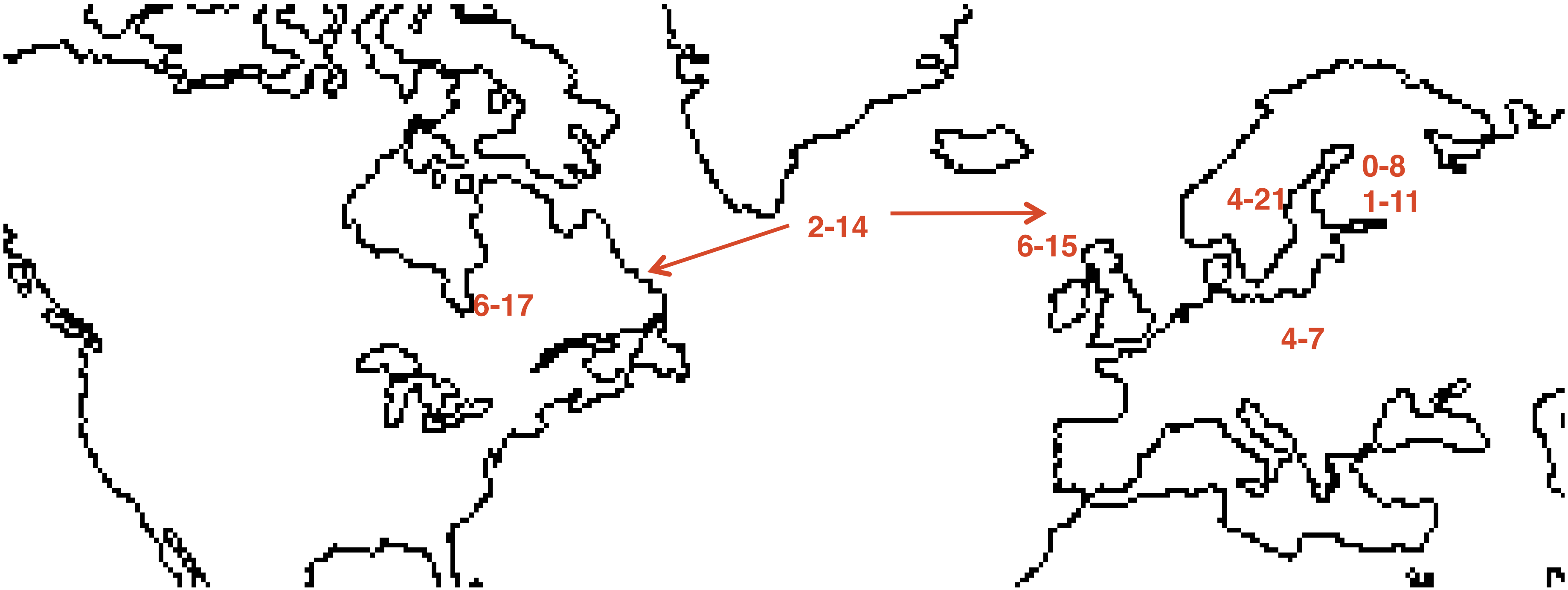
- *M.* x *giganteus* has highest yields in central Europe but poor survival in cold regions
- Yields shown on map are adjusted for 35% biomass loss with overwinter drying.
- Reviews give: 8 (Scurlock, 1999); 5-20 (Lewandowski et al., 2000); 9-17 (ADAS, 2008)

Switchgrass yields (t ha^{-1})



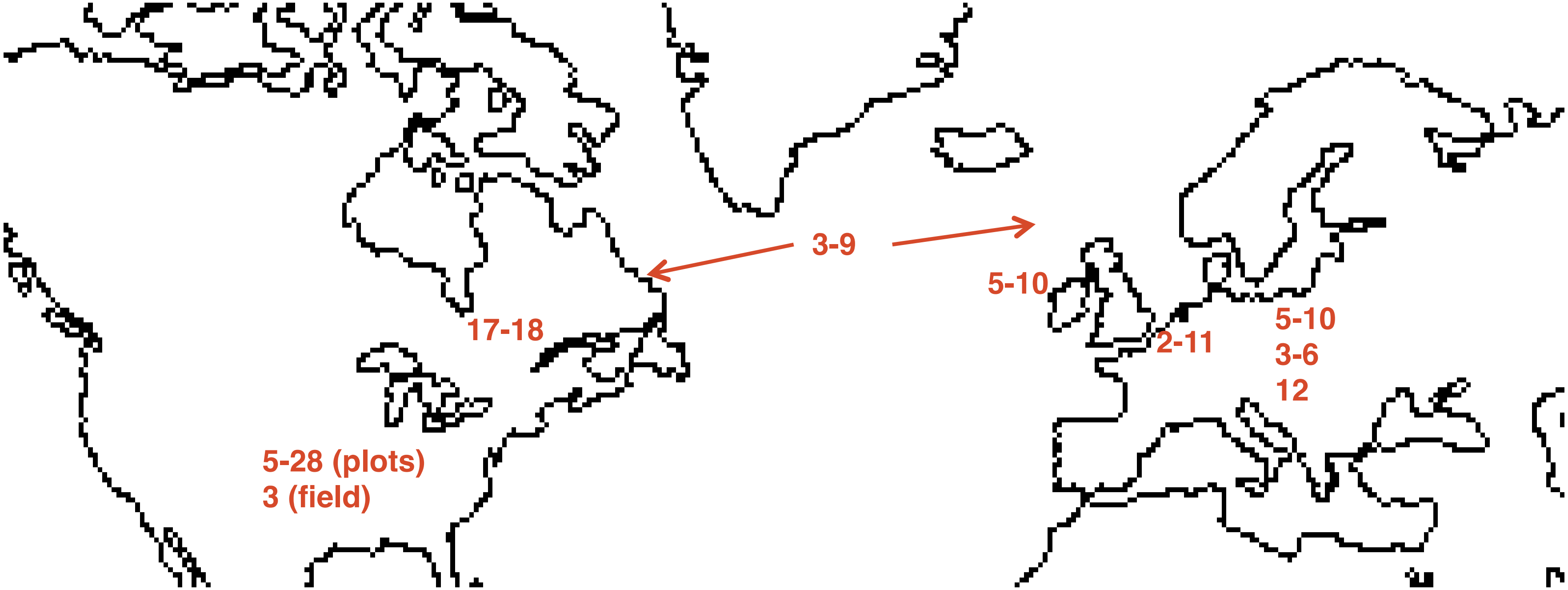
- Reviews give: 10-21 (McLaughlin & Adams Kszos, 2005); 10 (Powlson et al., 2005); 11 (Wang et al., 2010); ~8 (ADAS, 2008).
- Yields shown on map are adjusted for 20% biomass loss with overwinter drying.
- Measured yields are typically lower than reported in review papers.

Willow yields (t ha^{-1})



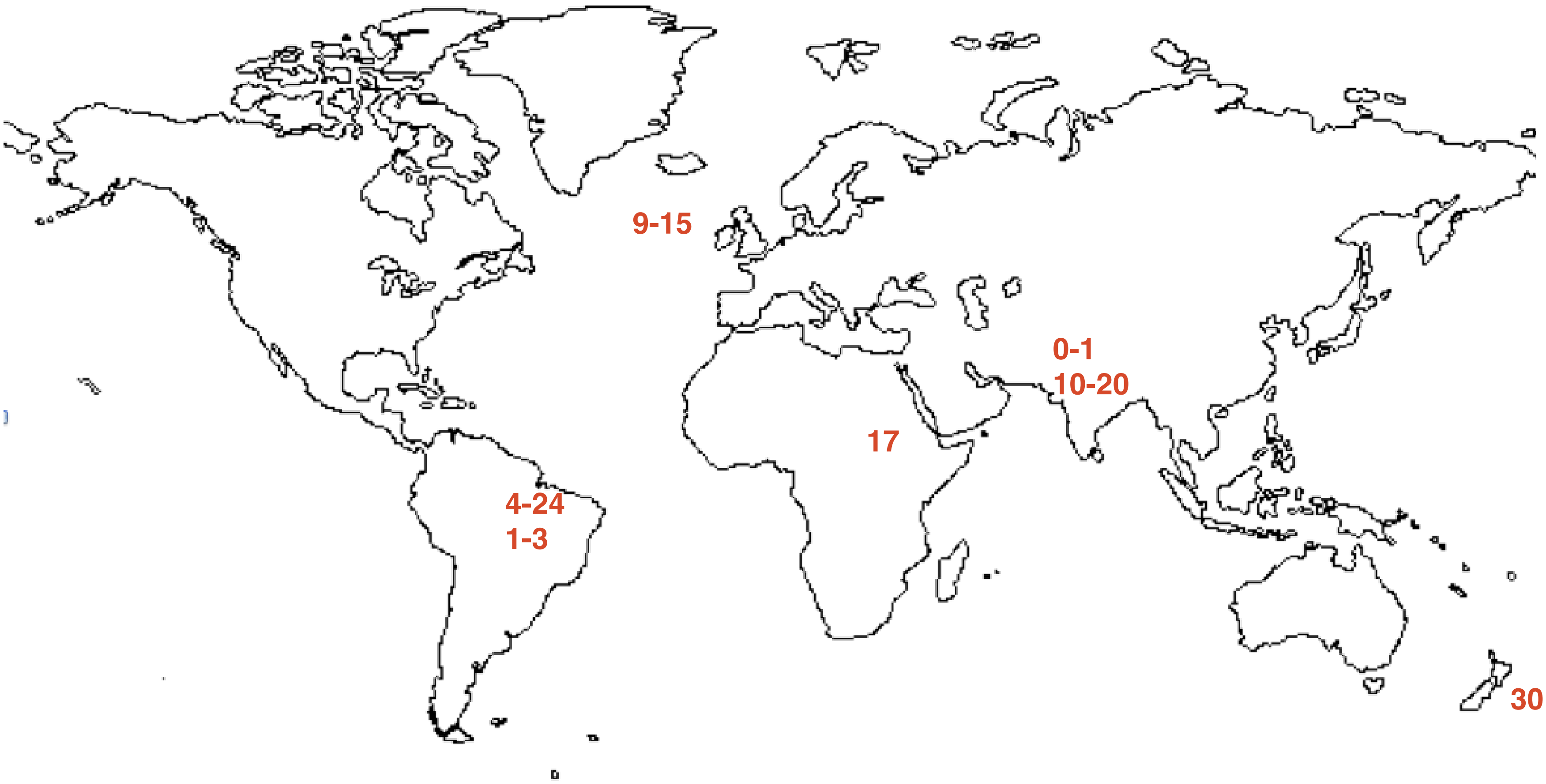
- Reviews give: 7 (Powlson et al., 2005); ~7.5 (ADAS, 2008).
- Not tolerant of drought or cold. High mortality rates in northern regions (e.g. Finland).

Poplar yields (t ha^{-1})



- Reviews give: 7 (Powlson et al., 2005); ~7 (ADAS, 2008).
- Not tolerant of drought.

Eucalyptus yields (t ha^{-1})



Yields are often lower at large scale

- Yields lower in field-scale experiments (2-7 t ha^{-1}) vs. small plots (4-9 t ha^{-1}) in switchgrass (Alder et al., 2006)
- Yields in large-scale, semi-commercial trials are about half that of small plot experiments in Miscanthus (Scurlock et al., 1999)
- "Our results show that actual yields in commercial production switchgrass fields are considerably lower and more variable than commonly reported in the literature.” (Fales et al., 2008)
- “Current record small-plot yields still exceed field trials by 4 to 7 times” in poplar (Hansen,1991)
- Not unique to energy crops: e.g. corn yields have been as high as 36 t/ha on one farm, vs. US avg of 9.6 t/ha

Yields are lower on marginal land

- Yields are much lower on poor soil (3-6 t ha^{-1}; Bungard & Huttl, 2003) than on agricultural soil (12 t ha^{-1}; Hofmann-Schielle et al., 1999) in the same poplar clone in Germany
- Eucalyptus yields in India sharply lower on dry, degraded land (0.4-1.8 t ha^{-1}; Gupta, 1990) than under reasonable conditions (10.3-20.4 t ha^{-1}; Hunter, 1999)
- Average switchgrass yields ~1/3 lower on poor soil vs. better plots (McLaughlin & Adams Kszos, 2005)

Challenges in improving yields

<table>
<tr><th>Miscanthus</th><th>Switchgrass</th><th>Willow</th><th>Poplar</th><th>Eucalyptus</th></tr>
<tr><td>Can’t breed (triploid)</td><td>Can’t inbreed</td><td colspan="3" rowspan="2"></td></tr>
<tr><td colspan="2">Little response to fertilizer</td></tr>
<tr><td colspan="5">Relatively low demand, investment in research</td></tr>
<tr><td colspan="5">Long breeding cycles because perennials</td></tr>
<tr><td colspan="5">Can’t exploit harvest index</td></tr>
<tr><td colspan="5">Climate change</td></tr>
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Environmental impacts and concerns

Miscanthus	**Switchgrass**	**Willow**	**Poplar**	**Eucalyptus**
High water consumption	Can support biodiversity			High water consumption
Invasive potential (*M. sinensis*)				High invasive potential
May improve soil C	May improve soil C			

Safeguards needed

- Policy intervention required to target energy crop production on non-agricultural land, to minimize food market impact and iLUC risk
  - “The value of the higher yields that can be expected on ‘good’ lands generally outweighs the additional cost associated with acquiring that land.” (Azar & Larsen, 2000)
- Sustainability criteria to protect local ecosystems from invasive species and water loss and pollution

Realistic yields

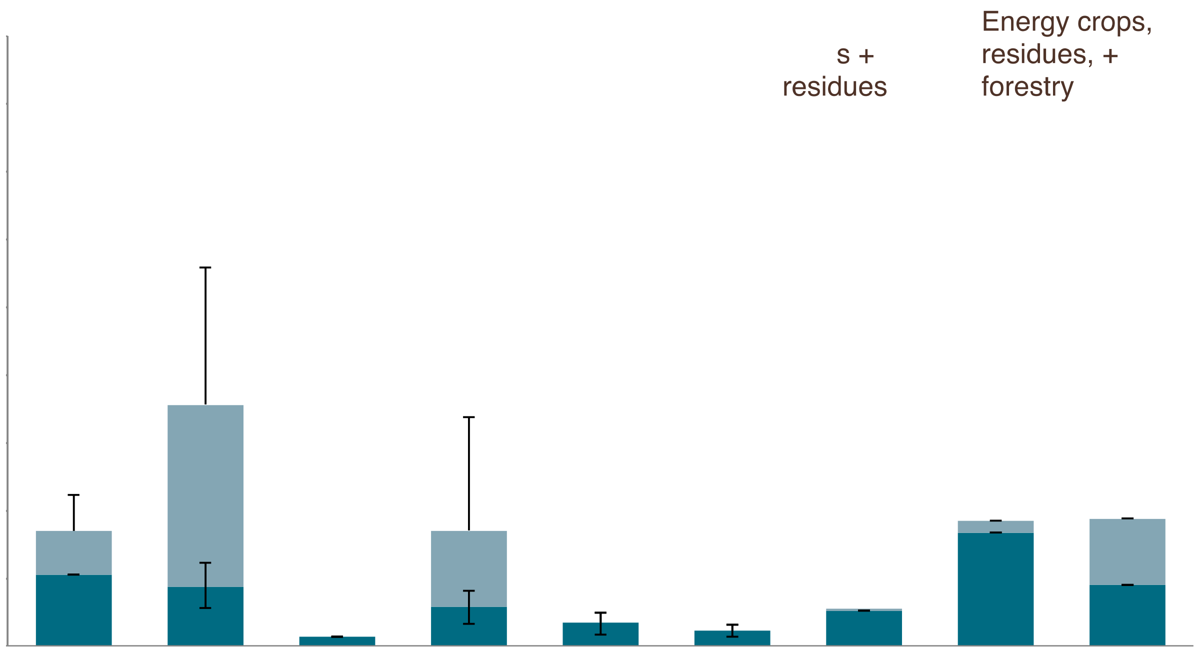
Commercial producers should expect yields at least 1/3 lower than average small trials:

- Miscanthus: 7-15 t ha^{-1} in central and southern Europe
- Switchgrass: 3-8 t ha^{-1} in U.S.
- Willow: 4-12 t ha^{-1} in Europe and U.S.
- Poplar: 4-10 t ha^{-1} in Europe and U.S.
- Eucalyptus: 8-15 t ha^{-1} in tropical/temperate regions
- Compare to U.S. corn yields of 9.6 t ha^{-1}

Implications

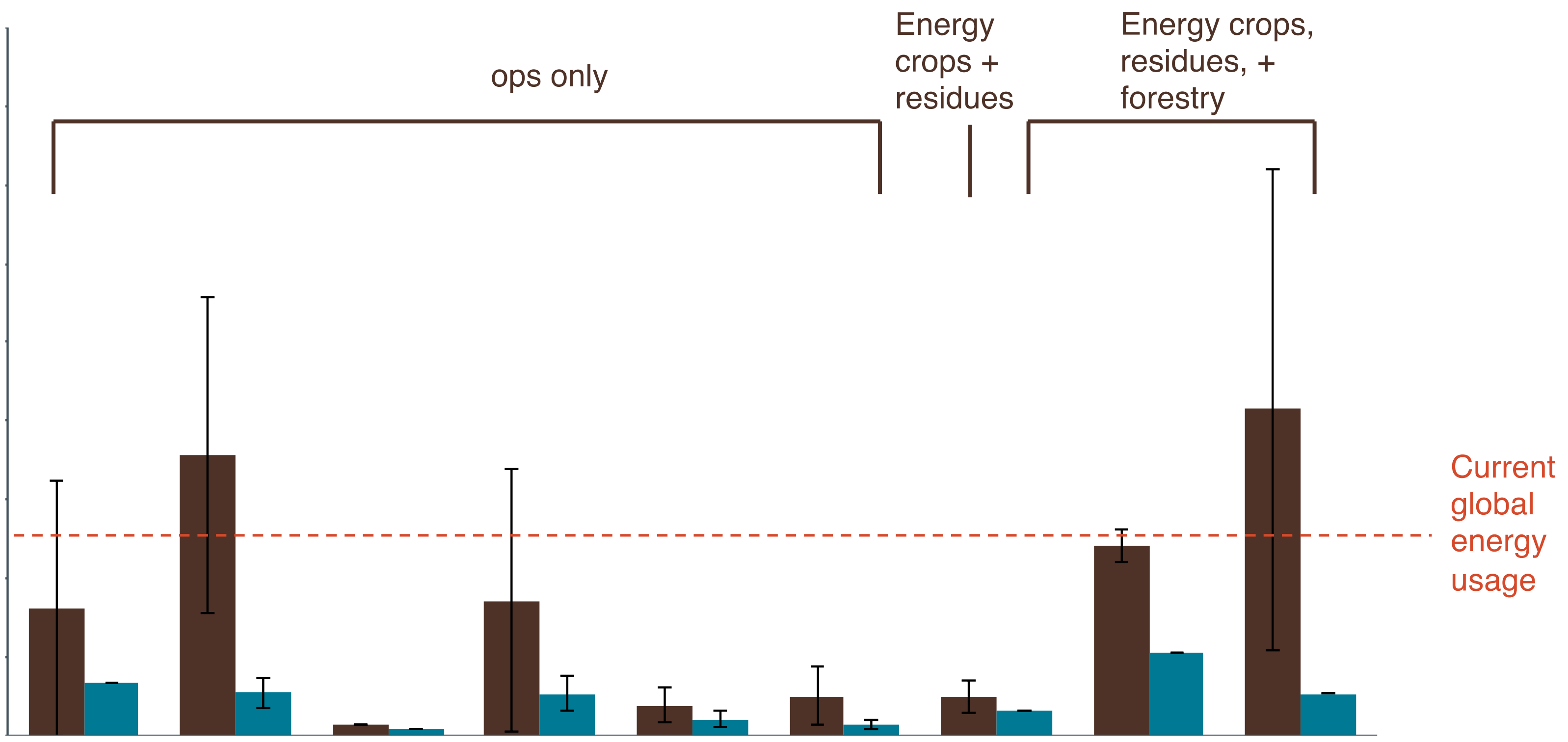
- Lower than expected yields lead to:
  - Energy crop production that is more expensive and hence less economically viable and less competitive
  - Slightly lower GHG savings from cellulosic biofuel and power
  - Lower global potential of biomass production

Adjusting global bioenergy potentials for crop yields



- We considered a realistic projection of food crop yield growth to be that of the FAO, of around 25 kg ha^{-1} yr^{-1} from 2000 to 2050, and of biomass crops such as grasses to be somewhat lower than historical yield growth of sugarcane.

Some studies likely overstate realistic bioenergy potentials



Thanks!

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