Incorporating Miscanthus into Building Materials

John R. Schlup and Larry E. Erickson

Department of Chemical Engineering
Kansas State University
Manhattan, KS 66506

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Project Goals

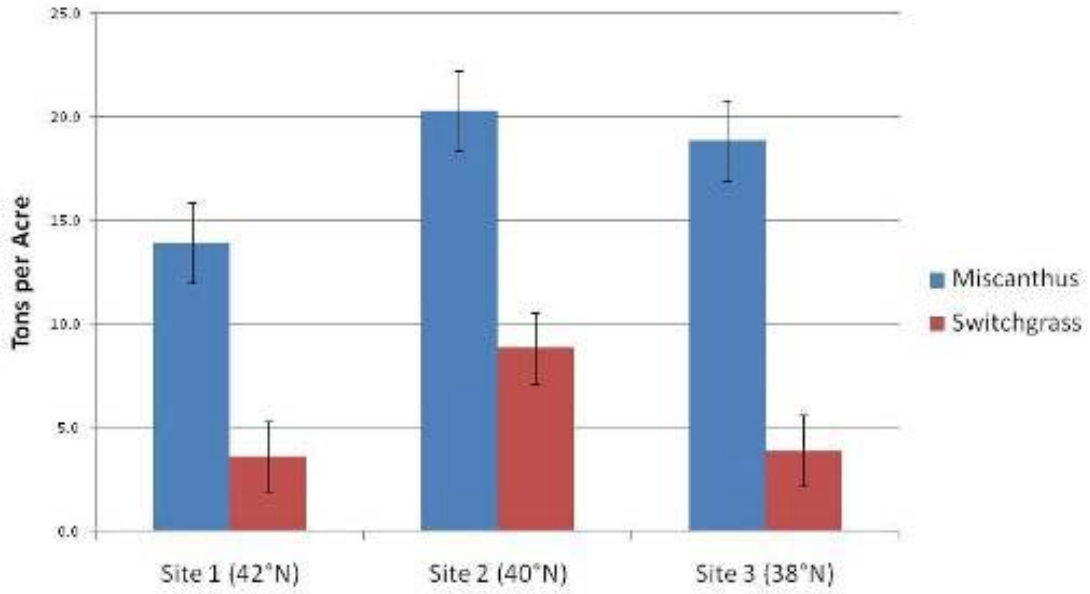
1. To restore contaminated land to productive use by establishing fields of miscanthus that can be harvested annually for beneficial uses.
2. To improve soil quality while growing and harvesting this perennial crop for many years.
3. ***To develop good product markets for miscanthus that have commercial viability.***

What Is Miscanthus?

http://articles.extension.org/pages/26625/miscanthus-miscanthus-x-giganteus-for-biofuel-production

- A family of grasses (resembles bamboo) having a C4 photosynthetic pathway
- Native to Africa, Eurasia, and the Pacific Islands
- Characterized by high growth, low mineral content, and high yields of biomass (M. giganteus … reported as high as 25 tonnes /hectare)
- A perennial
- Lifespan with annual harvest … 15 – 20 years

Why Miscanthus?



Average annual yield of biomass from giant miscanthus (cultivated in Illinois)

E. A. Heaton, et al., *Global Change Biology* **14** (2008) pp. 2000 – 2014

From: http://articles.extension.org/pages/26625/miscanthus-miscanthus-x-giganteus-for-biofuel-production

Miscanthus Production Metrics

- **Biomass yield per unit area.**
  - Miscanthus has a high yield. It is a C-4 plant with a high photosynthetic efficiency.
  - Miscanthus is a perennial grass that can be harvested annually for many years.
- **Miscanthus yield per mm of water supplied.**
  - Water is used efficiently.
- **Mass of miscanthus per mass of fertilizer applied.**
  - Very little fertilizer is needed because nutrients are used efficiently.
- **Biomass yield per unit of energy expended.**
  - Large quantities of a high quality product are produced.
- **Carbon analysis for production of miscanthus including:**
  - Carbon incorporated into miscanthus.
  - Carbon incorporated into soil.
  - Carbon emissions associated with production activities.

Beyond a "Bale House"

Construction in Wales

Collaborators:

University of Aberystwyth, The Centre for Alternative Technology (CAT), and

Terravesta

Pictures from:
http://www.constructionmanagermagazine.com/news/welsh-team-build-house-miscanthus/

Miscanthus in Building Materials

- Insulation
- Composite materials
- Fiberboard
- Miscanthus-concrete
- Miscanthus biocomposites

Miscanthus Insulation Board

One set of resources

- Florian Meyer, F., M. Wagner, and I. Lewandowski, (2017) “Optimizing GHG emission and energy-saving performance of miscanthus-based value chains,” *Biomass Conversion and Biorefinery* **7:**139 - 152
- Uihlein A., Ehrenberger S., Schebek L. (2008) “Utilisation options of renewable resources: a life cycle assessment of selected products,” *J.Clean Prod.* **16**:1306–1320.

Miscanthus Insulation Board

Basis for one study … MEHA Dammstoff und Handels GmbH in Schifferstadt, Germany

- 15,000 m^3 of insulation material from 3168-t biomass (8% moisture)
- Incorporates ~1.75% borax, 1.75% sodium carbonate, and 0.5% fungicide
- Basically steam explosion, then pressed to fiberboard
- Properties:
  - Heat transfer coefficient … 0.04 $Wm^{-1}L^{-1}$
  - Density … 0.220 Mg/m^3
  - 8 wt% moisture

Miscanthus Insulation Board

- Thermal Insulation Board Based on Miscanthus Residual Fibers," Cardenas, et. al., 6th Annual Bioindustrial Meeting (University of Alberta), Nov. 22 – 25, 2015.
- Isocalm … an insulation board fabricated from "elephant grass"
  - Originated in Ghana
  - Dipl.Eng. Karl Schock (www.youtube.com/watch?v=kmfXjIKQ9-Y)
- Insulation board by Novabiom (http://www.novabiom.com/en/miscanthuseng/uses)

Miscanthus Insulation "Board"

Good Start Packaging distributes clamshell products produced by World Centric (http://www.worldcentric.org/) and Aloterra (http://www.aloterrallc.com/). These are miscanthus-based (based on a product marketed as MxG Eco-Fibers).

https://www.goodstartpackaging.com/miscanthus-fiber-products/?search_query=&page=1&limit=50&sort=featured&brand=27&category=244&is_category_page=1

Particleboard / Fiberboard

- *Plywood* … wood veneer
- *Particleboard* … wood particles; slivers of lignocellulosic material (stalks, roots, husks)
- *Fiberboard* … lignocellulosic fiber (can be layered (smoother material on exterior)
- *Strand board* … lignocellulosic strands

All of the above typically involve some kind of bonding agent.

Particleboard / Fiberboard

- Densities … 300 – 750 kg/m^3
  - "density of boards"
  - High-density boards (HDF)
  - Medium-density boards (MDF)

There are low density boards

- Wet & dry processing is done, although MDF typically is done dry
- Typical composition 82% "wood", 9% resin, 1% paraffin, 8% water

Miscanthus Fiberboard

Recent literature focused on binderless fiberboard

- Steam explosion of miscanthus
- Hot press (with lignin as adhesive)
- Some studies with addition of lignin for better binding

Pressed miscanthus cane board

https://extension.psu.edu/alternate-markets-for-dedicated-grass-energy-crops

Miscanthus Fiberboard

From work of Velazquez, Ferrando, and Salvado, *Wood Sci. Technol.* **37** (2003) 279 – 286.

- Density: 0.99 – 1.2 Mg/m^3 (MDF: 0.9 – 1.0)
- Specific modulus: 6.0 MPa/kg/m^3 (MDF: ~ 6 - 8)
- MOR: 50 - 60 MPa (MDF: 60 – 90)
- Thickness swelling: 5 – 60%
- Water absorption: 20 – 40%

(MDF data from CES Selector 2017 by Granta Design, Ltd.)

Miscanthus Fiberboard

Primary Production Data

	MDF[2]	OSB[1]	Kenaf[2]	Bamboo[3]
Embodied Energy (10^4 BTU/lb)	1.63 – 1.80	7.91 – 8.73	2.76 – 3.04	6.15 – 6.79
CO2 footprint (lb/lb)	0.723 – 0.797	0.844 – 0.931	2.67 – 2.94	0.00194 - 0.00214
Water Usage (ft^3/lb)	11.4 – 12.6	10.4 – 11.74	8.02 – 24.0	1.06 – 1.17

Data obtain via CES Selector 2017 (Granta Design LTD)

[1] Econinvent v2.2, among others

[2] Ecoinvent v2.2

[3] Reiner, M., M. Pitterle, and M. Whitaker. 2007. How do you define green? Embodied energy considerations in existing LEED credits. http://www.oriental-bamboo.co.za/reference/embodied_energy_considerations_in_existing_leed_credits.pdf. Accessed October 2017.

Lightweight Concrete

Relatively new concept

Examples:

- US Patent 7,407,615 B2 (Aug. 5, 2008) Method for Producing Concrete or Mortar using a Vegetal Aggregate. Inventor: Heribert Hohn; Assignee: Miscanthus-Holding, S.A., Luxembourg
- Y. Chen, Q. L. Yu, H.J. H. Brouwers, "Acoustic Performance and Microstructural Analysis of Bio-based Lightweight Concrete Containing Miscanthus," *Construction and Building Materials* **157** (2017) pp. 839 – 851.
- "Design of an Innovative Bio-Concrete using Miscanthus Fibres," J. E. S. Ezechiels (Master's Thesis, Eindhven University of Technology) 2017.

From http://www.belalternative.be/AlternHome-le-Miscanthus.html

Lightweight Concrete … Some Data

- One common goal / theme … “mineralize” vegetable fiber

- Densities ranging from 0.650 – 1.250 Mg/m^3
- Want compressive strengths exceeding 2.5 Mpa.
- Correlates with densities greater than or equal to 0.800 Mg/m^3
- Strength behavior correlates with that of other fillers used to obtain lightweight concrete
- At a density of 0.800 Mg/m^3, the thermal conductivity would be approximately 0.17 $W/m \cdot K$ (increases with increasing density)

Data from “Masonry Blocks from Lightweight Concrete on the Basis of Miscanthus as Aggregates,” D. Waldmann, v. Thapa, F. Dahm and C. Faltz, in Perennial Biomass Crops for a Resource-Constrained World (S. Barth et al. (Eds.) (Springer International, 2016).

Lightweight Concrete

When considering metrics, units are key.

- 9 vol% fiber yields a density reduction of 20%.
- 9 vol% $\Rightarrow$ 0.98 wt% in mix

Primary production quantities for structural lightweight concrete:

- Embodied energy $\Rightarrow$ 335 – 369 BTU/lb
- CO_2 footprint $\Rightarrow$ 0.116 – 0.128 lb/lb
- Water usage $\Rightarrow$ 0.229 – 0.253 ft^3/lb

Miscanthus Biocomposites

http://us.archello.com/en/materials/other-naturals/unknown?page=6

Research Results:

- Poly(butylene succinate)-perennial grass

  R. Murhuraj, et al., *ACS Sustainable Chem. Eng.* (2015) **3,** pp. 2767 – 2776.

- Poly(3-hydroxybutyrate-co-hydroxyvalerate)-miscanthus core materials

  K. Zhang, et al., *Macromol. Mater. Eng.* (2014) **299**, pp. 436 – 446.

- Biodegradable binary blend-miscanthus

  R. Muthuraj, et al., *RSC Adv.* (2014) **7**, 27538 – 27548.

Lignocellulosic Biocomposites

- Typical fiber properties

Fiber	Density (Mg/m^3)	Tensile Strength (GPa)	Specific Modulus ($GPa/kg/m^3$)	Elongation to Break (%)
E-glass	2.550	2.400	29	3
Flax	1.4	0.8 – 1.5	26 – 46	1.2 – 1.6
Jute	1.46	0.4 – 0.8	7 – 21	1.8

Miscanthus Biocomposites

Early comparison
(natural fibers with E-glass fiber)

	E-glass[1]	Kenaf[2]	Bamboo[3]
Cost (USD/lb)	0.739 – 1.48	0.118 - 0.236	0.608 - 0.912
Cost (USD/ft^3)	118 - 240	22.8 – 45.6	22.8 – 45.6
Density (lb/ft^3)	159 – 162	74.3 – 75.0	37.5 – 49.9
Embodied Energy (10^4 BTU/lb)	2.12 – 2.33	2.76 – 3.04	6.15 – 6.79
CO2 footprint (lb/lb)	2.85 – 3.14	2.67 – 2.94	0.00194 - 0.00214
Water Usage (ft^3/lb)	1.44 – 1.59	8.02 – 24.0	1.06 – 1.17

Data obtain via CES Selector 2017 (Granta Design LTD)

[1] Econinvent v2.2, among others

[2] Ecoinvent v2.2

[3] Reiner, M., M. Pitterle, and M. Whitaker. 2007. How do you define green? Embodied energy considerations in existing LEED credits. http://www.oriental-amboo.co.za/reference/embodied_energy_considerations_in_existing_leed_credits.pdf. Accessed October 2017.

Preliminary Data

- Consider R. Muthuraj, et al., *RSC Adv.* (2014) **7**, 27538 – 27548 … poly(butylene succinate)/poly(butylene adipate-*co*-terephthalate blends for matrix

	Tensile Strength (MPa)	Tensile Modulus (MPa)	Flexural Strength (MPa)	Flexural Modulus (MPa)
Matrix only	32.5	350	17	750
30 wt% fiber	20	1350	35	1500
30 wt% fiber + 5 wt% compatibilizer	27.5	1400	42	1550
50 wt% fiber	17	2100	30	2200
50 wt% fiber + 5 wt% compatibilizer	30	2450	49	2700

Bottom Line on Sustainability

- Need to establish more specific & detailed databases to better establish sustainability
- Fiberboard applications
  - Some advantage in water use
  - Drivers will be cost & performance
- Lightweight Concrete
  - Density reduction but little contribution to sustainabililty
  - Gain is with less material per volume
- Biocomposites
  - Several trade-offs between metrics
  - Advantages
    - Lower costs
    - Lower densities

Possible Metrics Applicable to Building Materials

- Fraction of renewable mass in the product …Possible reduction in materials usage?
- Composite product qualities:
  - Compressive strength, shear strength, impact resistance, Young's modulus, tensile strength, flexural strength, and heat deflection temperature.
  - Thermal conductivity, acoustic qualities, and fire safety rating
- In terms of total life cycle …
  - Metrics associated with construction, including possible efficiencies
  - Metrics associated with maintenance
- Greenhouse gas emissions and carbon footprint
- Durability, including impact on end of use

Further Sustainability Questions

There is a need to understand fate of contaminants during the total lifecycle

- Clarity with uptake
- Fate within miscanthus and possible return to environment
- Residuals within products and their impact
- Impact with end of life