Energy and Greenhouse Gas Analysis for Biogas Power Plants

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Basic Operation

- Plants convert solar radiation, ground water, and atmospheric CO_2 into biomass
- Fermenting the shredded plants releases methane, which is burned to liberate some of the original solar energy

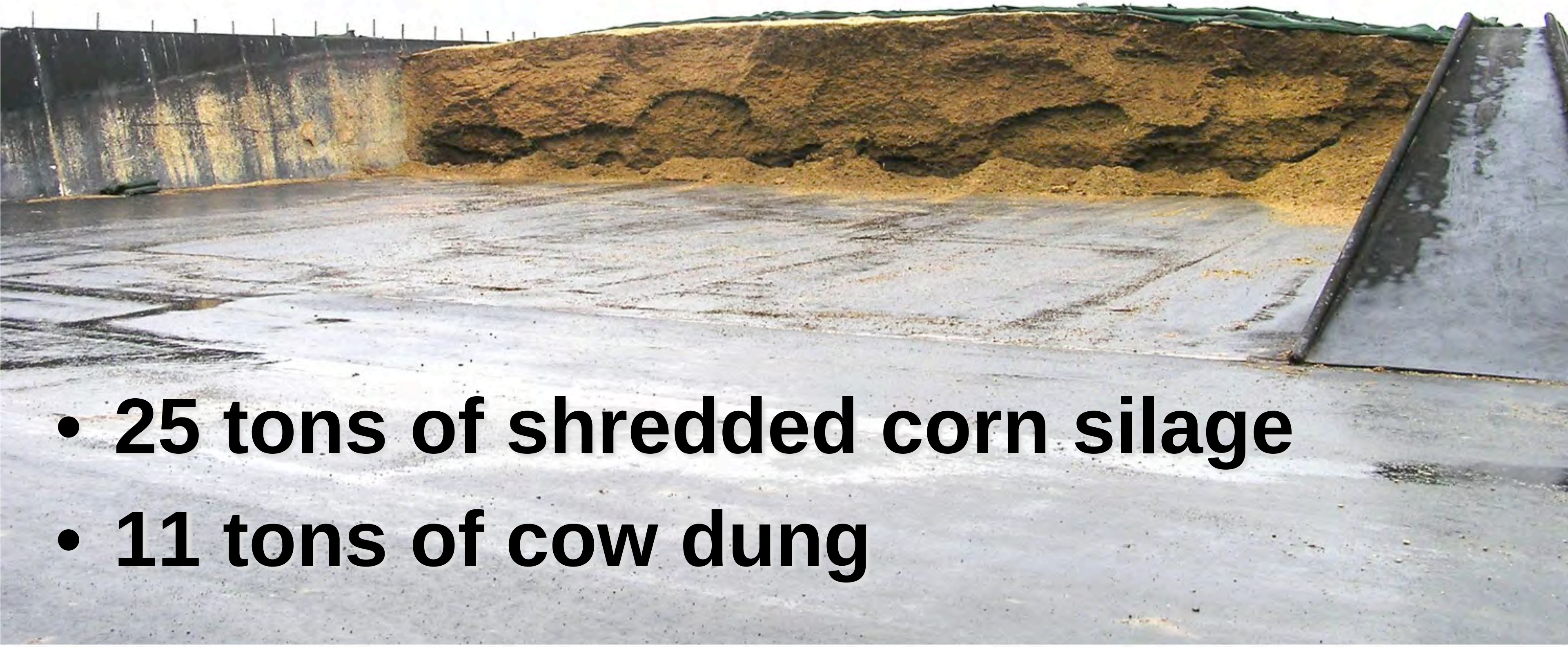
- **CARBON - NEUTRAL energy "production"**

European Association for the Development of Renewable Energies, Environment and Power Quality (EA4EPQ)

International Conference on Renewable Energies and Power Quality (ICREPQ'12)
Santiago de Compostela (Spain), 28th to 30th March, 2012

Energy Crop: Corn (whole plant)

Biomass Consumption / Day



- 25 tons of shredded corn silage
- 11 tons of cow dung

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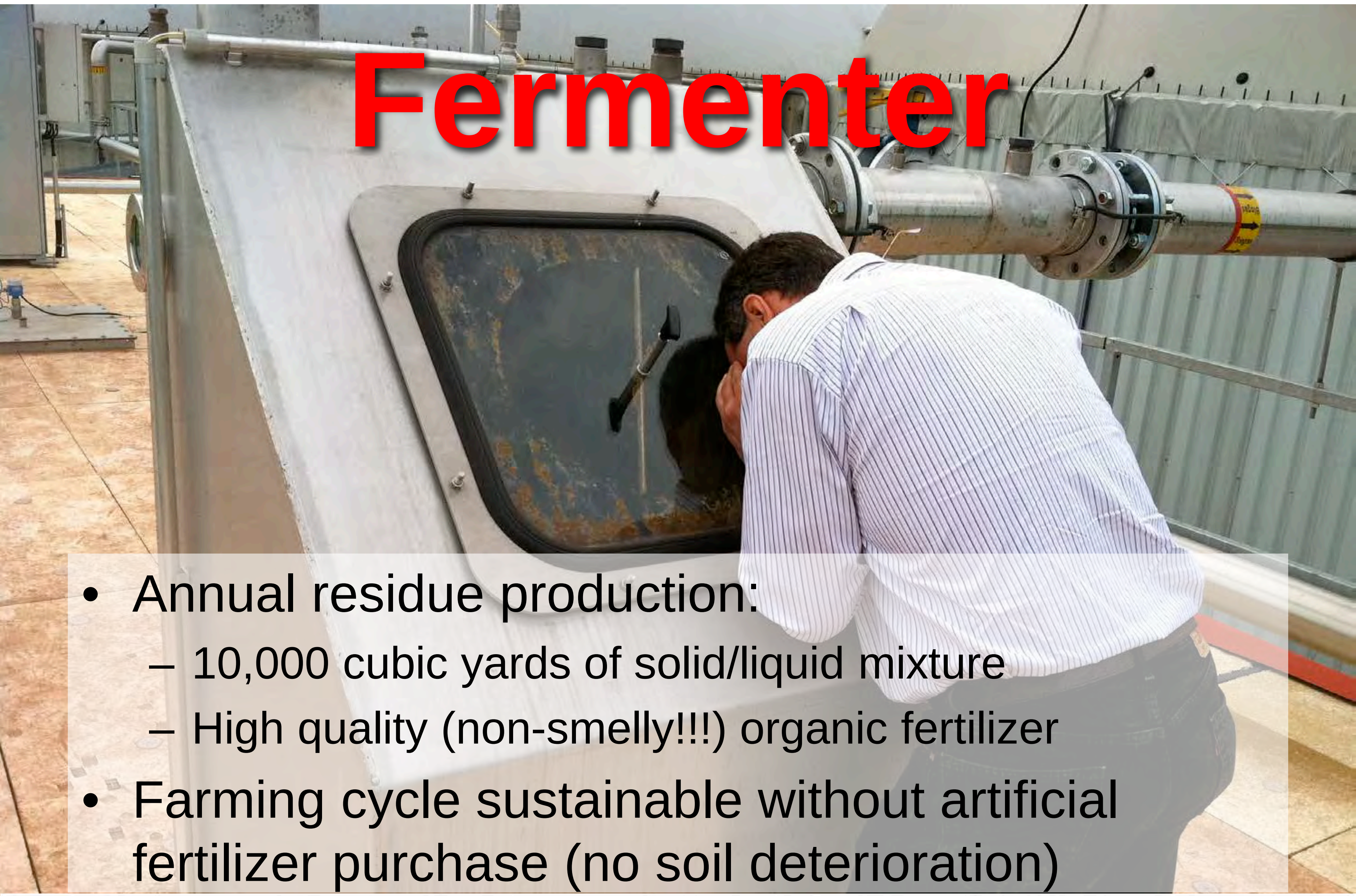
Mixer

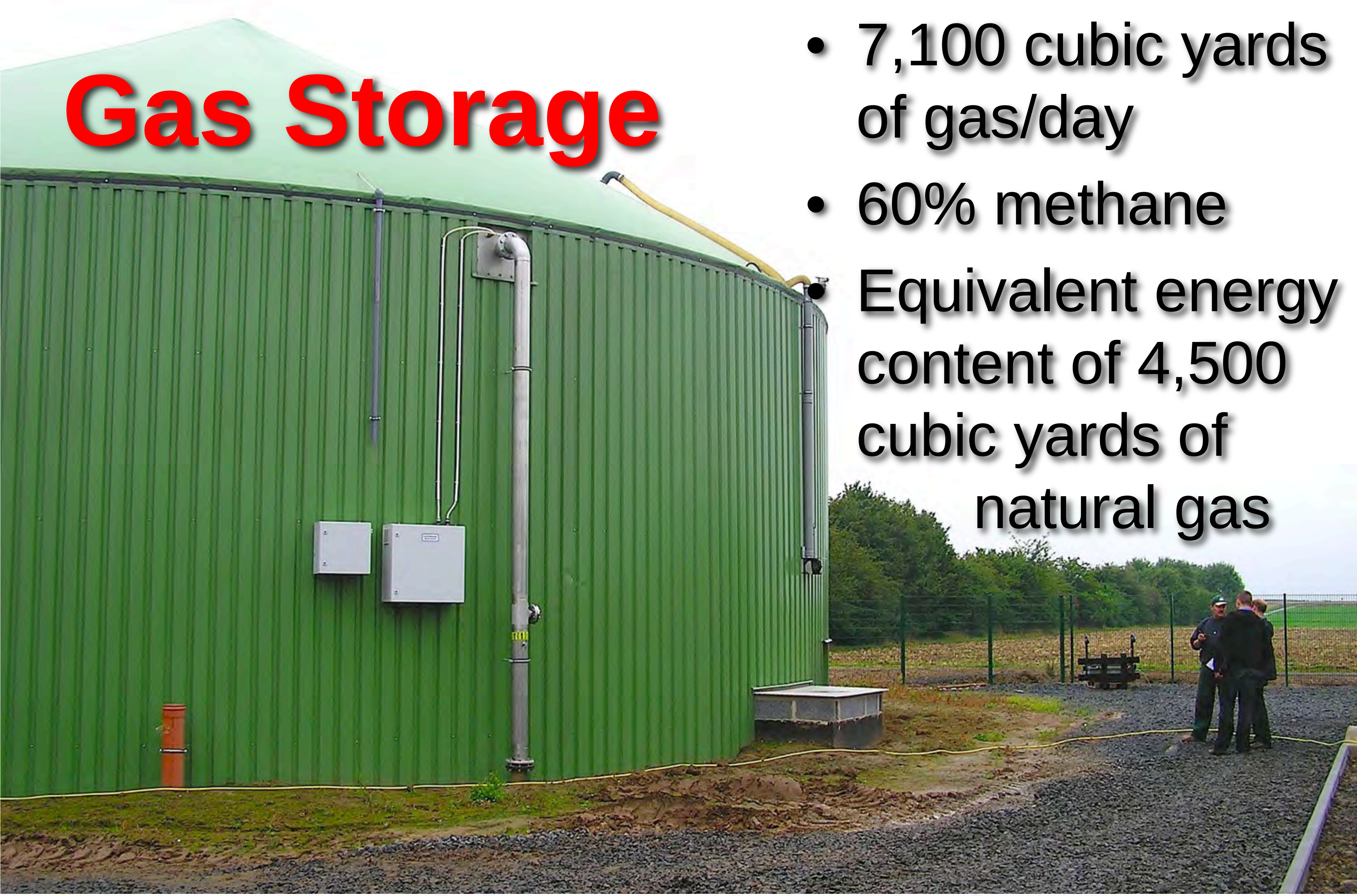


Fermenter

- Annual residue production:
  - 10,000 cubic yards of solid/liquid mixture
  - High quality (non-smelly!!!) organic fertilizer
- Farming cycle sustainable without artificial fertilizer purchase (no soil deterioration)

Gas Storage

- 7,100 cubic yards of gas/day
- 60% methane
- Equivalent energy content of 4,500 cubic yards of natural gas

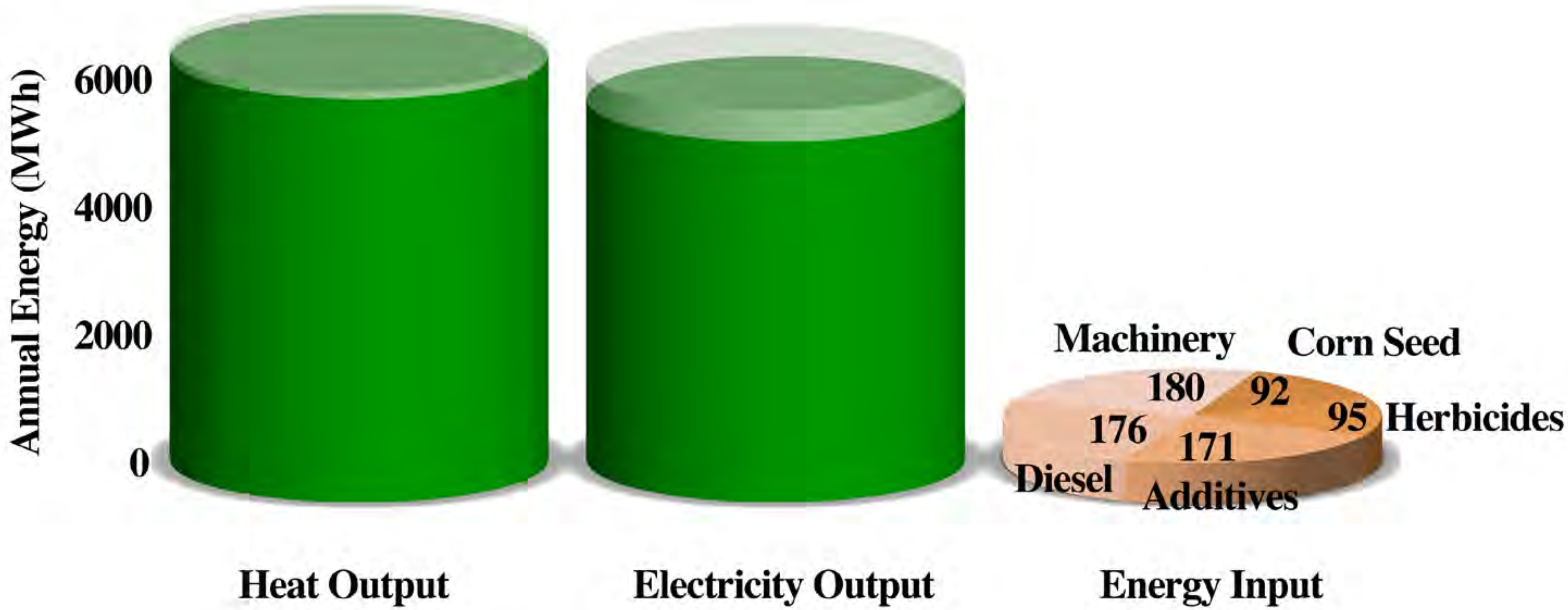



Generators (82% efficient)
• 2 engines rated at 526 kW electric power each (=705 horsepower)
• Another 540 kW of heat

Bottom Line

- Initial investment: ~ $3-5 million
- Land required to grow biomass: 150 hectares
- 6.2 million kWh of electrical energy/year
- 6.5 million kWh of thermal energy
- Payoff time (@10¢/kWh): 3-4 years

Energy Balance



Factor **8** more electricity output than total energy input!

Net Energy Ratio

$$R_E = \frac{\text{Net Energy Output}}{\langle \text{Fossil Energy Input} \rangle_{\text{Life Cycle}}}$$

Bauer, W, Bauer, S, Bauer, T (2011, sub) *Proc Natl Acad Sci USA*.

Liska, A J, Yang, H S, Bremer, V B, Klopfenstein, T J, Walters, D T, Erickson, G E, Cassman, K G (2009) Journal of Industrial Ecology 13: 58 (2009).

Pimentel, D, Patzek, T W (2005) *Natural Resources Research* 14(1): 65–76.

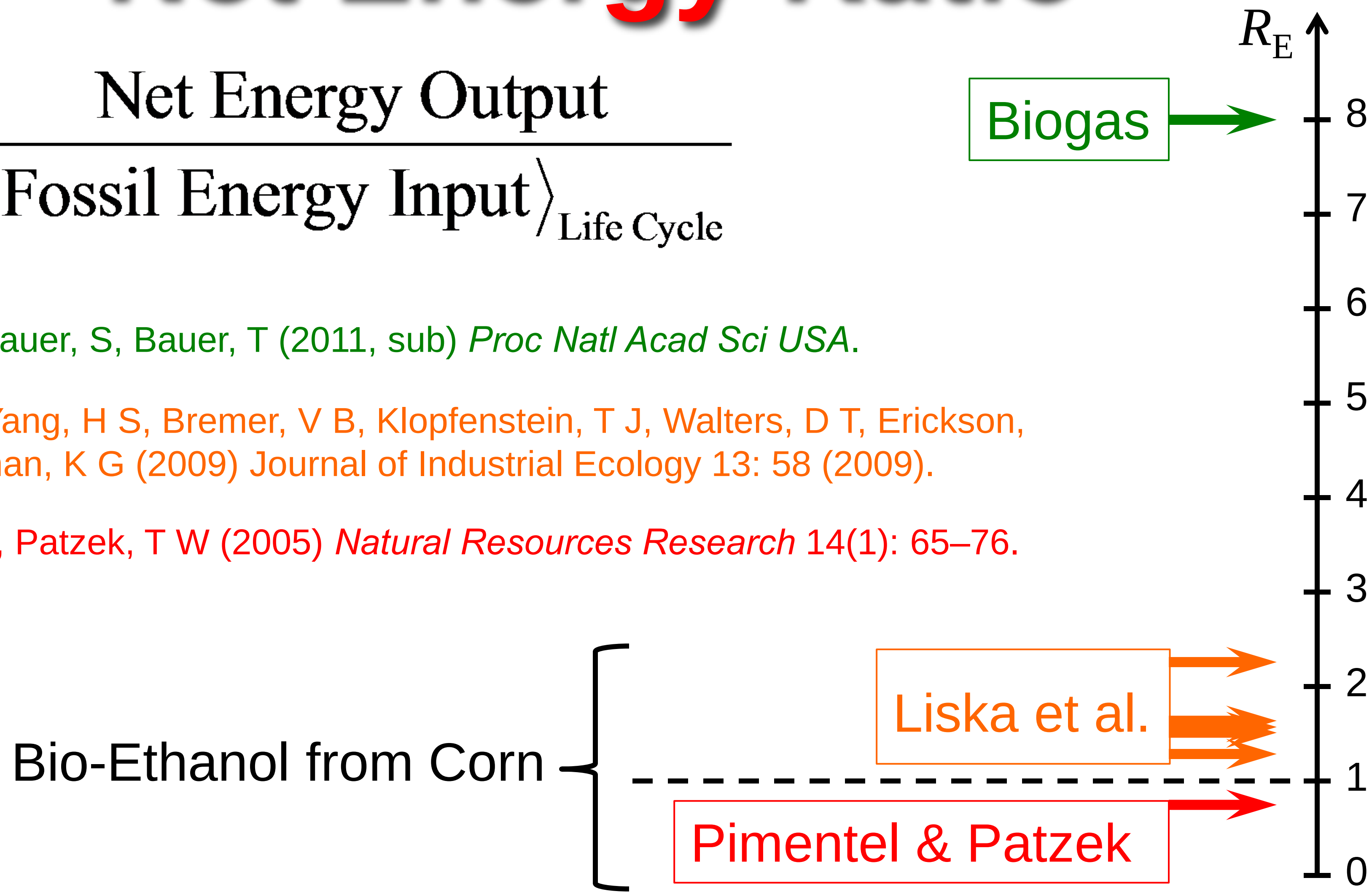


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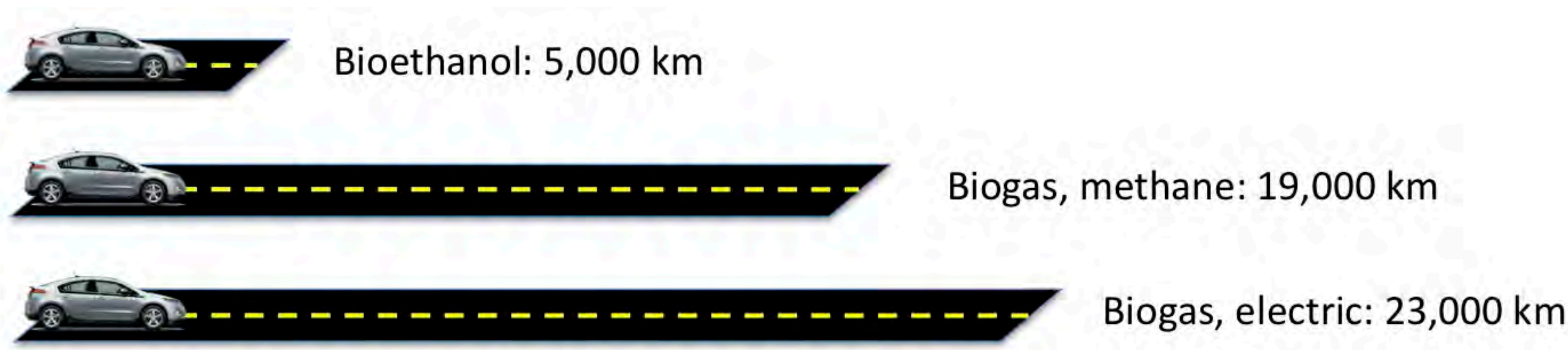
Figure of Merit

- Solar constant: 1.37 kW/m^2
- Real *average* value for Germany: ~75 W/m^2 ($\cos\theta$, day/night, clouds, growing season…).
- 150 hectares = $1.5 \cdot 10^6$ m^2
- Maximum possible power capture: ~$1.1 \cdot 10^8$ W
- Present efficiency = 0.7 MW / 0.11 GW = 0.6%
- Room for improvement!
  - Research on better microbes, better energy crops, better conversion processes
- (But already much better than covering 7 ha of land with 15% efficient photovoltaic cells)

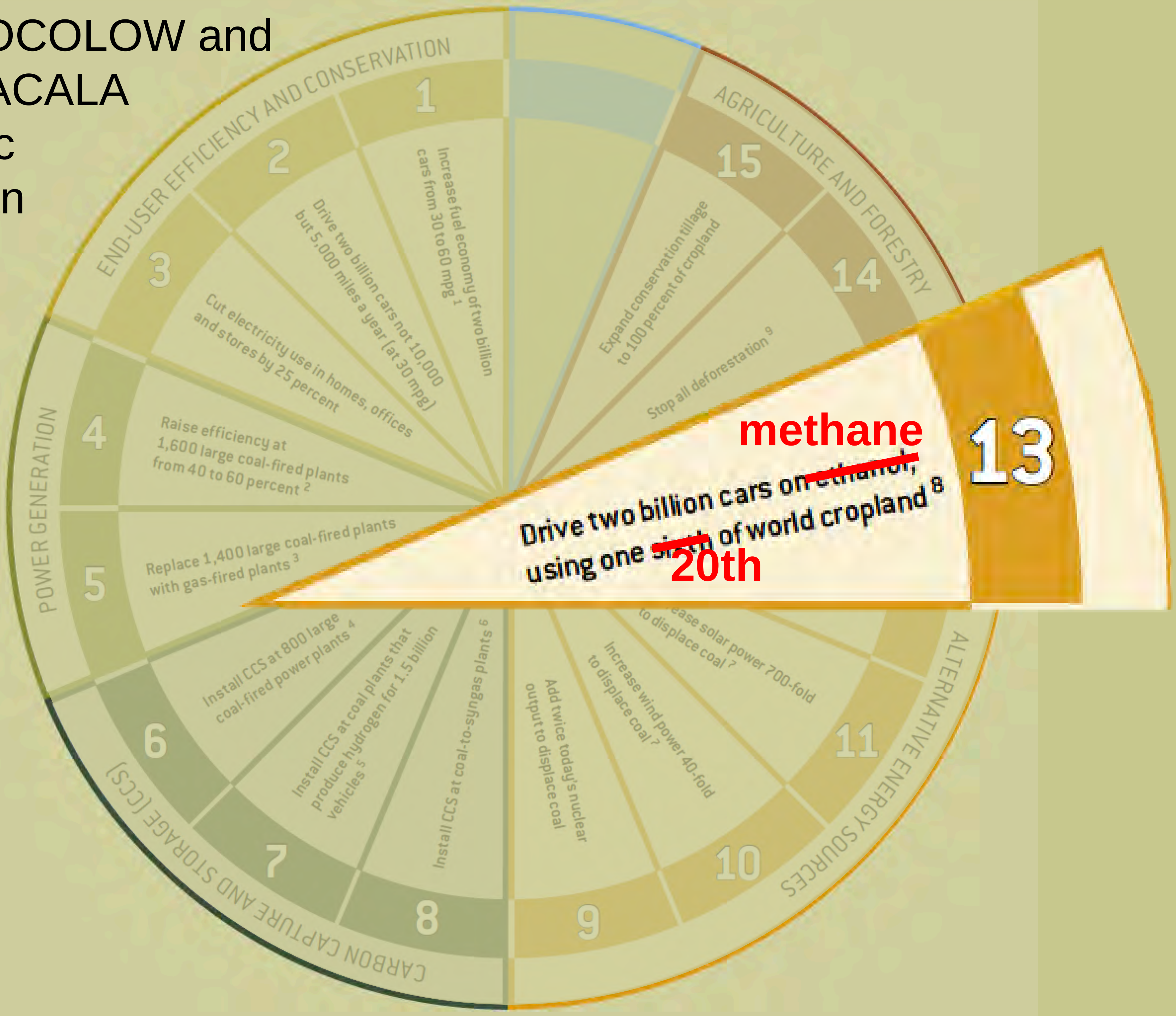
Transportation Fuel

- Could produce 0.68 M liter of ethanol / year
  - Industry standard output from our corn yield on 150 ha
- Are producing 2.6 M liter of (liquid) CH_4 / year
- Factor of **3.8** better yield!
  (heat of combustion per liter almost identical for ethanol and methane, ~ 2/3 of gasoline)



Driving distance per hectare (numbers for Chevy Volt)

R. H. SOCOLOW and S. W. PACALA Scientific American 2006



US Economic Impact

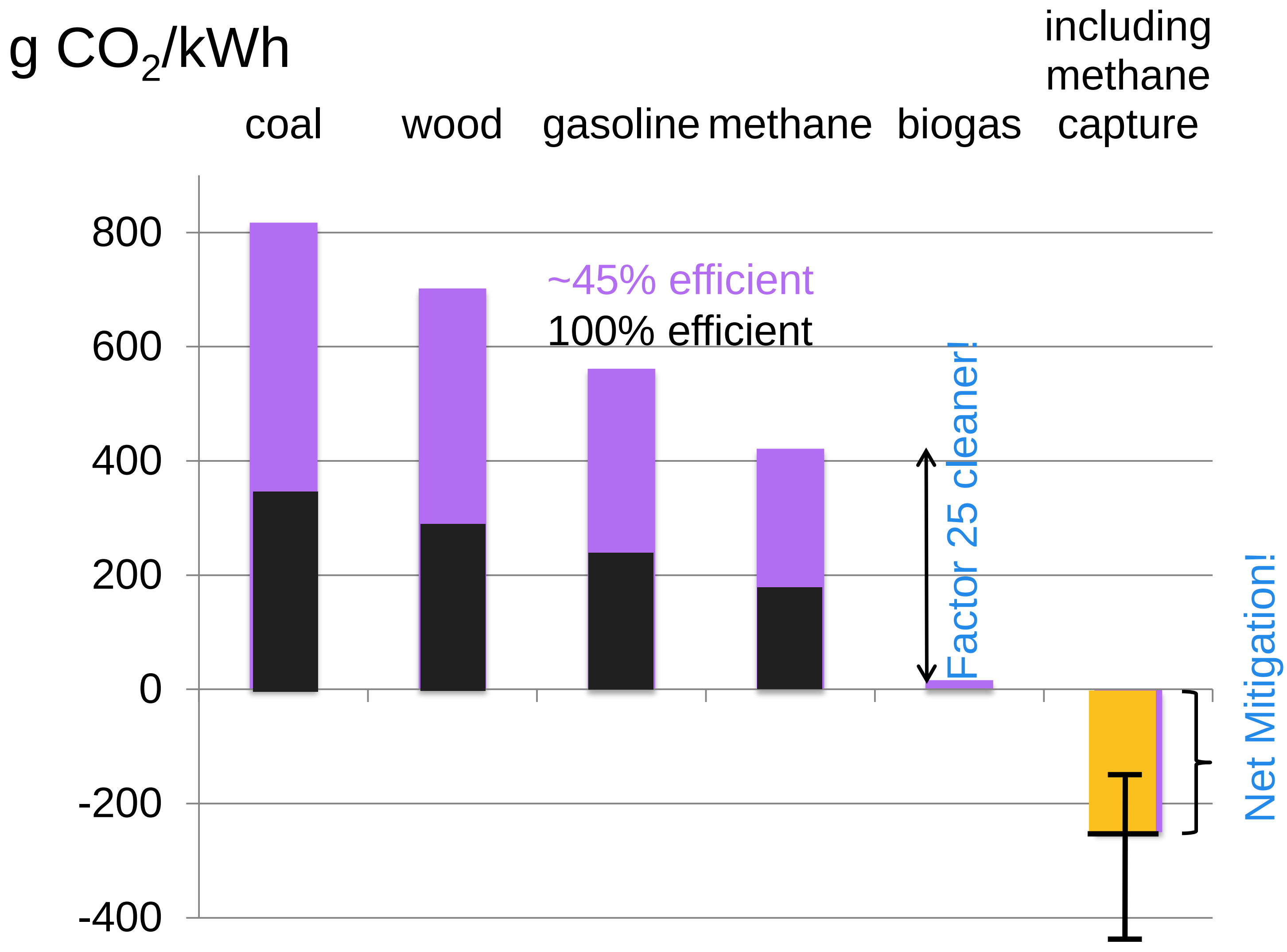
2015 projected bioethanol yield: 50 billion liters

Proposal: Convert to biogas reactors

Make 190 billion liters methane

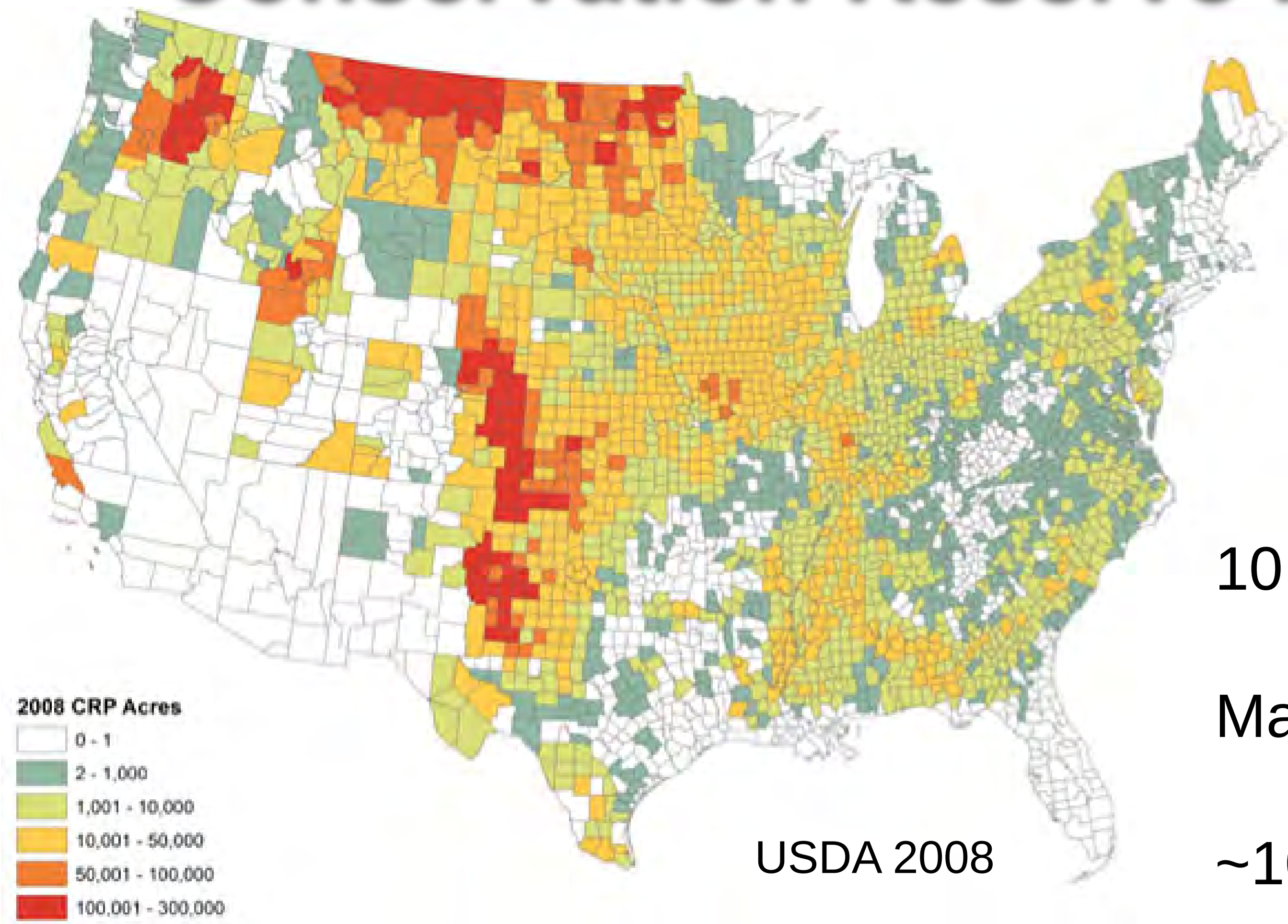
More than **$100 billion/year** profit!

Greenhouse Gas Balance



Methane is ~25 times more powerful greenhouse gas than CO_2
- our process prevents methane from cow dung to escape

Food vs. Fuel?
Conservation Reserve Program



USDA 2008

10 M hectare

Marginal land(?)

~100 GW potential

Summary (yes, we can …)

- We can produce lots of "green" energy
- We can build environmentally friendly power plants
  - High net energy ratio (~ 4-8 x that of corn-ethanol)
  - High transportation fuel yield (> 3 x that of corn-ethanol)
  - Negative carbon emissions (~ -100g CO_2/kWh)
  - No intermittency / excellent power quality
- We can make lots of small farms very profitable
- We can make $$$, £££, €€€, … from our waste
- We can create lots of great jobs in the process
  - Distributed ownership of energy resources

Final Word

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- Email contact: bauer@pa.msu.edu