De-Risking & Scale-Up of Bio-Based Technologies

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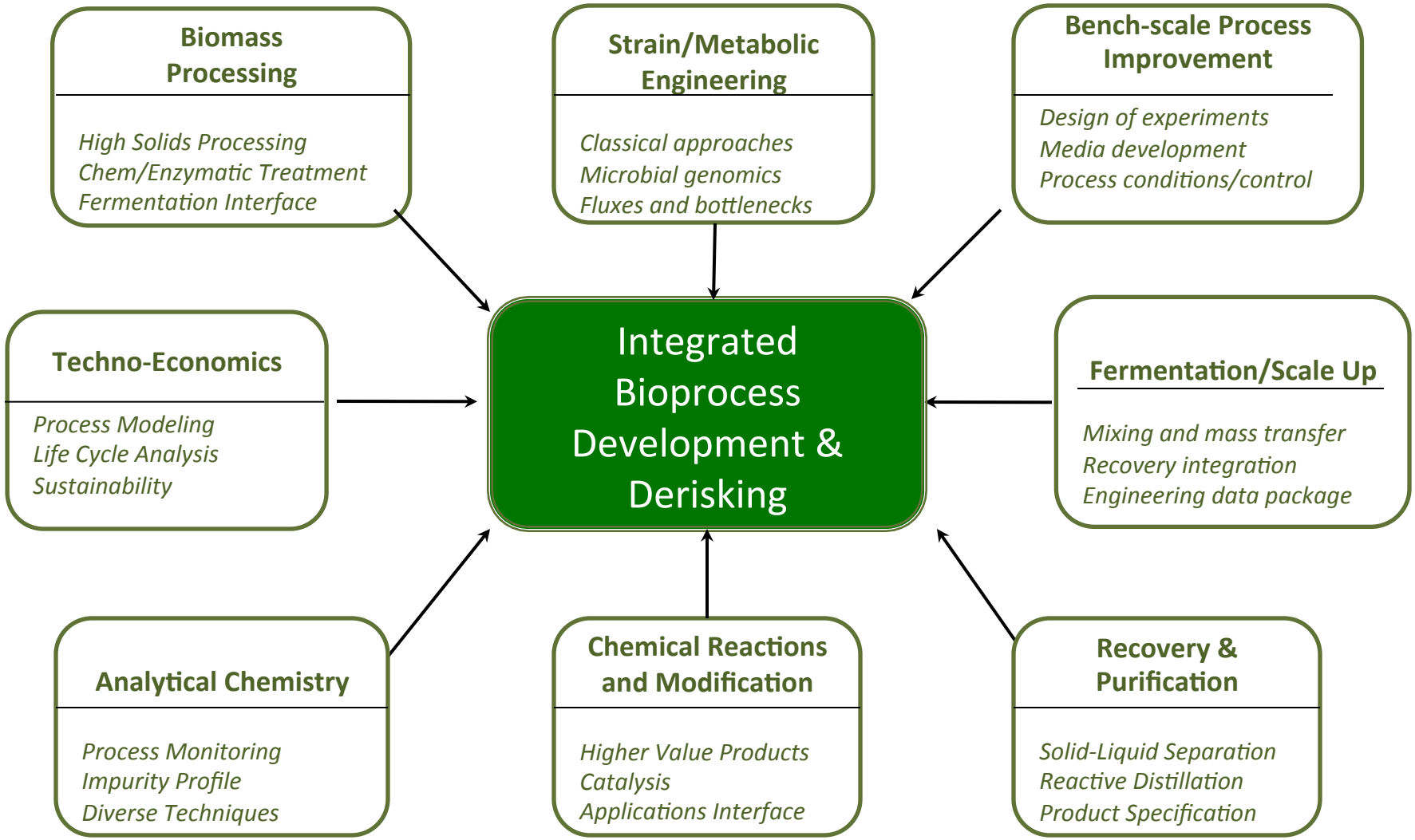
mbi® | De-Risking and Scale-Up of Bio-Based Technologies

MBI: Mission and Capabilities

- **Who we are**: Not-for-profit, founded in 1981, subsidiary of MSU Foundation
- **Mission**: Accelerate development, scale-up and commercialization of bio-based technologies
- **What we do**: develop and derisk early stage bio-based technologies, demonstrate commercial viability, transition to commercial partners
- **Capabilities**: biomass processing, strain engineering, bench and pilot fermentation development, downstream processing

MBI Capabilities & Resources



MICHIGAN STATE UNIVERSITY

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Technology Readiness for Bio-based Processes

Phase	TRL	Maturity Level
Commercial Deployment	9	Large-scale commercial operations
	8	Semi-works-scale technology demonstration
Commercial Transition	7	Detailed engineering /plant design
Viability Demonstration	6	Scale up and pilot-scale technology validation
	5	Production enhancements/techno-economic model
Technology Development	4	Lab-scale development and integration
Feasibility Demonstration	3	Lab-scale experimental proof of concept
	2	Technology application formulated
Basic Research	1	Promising research finding

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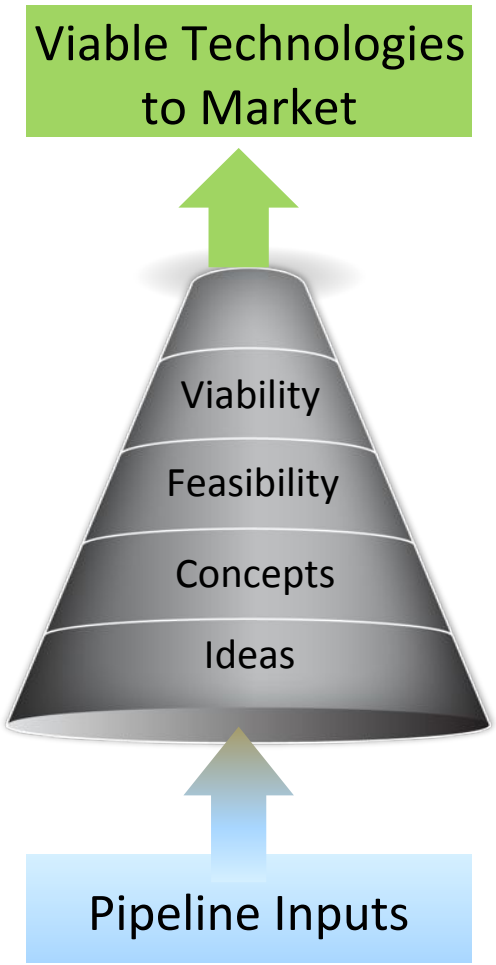
De-Risking: Disciplined, Methodical Management of Risk



Idea Stage:

- Identify a technology approach and a commercial need it addresses

Concept Stage:

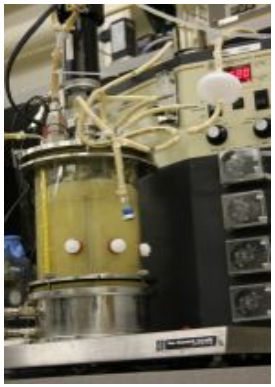
- Identify, characterize and prioritize risks

Feasibility Stage:

- Address "Deal Breaker" risks first
- Confirm approach is technically feasible

Viability Stage:

- Technology development phase, to hit commercial targets
- Process scale up to pilot scale (2-3800 L)
- Generate commercially viable technology transfer package
- Produce samples (100+ kg) for customer qualification



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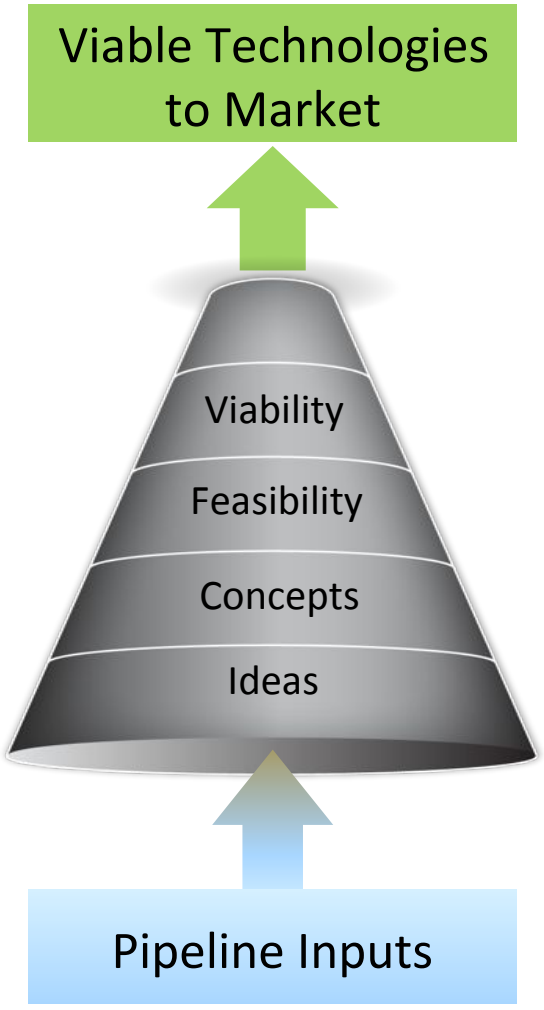
MBI Pipeline – Demonstrated Success



- Projects can enter the pipeline at any stage
- We have run successful projects with organizations large & small, public & private, for-profit & not-for-profit
- Pipeline typically includes a mix of internal MBI projects and external collaborations

NatureWorks®

DUPONT®

novozymes® Rethink Tomorrow

opxbio good chemistry.

Draths CORPORATION

AMYRIS

genomatica sustainable chemicals

MSU BioEconomy Network COLLABORATE. DISCOVER. INNOVATE.

GREAT LAKES BIOENERGY RESEARCH CENTER

CBiRC NSF Engineering Research Center for Biorenewable Chemicals

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Case Study

AFEX™: Unlocking the Potential of Biomass

The Challenge:

Ag residue biomass is low density
Inefficient to store or transport
Potential for spoilage
Not close to biorefineries

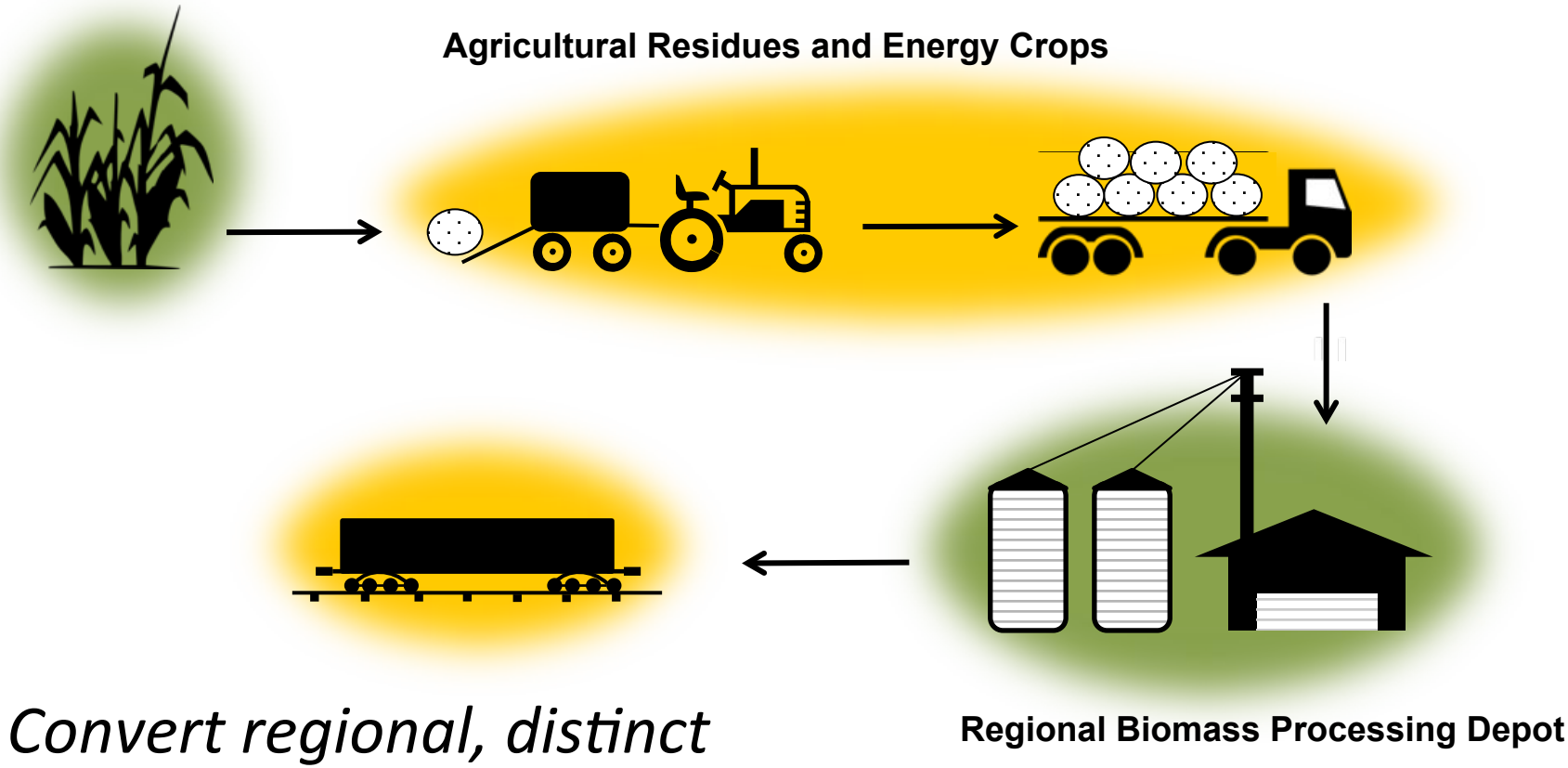
Biomass Logistics Challenges

Requirements for a 100 million gallon/ year ethanol plant

	Corn Grain Refinery	Corn Stover Biorefinery
Bulk density (kg/m^3)	700	120
Collection radius (miles)	20	**40**
Farms to contract with	N/A	**2600**
Storage footprint	37 acres	**630 acres**

Images courtesy of NREL (www.nrel.gov)

Decentralization Solution: Move Processing Closer to the Farm



Convert regional, distinct biomass sources into ***dense, stable, shippable intermediate commodities***

Key Elements of Regional Biomass Processing Depots (RBPDs)

***Functions of RBPDs*:**

- Purchase biomass (corn stover, rice straw, grasses) from growers
- Short term storage of biomass
- Size reduction of biomass, separate dirt
- Biomass densification
- Biomass pretreatment?

***Pretreatment processes for RBPDs require*:**

- Low capital costs
- Economic scale-down (100-200 tons/day)
- Suitability to a wide variety of feedstocks
- Low water use
- Simple operation

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The Solution:

AFEX™

Ammonia Fiber Expansion Process

"Unlocking the Power of Biomass"

A ***transformational technology*** to create a cost efficient, storable, readily transportable ***biomass commodity*** utilizing ***decentralized*** AFEX depots

The AFEX Solution:

- Transformational Technology
- Multiple viable market applications
- Decentralized biomass processing

The AFEX Process

AFEX Reactor System

Biomass Prep

Pre-heat, NH_3 Charge, Soak, Expansion, NH_3 Stripping

Drying , Pelletizing

The 5 Step AFEX Process:

1. Pre-steam (add moisture & heat)
2. Ammonia charge
3. Ammonia soak
4. Expansion
5. Ammonia stripping & recycle

AFEX Is A Transformational Technology

AFEX Process:

- Suitable for many types of grasses and agricultural residues
- No degradation of hemicellulose
- No wash streams or liquid waste
- Low chemical usage due to ammonia recycle
- Improves the digestibility of biomass for use as a hydrolysis/fermentation feedstock or directly as an animal feed

Impact on RBPD Concept:

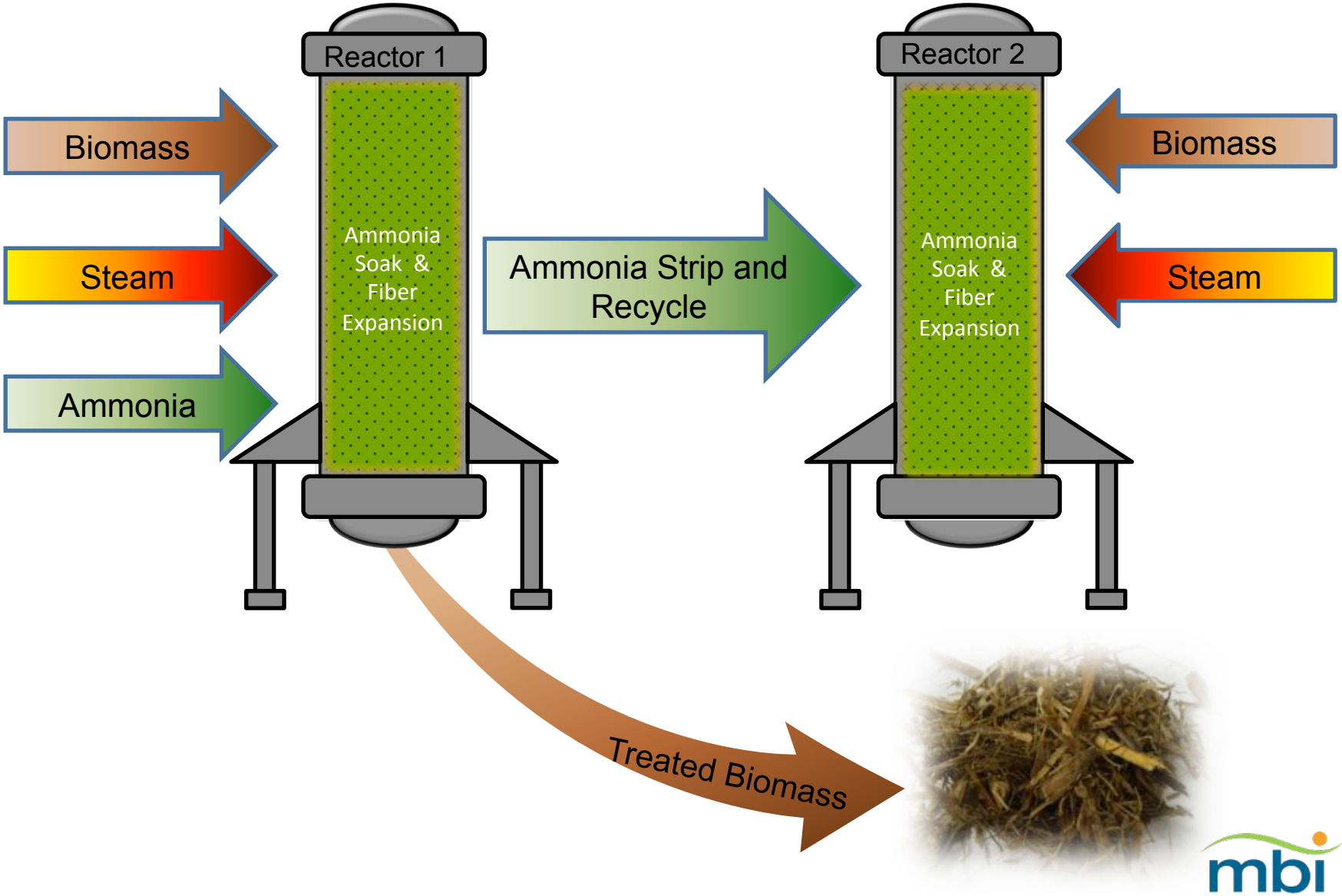
- Low capital cost
- Easy to scale down
- Simple operation
- Stable, conversion-ready product with multiple markets

MBI develops low-cost AFEX™ reactor

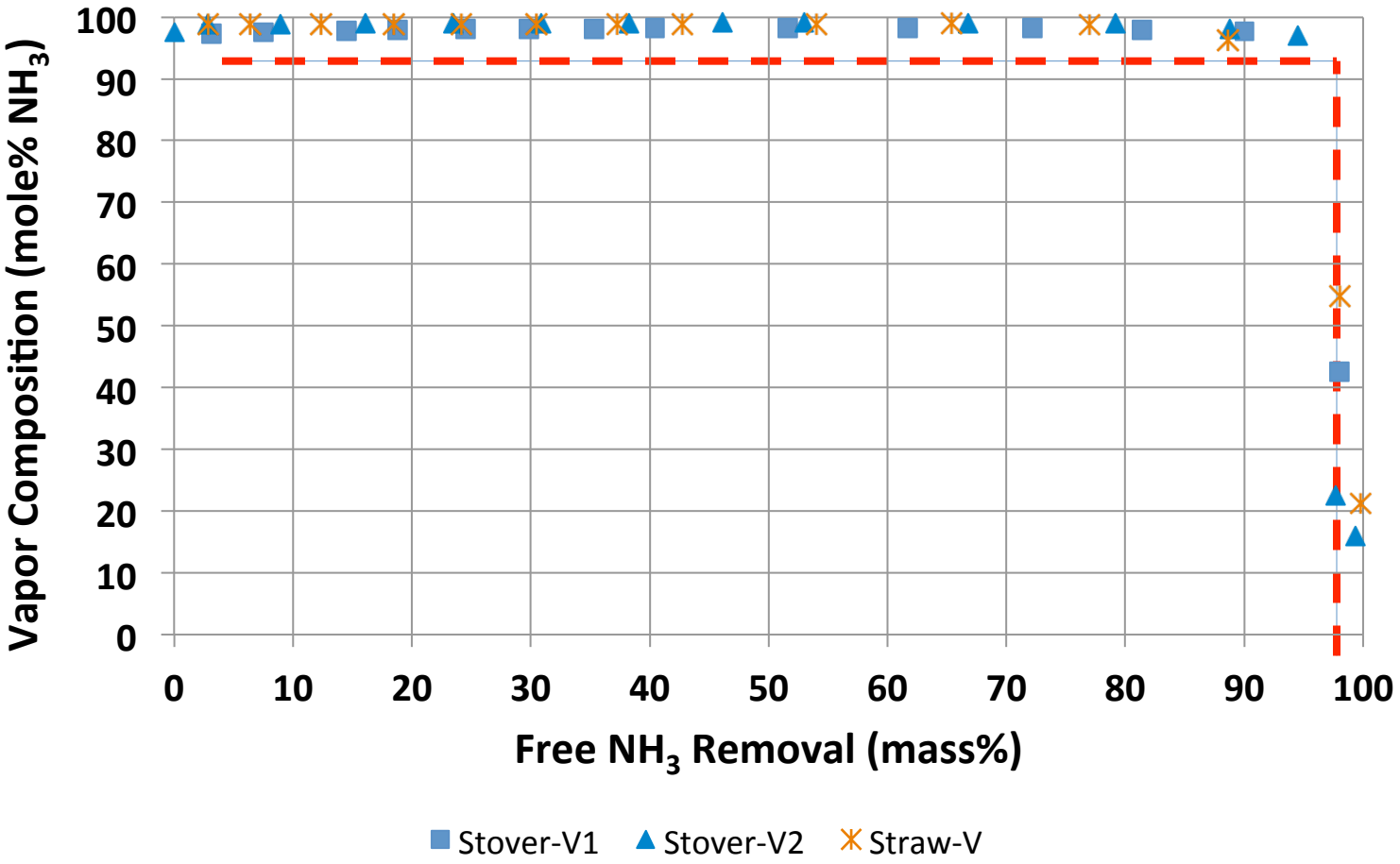
Performance in 10-L prototype meets ideal-batch reactor benchmarks

Ammonia recovery & reuse demonstrated

The AFEX Process



Ammonia Recovery & Recycle



NH_3 removed as <u>dry</u> vapor

Pilot Scale AFEX

- **DOE Award 2011**
  - **$5.3 Million**
  - **100-fold Scale-up**
- **Project partners**
  - **Idaho National Lab**
  - **Michigan State University**
- **Engineering/design 2011-2012**
- **Installed March 2013**
- **Bed dimensions (2):**
  - **17 inch D X 110 inch L**
  - **30 – 40 kg biomass per bed**
- **In operation since July 2013**

Bruce Dale
University Distinguished Professor
Michigan State University

Unique AFEX Attribute - Densification

	AFEX-treated, loose	AFEX-treated, pellets
Corn stover		
Wheat straw		

Bulk Density Increases from <60 kg/m^3 to >500 kg/m^3

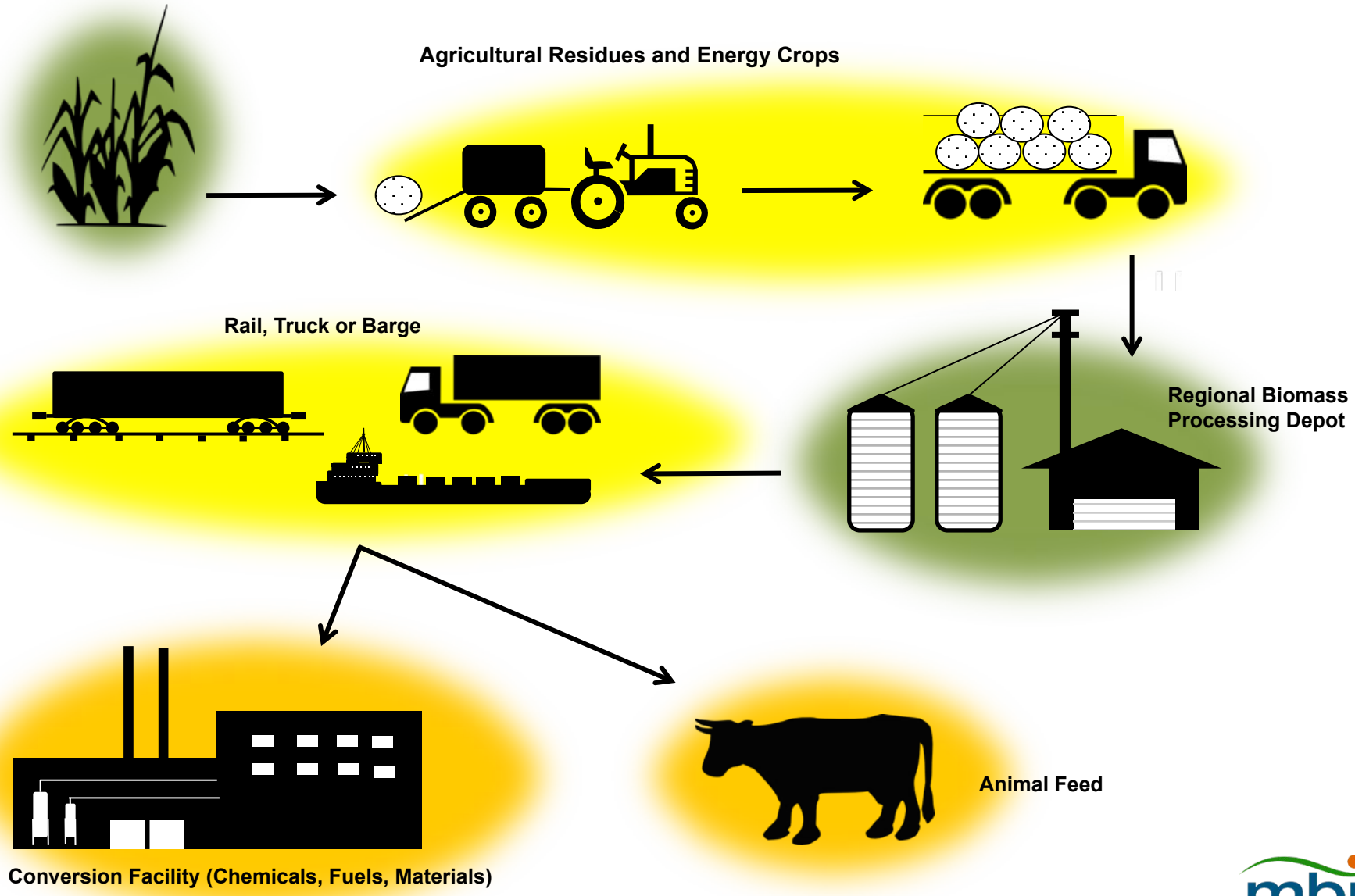
The AFEX Solution:

Transformational Technology

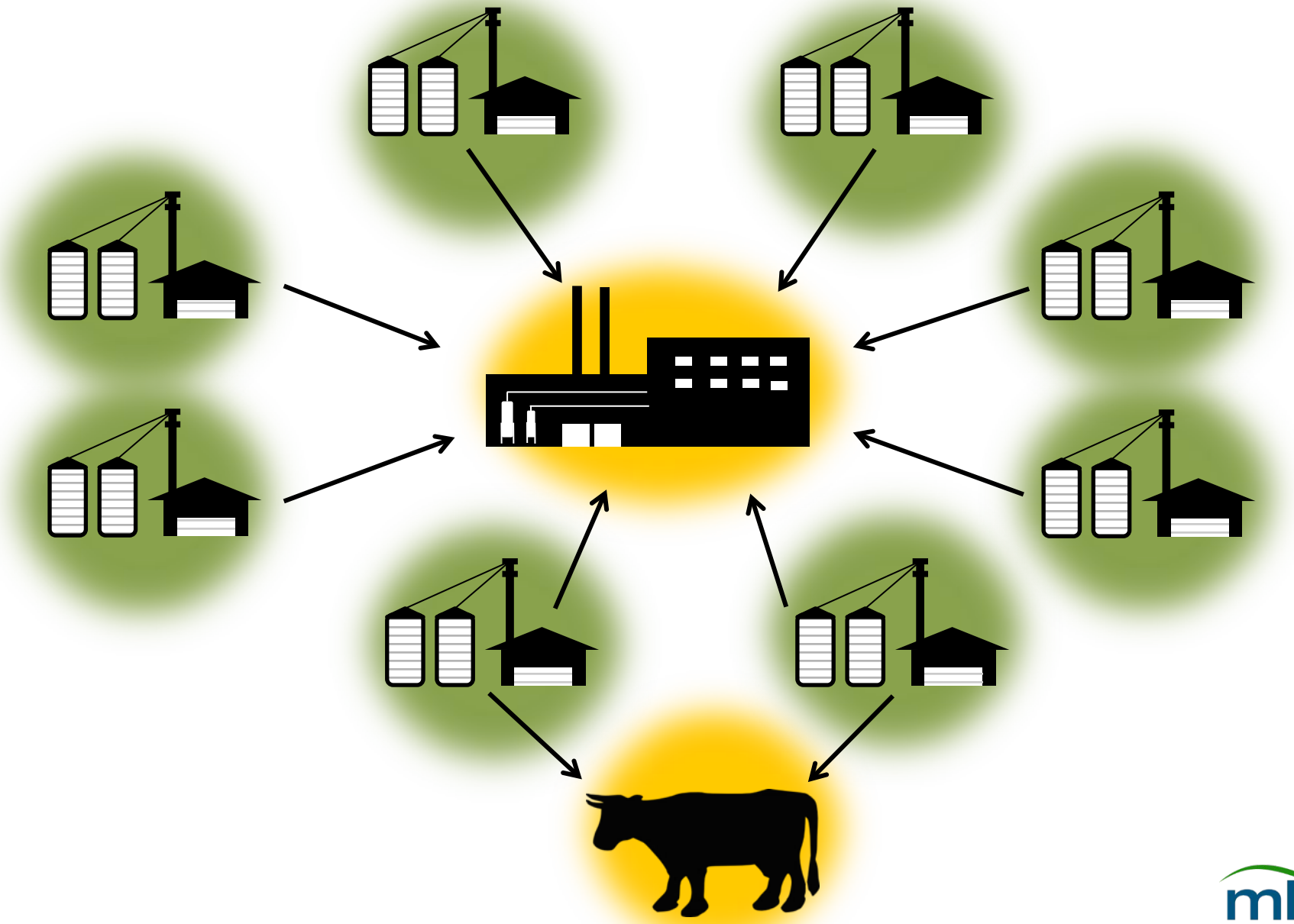
Decentralized biomass processing

Multiple viable market applications

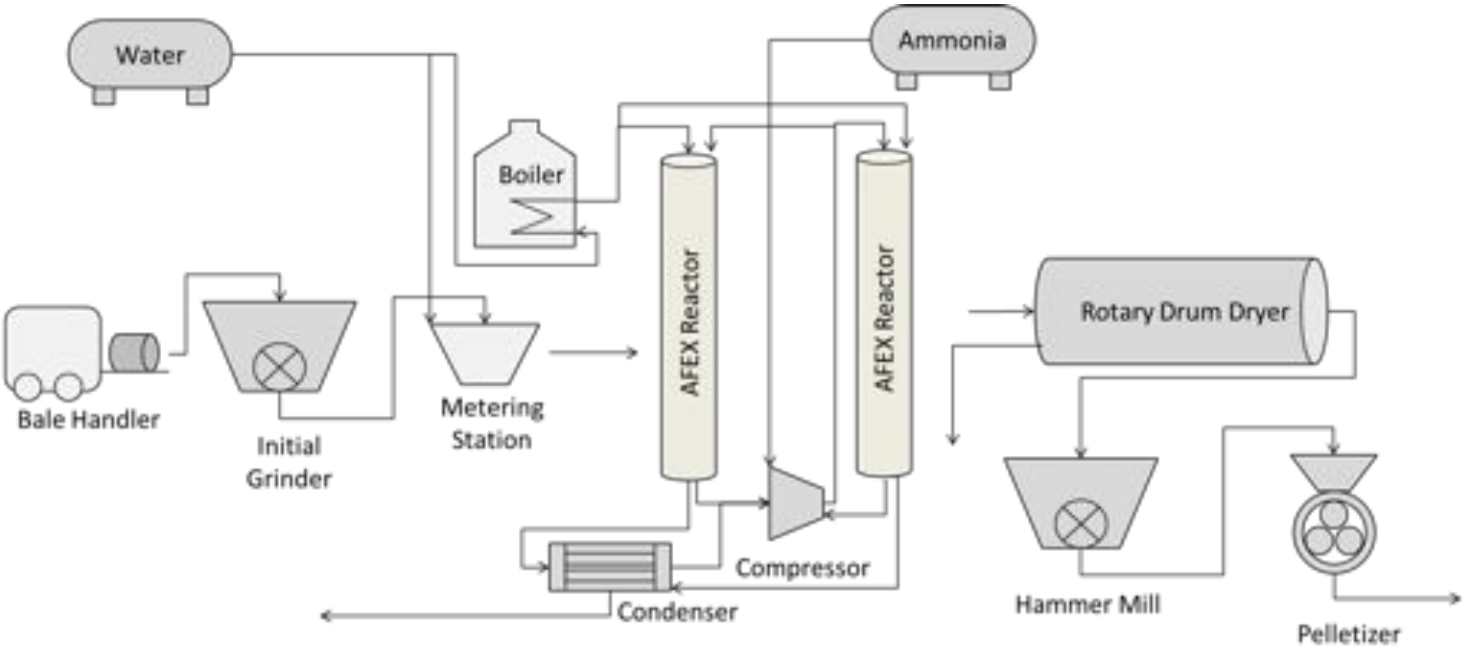
Biomass Processing Depots



Biomass Processing Depots



Packed Bed AFEX for RBPDs



- **Upstream of AFEX**
  - Bale storage, initial (<1") particle size reduction, moisture adjustment
- **Downstream of AFEX**
  - Rotary dryer, final (<1/4") particle size reduction, pelletization, pellet storage

For 100 TPD capacity

Bed dimensions (4):

- 5 foot D X 30 foot L
- 1,500 – 2,000 kg biomass per bed

AFEX Processing Costs = $50 to $75 per ton

Assumptions:

- Throughput 100-200 metric tons per day
- Brownfield site, some existing infrastructure
- Capital investment $8.5 - $15 million

Category	Cost Breakdown ($ per ton biomass)
Labor	9 - 17
Maintenance	4 - 5
Utilities	12-13
Ammonia	12-16
Subtotal	35-51
Depreciation	13-16
Cost of Capital/Interest	5-7
Total	50 - 75

The AFEX Solution:

Transformational Technology

Decentralized biomass processing

Multiple viable market applications

AFEX Pellets: A Versatile Biomass Commodity

- Biorefinery sugar feedstock
- Releases 75+ % of sugars for fuels and chemicals

- Ruminant animal feed for beef and dairy cattle
- Potential to displace corn grain

Sugars for Biorefinery
High Solid Loading Hydrolysis and Fermentation

Enzyme Hydrolysis of AFEX Pellets

Pelleted AFEX treated corn stover

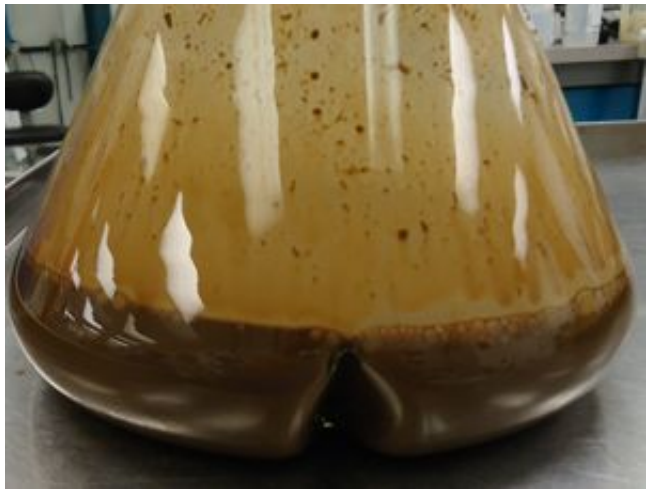
Water + enzyme

20% solid loading

0 hr

@50°C
200 RPM
shaker

1 hr



4 hr

Summary:

Enzyme :
Ctec 3+ Htec 3(Novozymes)

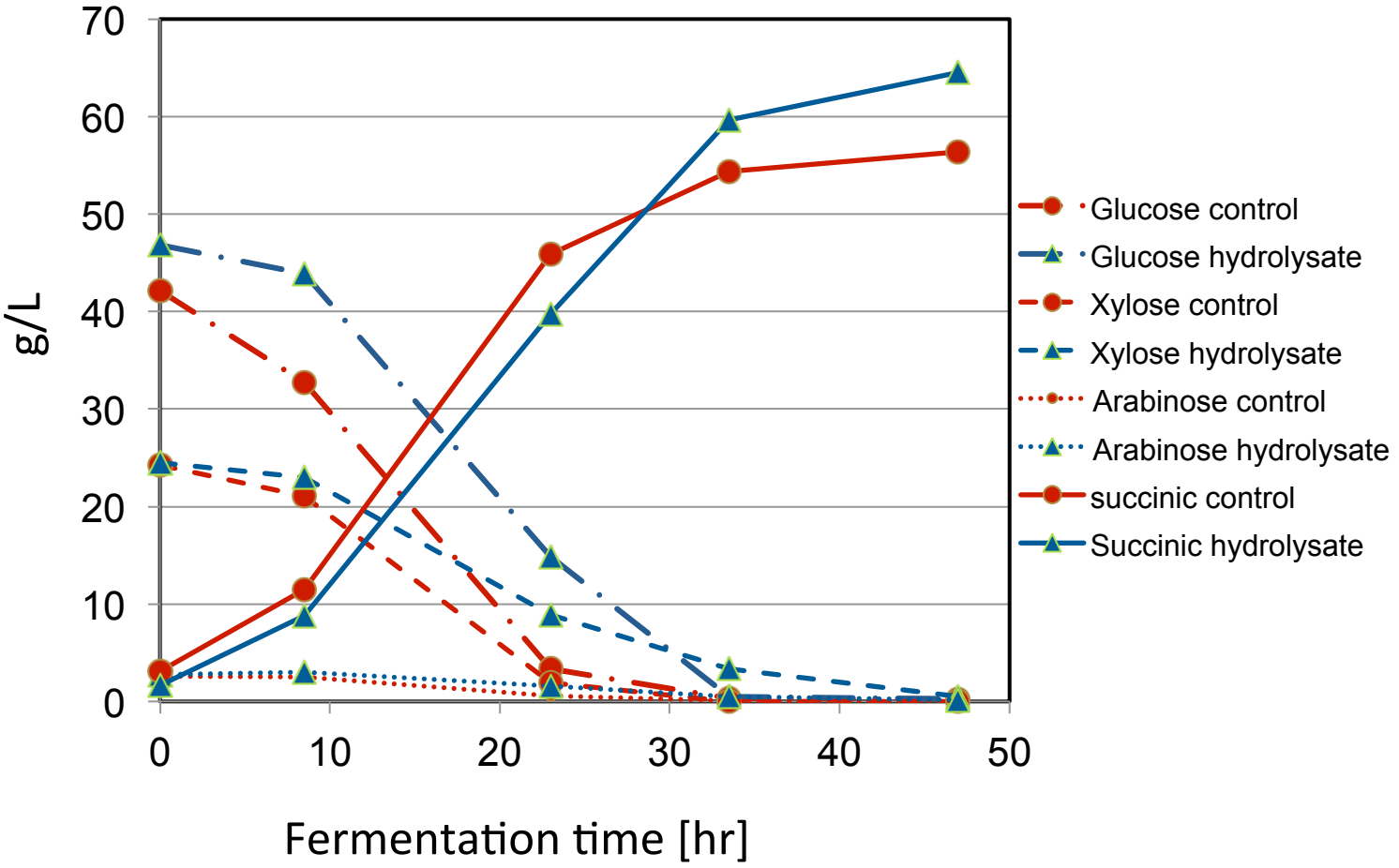
Enzyme loading:
20mg of enzyme protein/ g glucan

Hydrolysis Time: 72 hr

Glucose yield: 75%

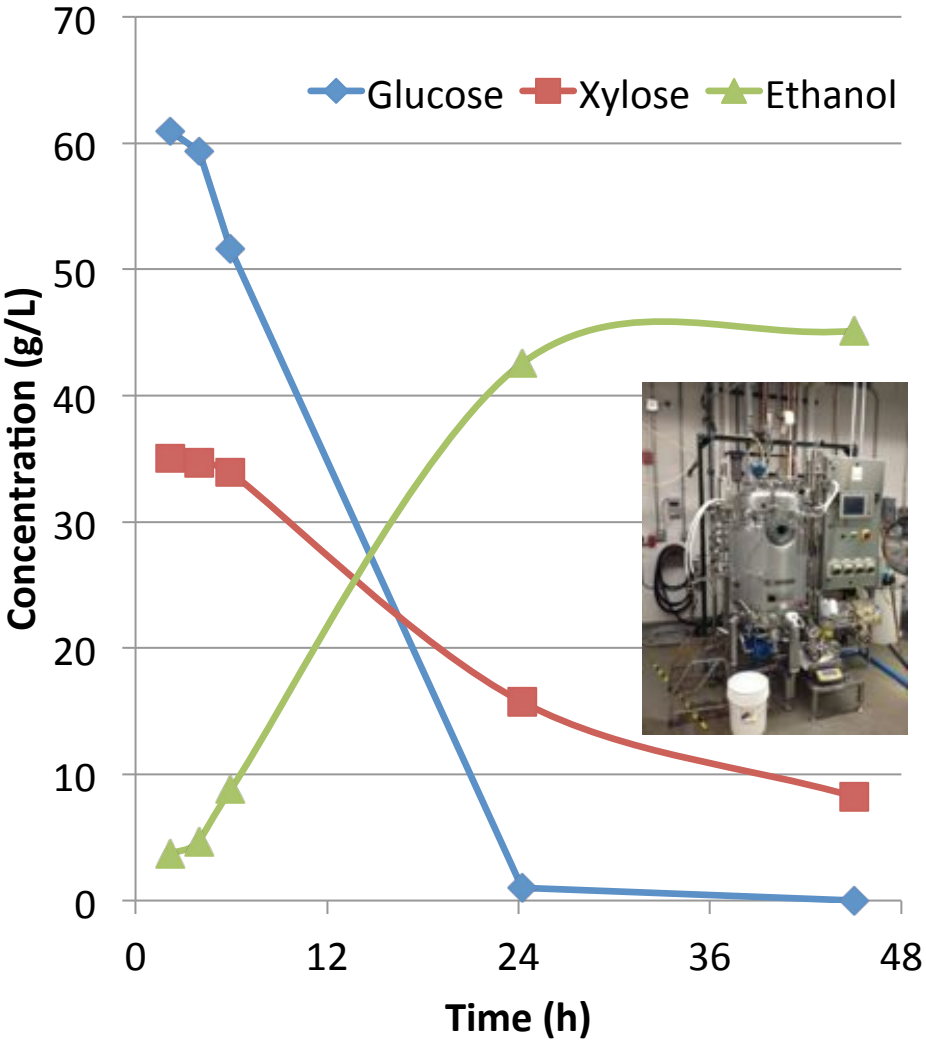
Xylose yield: 69%

Biomass: Pelleted AFEX treated Corn Stover
Product: Succinic Acid
Microorganism: Actinobacillus succinogenes



Fermentation of AFEX Pellets - Ethanol

- 20% solids loading of AFEX pellets
- Sterilized water and enzymes added
- Did not remove unhydrolyzed residue prior to inoculation
- SHF fermentation using *Z. mobilis* (utilizing both C5 and C6)
- Glucose completely consumed within 24 hours
- Xylose ~80% consumed after 48 hours

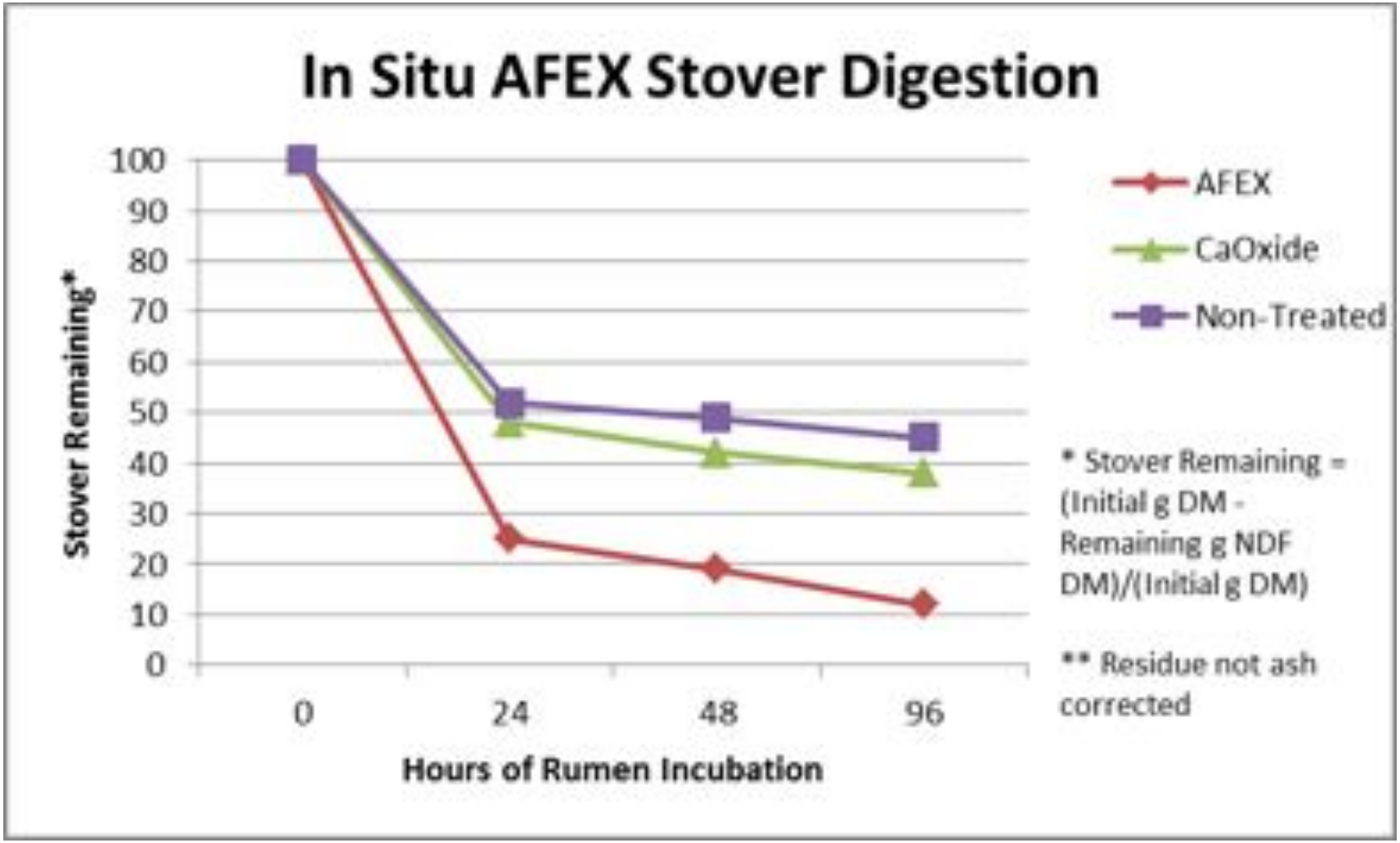


Value Proposition: Biorefinery Feedstock

Category	Cost ($ per ton biomass)
Harvested Biomass	50 - 70
Depot Processing	50 - 75
Subtotal	100 - 145
Transport to biorefinery	5 - 10
Enzyme hydrolysis at biorefinery (NREL Estimate)	25 - 50
Total	$130 - 205

- At yields of 1000 pounds of sugar per ton of biomass, sugar costs are estimated at $0.13 – $0.20 per pound
- *Corn sugar cost is $320/ton (16 cents/lb) at $6 per bushel*

AFEX-treated Biomass as a Rumen Feed Ingredient


In Situ AFEX Stover Digestion
Stover Remaining*
100
90
80
70
60
50
40
30
20
10
0
0
24
48
96
Hours of Rumen Incubation
AFEX
CaOxide
Non-Treated
* Stover Remaining = (Initial g DM - Remaining g NDF DM)/(Initial g DM)
** Residue not ash corrected

Rumen Feed Ingredient

Pellets break down in the rumen to release sugars and provide a nutritional energy source similar to that provided currently by grain.

MBI recent progress and development in using AFEX treated pellets for animal feed

- In 2012:Completed preliminary palatability trials in sheep using pellets made with AFEX treated corn stover with positive results.
- In 2013: Through collaboration with Michigan State University (MSU) a funding source was secured for a cattle feed efficacy trial.

Cattle Feeding Trial at Michigan State University

Steven Rust
Professor, Beef Cattle Nutrition & Management
Department of Animal Science

MICHIGAN STATE UNIVERSITY

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Ongoing Cattle Feed Trial

Trial started on September 19th 2013

- ***Location:*** MSU Beef Cattle Teaching and Research Center, led by Dr. Steve Rust, Department of Animal Science
- ***Purpose:*** To determine if pelleted AFEX treated corn stover can be substituted for corn grain as an energy component in feed
- ***Duration:*** 160 days
- ***Number of cattle:*** 24 Holstein beef steers, 12 on standard feedlot diet as control, and 12 on diet containing 30% AFEX treated corn stover pellets
- ***MBI's role:*** Providing 10 tons AFEX treated corn stover pellets
- ***Collected data:*** Palatability, weight gain, carcass meat quality

Value Proposition: Animal Feed

Category	Cost ($ per ton pellets)
Harvested Biomass	50 - 70
Depot Processing	50 - 75
Subtotal	100 - 145
Transport to Market	0 - 10
Total	100 - 155

- Estimated costs of AFEX pellets is $100 - $155 per ton
- *At $6 per bushel , corn grain costs $214/ton*

The AFEX Solution: Global Impact

Opportunity:

2 Billion tons of agricultural residue/yr from corn, wheat, rice

Potential Impact:

- 1 Billion tons of AFEX pellets as animal feed = 1.2 Billion tons of milk = nutritional protein demand for 25% of world population
- 1 Billion tons of AFEX pellets as biorefinery feedstock could replace 56 Billion gallons of gasoline, 40% of US annual demand
  - Elimination of 1.3 Billion barrels of oil consumption = 680 Million tons of CO_2 reduction, 9% of US annual emissions
- Rural depots create significant opportunity for economic development and new jobs

Acknowledgements

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"Unlocking the Power of Biomass"

Thank You!

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