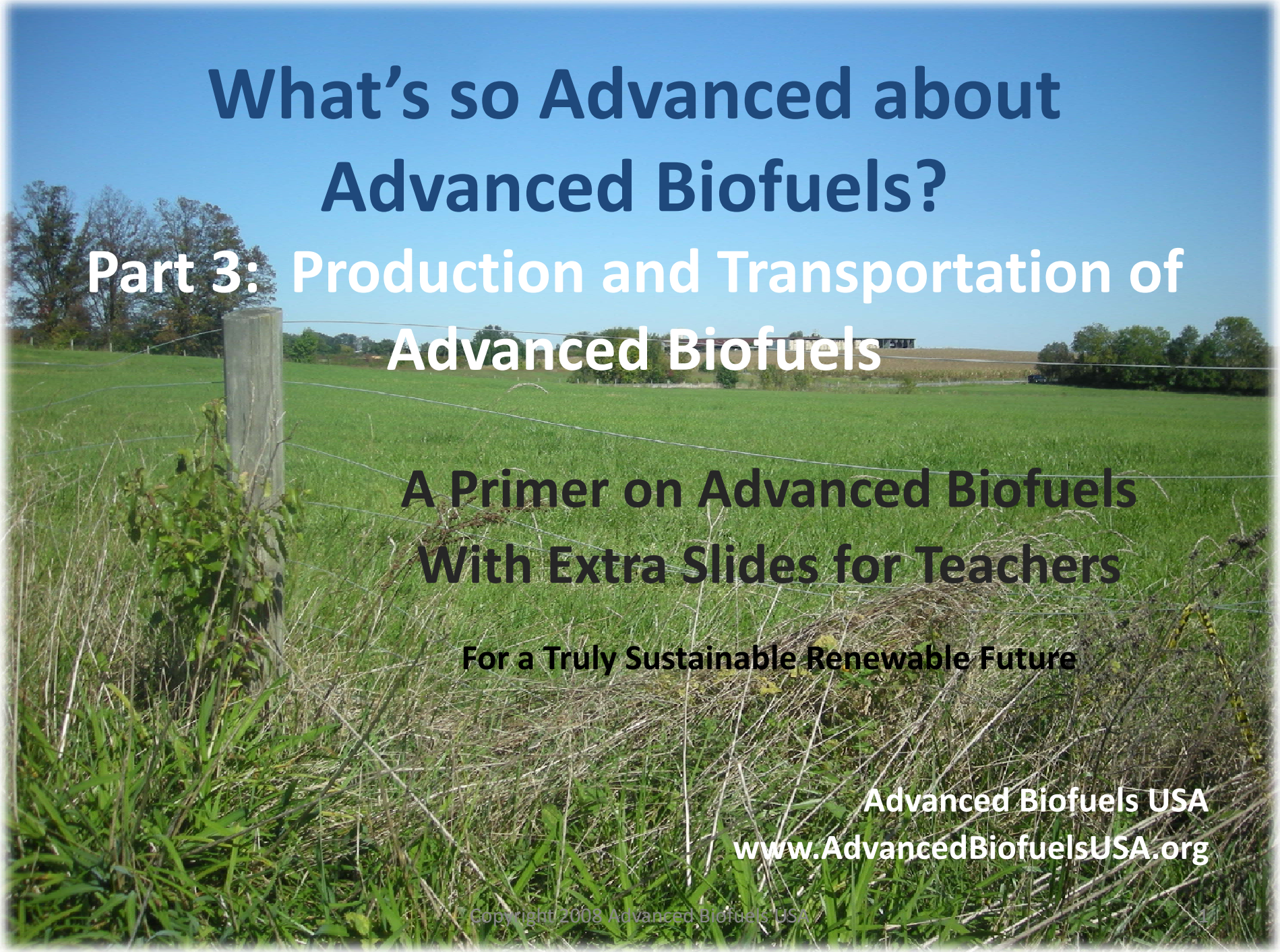


What's so Advanced about Advanced Biofuels?

Part 3: Production and Transportation of Advanced Biofuels

A Primer on Advanced Biofuels With Extra Slides for Teachers

For a Truly Sustainable Renewable Future

Advanced Biofuels USA
www.AdvancedBiofuelsUSA.org

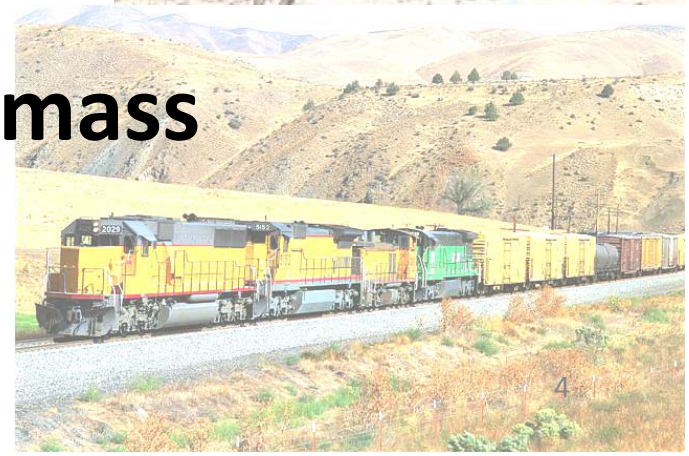
Extra Slides

- This teaching tool complements "What's so Advanced about Advanced Biofuels," a slide presentation about creating sustainable, low-input, high energy output renewable liquid fuels.
- It includes, after the presentations, slides with
  - Questions and thoughts about the presentation
  - Class projects adaptable to all ages
  - Advanced class research suggestions

How Will We Economically Produce and Transport Renewable Advanced Biofuels?

Economical Sustainable Advanced Biofuels

- Crop development
- Waste and Residues
- Use Existing Infrastructure
  - Processing
  - Transportation
- Increase Efficiencies in Biomass Conversion



How will We Economically Produce Renewable Advanced Biofuels?

- Develop **sustainable energy crops** , with low nutrient inputs and high per acre yields, tailored to specific environments
- Identify **agricultural and forestry waste and residues** that can be used for feedstock
- Develop **high conversion efficiency** processing and production technologies including breakthroughs in enzymatic and biochemical processes

How will We Economically Produce Renewable Advanced Biofuels?

- **Utilize existing** refinery, transportation and distribution **systems** whenever necessary
- Assure that **complete production systems are sustainable**, environmentally, economically and socially

Overcoming the Technical Roadblocks to Low-Cost Advanced Biofuel Production

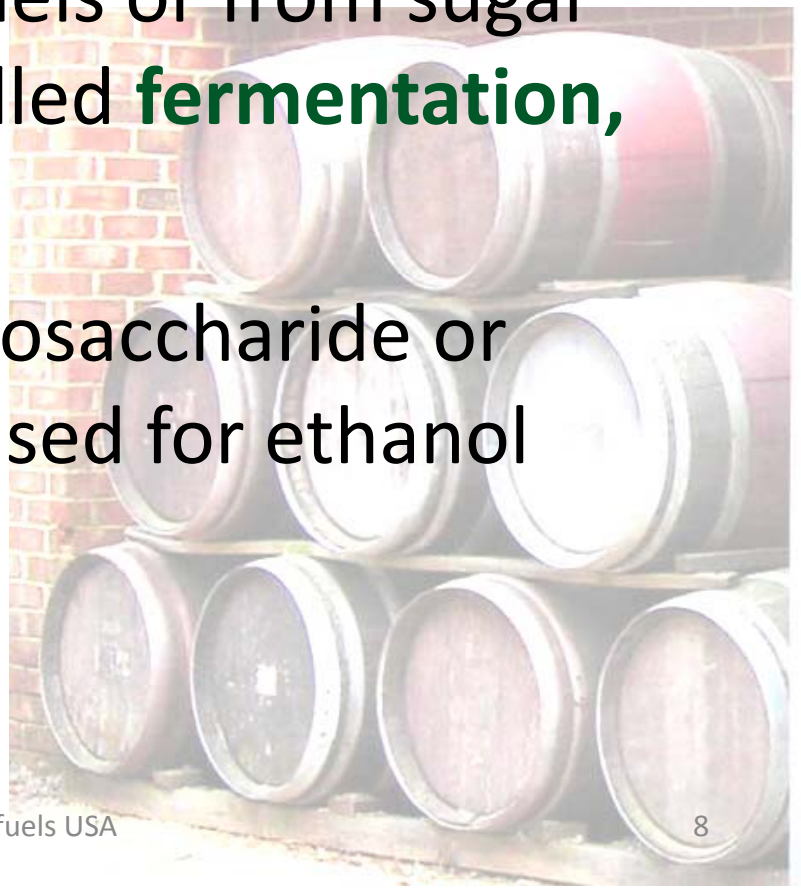
1. Make **all components of biomass** available for biofuel production (*Use the whole plant*)
2. Improve the **efficiency** of biomass to biofuel **conversion** (*Do it faster, cheaper, sustainably*)
3. **Minimize** the cost of biomass **transportation** (*Move more for less*)

University, industry, and government researchers are pursuing a number of different paths to overcome these technical barriers

Making Plant Biomass Available for Biofuel Production

1. Overcoming The **Limits of Sugar Fermentation**

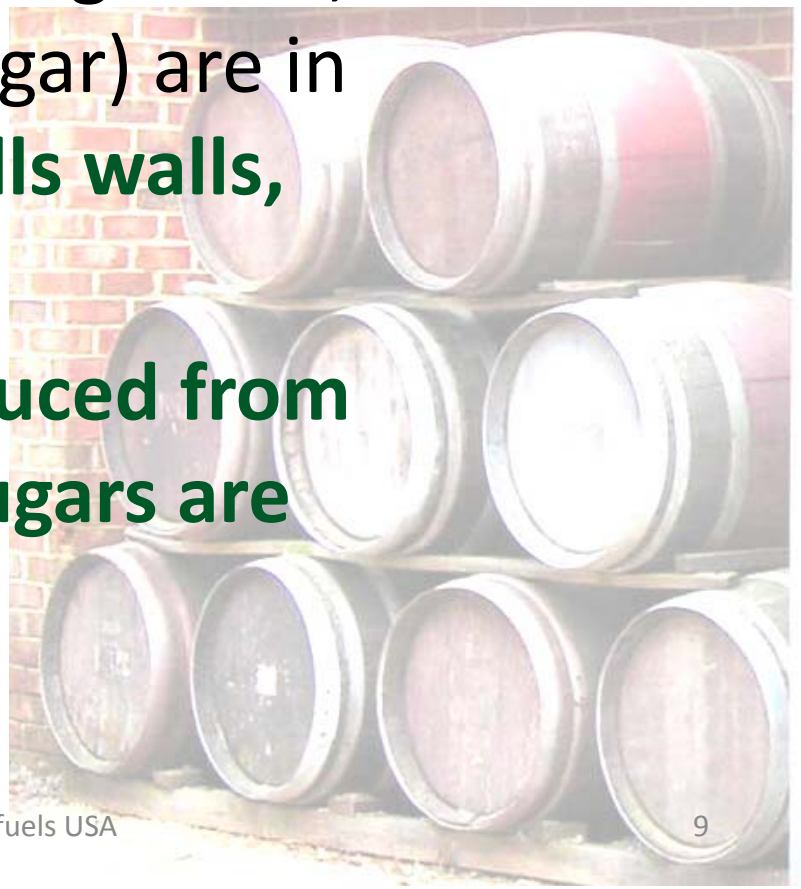
- Ethanol made from corn kernels or from sugar cane is made by a process called **fermentation,** or anaerobic respiration.
- **Only single or two unit**, monosaccharide or disaccharide, **sugars** can be used for ethanol fermentation



Making Plant Biomass Available for Biofuel Production

1. Overcoming The **Limits of Sugar Fermentation**

- These “simple” sugars, such as glucose, fructose, or sucrose (table sugar) are in **limited supply in all plant cells walls, except for fruits**
- So, **supplies of biofuels produced from naturally occurring simple sugars are limited**



Making Plant Biomass Available for Biofuel Production

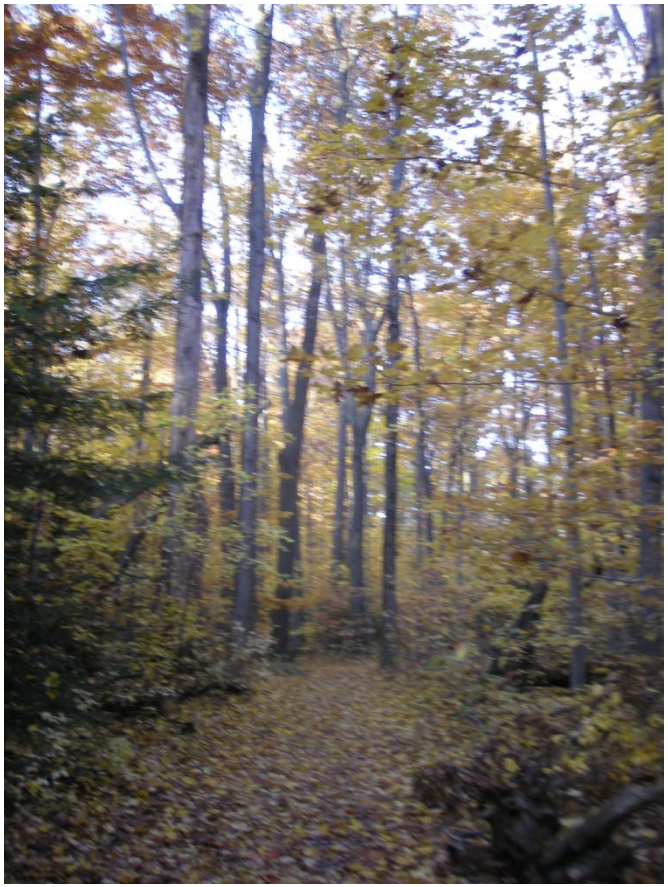
2. **Sugar** Availability in **Plant Cell Walls**

- Additional “simple” sugars are available in **plant and tree cell walls,** but are in more **complex forms** that are not readily available for biofuel production

- Plant cell walls are composed primarily of three components: **cellulose, hemicellulose, and pectin**

Making Plant Biomass Available for Biofuel Production

2. **Sugar** Availability in **Plant Cell Walls**



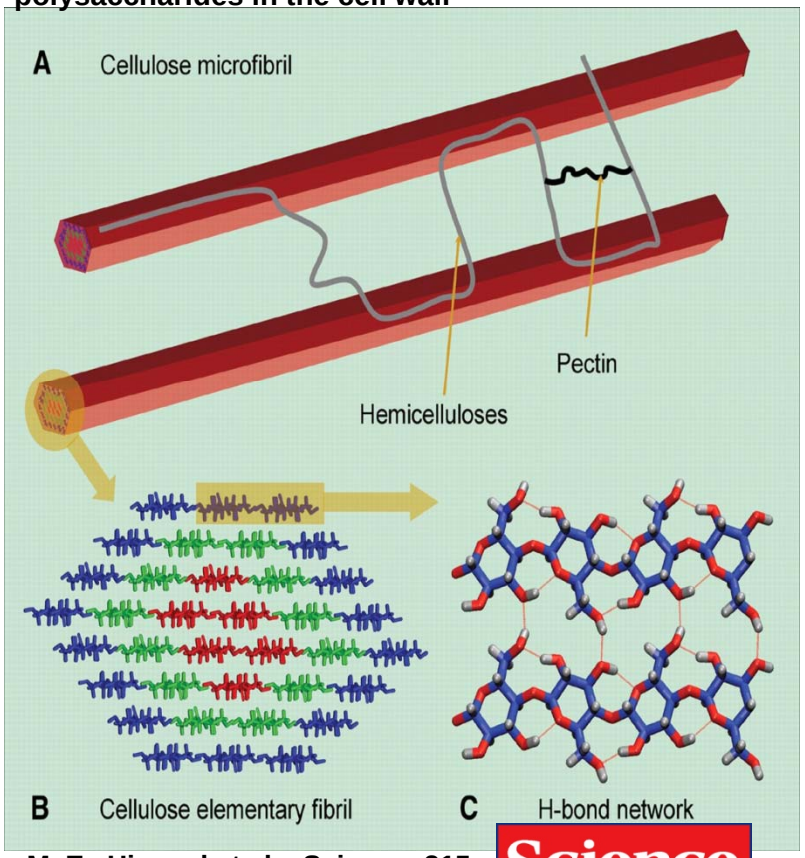
- **Tree cell walls** have an additional component, **lignin**.
  - This is the "woody" material that gives trees great tensile strength
- Cellulose, hemicellulose, and pectin are composed of monosaccharides strung together, they are called polysaccharides
- Lignin is composed of **polysaccharides and alcohols**

Making Plant Biomass Available for Biofuel Production

3. Biomass Recalcitrance

- Cellulose, hemicellulose, pectin, & lignin intertwine to create **complex cell wall** matrices
- This complex structure protects plants and trees from disease, moves nutrients, and provides for growth
- These complex structures also **restrict access to the "simple sugar" components**
- Current technologies to break up biomass: acid, ammonia, steam, or pressure are energy and cost intensive

A simplified model showing the interaction of the major polysaccharides in the cell wall



M. E. Himmel et al., Science 315, 804 -807 (2007)

Science
AAAS

Making Plant Biomass Available for Biofuel Production

4. **Overcoming** Biomass **Recalcitrance**

Researchers are pursuing **four different approaches** to overcome biomass recalcitrance

1. Reverse engineer plant cell wall genetics to discover enzymes that will “deconstruct” cell wall matrices
2. Adapt microbial “rotting” enzymes to dissolve cell wall sugars

Making Plant Biomass Available for Biofuel Production

4. **Overcoming** Biomass **Recalcitrance**

Researchers are pursuing **four different approaches** to overcome biomass recalcitrance

3. Breed plants and trees with cell wall structures more amenable to chemical or enzyme solubility
4. Reduce costs and energy requirements of chemical processes

Making Plant Biomass Available for Biofuel Production

5. Examples of Research Results

- University of Georgia researchers have discovered the **genetic pathway** for several types of plant biomass
- Atlantic Biomass has adapted microbial enzymes to produce **soluble sugars from hemicellulose** biomass
- North Carolina State researchers have produced fast growing **poplar trees with significantly lower proportions of lignin** biomass
- Michigan State researchers are working on a process to **recycle ammonia**, thereby reducing the cost of that biomass process

Improve Conversion of Biomass to Biofuel

Goals

- Expand **types of biofuels** produced beyond ethanol and plant seed/animal fat biodiesel
- Expand the **types of plant sugars/alcohols or algae fats/oils** that can be used as feedstocks
- Increase the **percentage of biomass** that can be converted to biofuel
- **Decrease the cost** of conversion processes

Improve Conversion of Biomass to Biofuel

Scientific Research Challenges

- **Fermentation is limited to producing alcohols** such as ethanol (CH_3CH_2OH)
- Alcohol **fermentation** is also only possible with a **limited number of sugars**, no polysaccharides can be used
- To produce higher energy fuels; gasoline, diesel, or jet fuel, hydrocarbon compounds such as **octane (C_8H_{18}) need to be produced from plant biomass**
- To produce hydrocarbons from plant biomass, **oxygen atoms have to be removed from sugars**

Improve Conversion of Biomass to Biofuel

Emerging Scientific Technologies

- **Chemical Catalytic Process**: Organic solvent systems, such as the Virent aqueous reforming process converts sugars to hydrocarbons called alkanes.
- Advantages: Can use a wide variety of polysaccharide sugars, has low energy inputs, adaptable to existing petroleum refineries
- Challenges: Need to increase amount of biomass carbon transferred to alkanes

Improve Biomass to Biofuel Conversion

Emerging Technologies

- **Pyrolysis/Rare Metal Catayst** : High temperatures and pressures, combined with specific metal catalysts can produce liquid as well as gas hydrocarbons from biomass.
- Advantages: Can use a wide variety of biomass, does not require pre-processing biomass to sugars, is adaptable to existing petroleum refineries
- Challenges: Need to increase amount of biomass carbon transferred to hydrocarbons, current efficiency is about 18%, reduce energy inputs and costs of catalysts

Improve Biomass to Biofuel Conversion

Emerging Technologies

- **Enzymatic Process**: "Reducing enzymes" can remove oxygen atoms from sugars producing compounds suitable for advanced biofuel production
- Advantages: Can use a wide variety of monosaccharide or polysaccharide sugars, has low energy inputs, adaptable to existing petroleum refineries
- Challenges: Need to increase yields from enzymes, reduce amount of biomass carbon released as CO_2 during oxygen removal, requires biomass-to-sugar preprocessing

Minimizing the Cost of Biomass Transportation

The Transport Conundrum

How can we gather enough Biomass to support a Cost-Efficient Biorefinery?

- **Plant biomass is low-density low-value bulky material**, transporting large quantities of it long distances is expensive
- **Fuels are high density, high value liquids,** long distance transportation by train or pipeline is economical

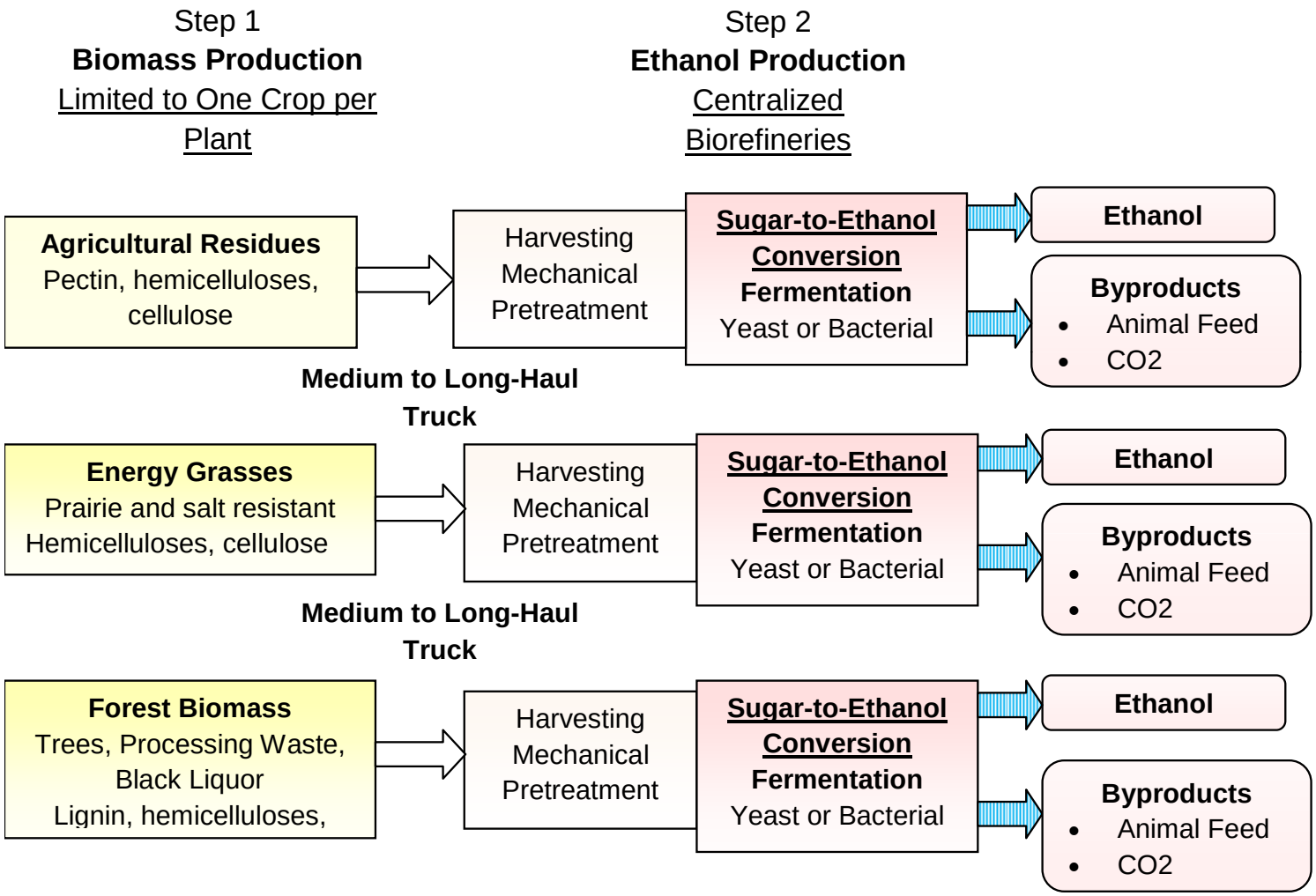
Minimizing the Cost of Biomass Transportation

The Transport Conudrum

Limitations of 1st Generation Ethanol Production

- The **size** of current generation of ethanol production plants is limited by the **amount of crop** that can be economically **trucked** to the plant
- Production plants can not take advantage of **economies of scale**
- Production plants may not operate year-round because of **harvest patterns**
- Production plants may not be able to **switch crops to reduce costs** because of longer transport distances

Cellulosic Ethanol
1st Generation Production System
Limited to Individual Crops, Growing Seasons & One Biofuel Market



Atlantic Biomass Conversions, Inc.

Minimizing the Cost of Biomass Transportation

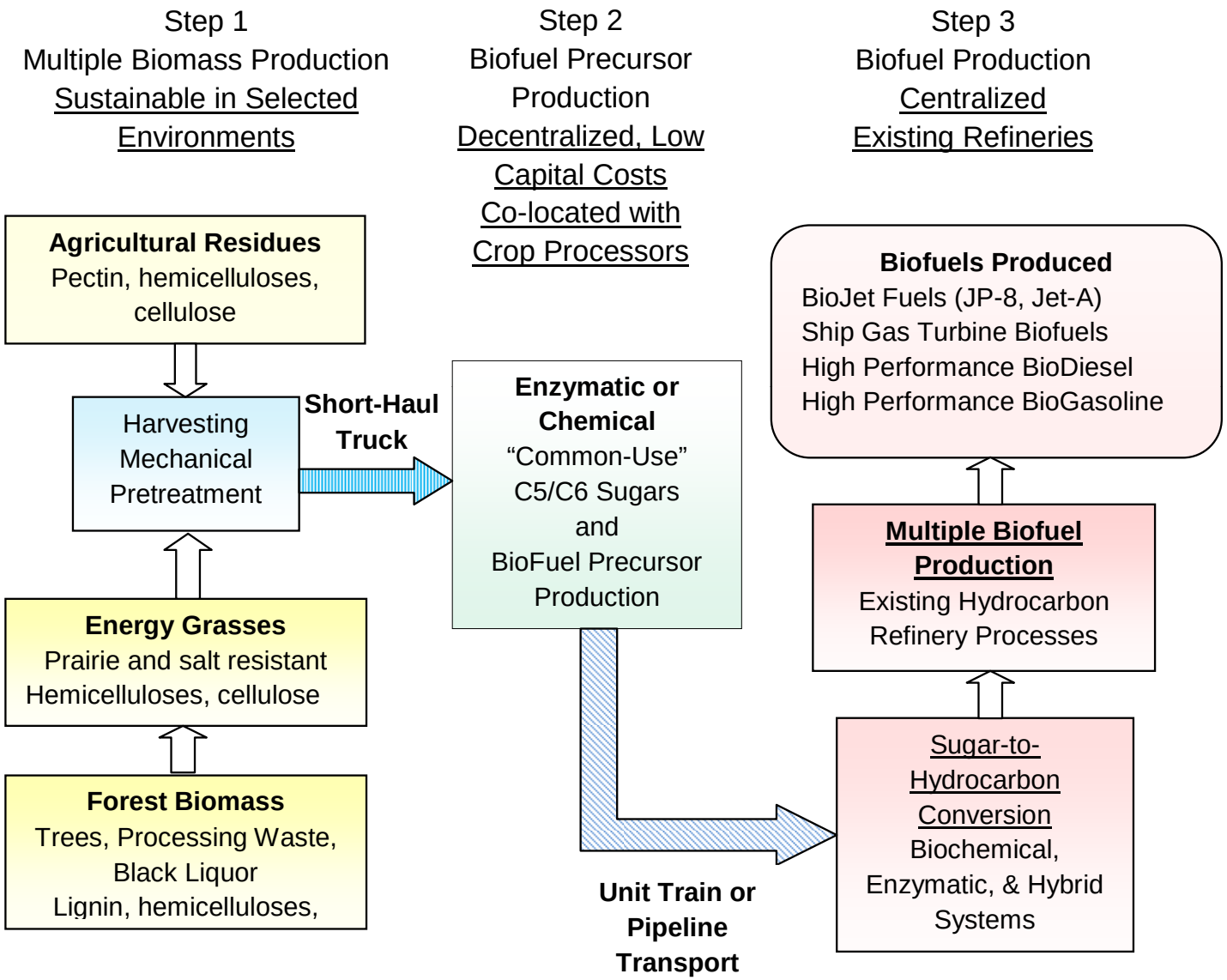
Breaking the Transport Conundrum

Separating biorefinery functions is an answer to the conundrum

1. **Conversion of biomass** to high density liquid sugars or other intermediate compounds would occur at a network of **decentralized, low-capital** facilities, often **co-located** with grain elevators
2. **Intermediate liquids ("Green Crude")** would be transported by truck or rail to existing petroleum refineries
3. Existing petroleum refineries would be **retrofitted** to utilize intermediates as a feedstock alternative to oil
4. Biofuel production would be **year-round**, utilizing a variety of different biomass sources harvested at different times of year
5. **Multiple biofuels and other bio-chemicals** would be produced at one facility, provides **market response flexibility**

Multiple Biomass/Multiple Biofuel Decentralized/Centralized Production System™

Year-Round Production/Multiple Fuel Markets



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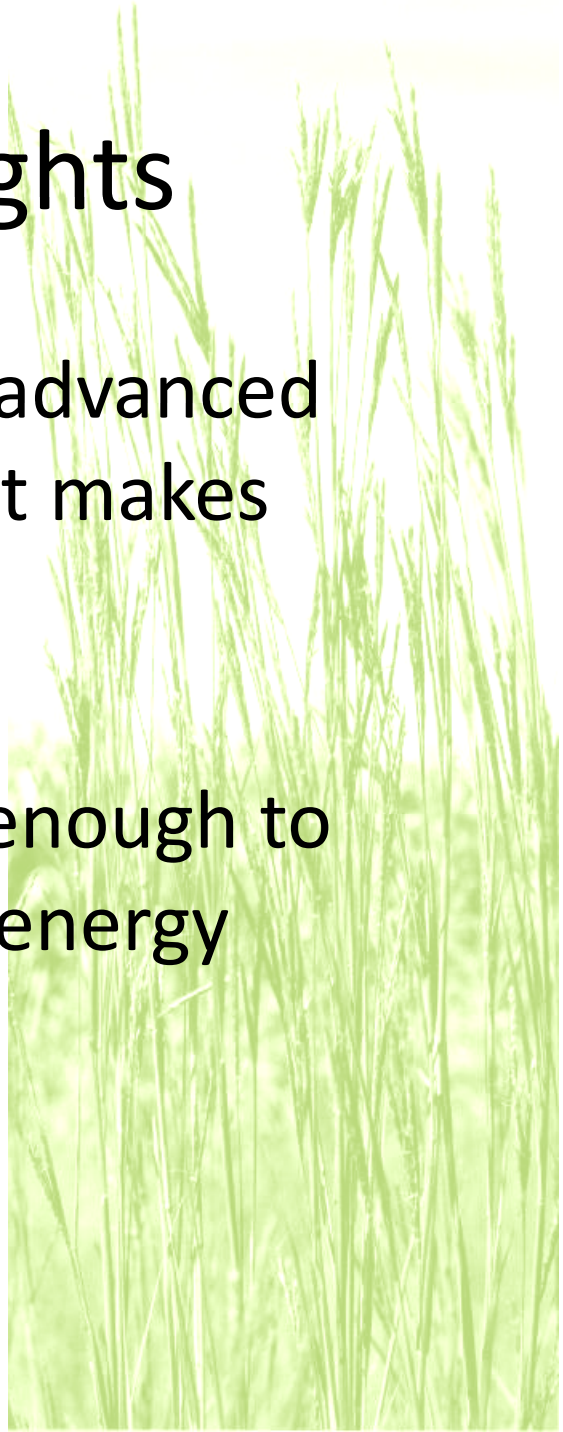
Questions and Thoughts

- List different ways that crops and advanced biofuels can be transported. What makes some more efficient than others?
- Discuss: An important element of "sustainability" is to pay growers enough to use sustainable practices to grow energy crops. What does this mean?



Class or Student Projects

- Describe different technologies, pathways or platforms for converting biomass to advanced biofuels.
- Devise experiments that you can do in your classroom to demonstrate one or more of these technologies.
- Visit a local cellulosic or advanced biofuels production facility. Take pictures/video and write an article or produce a web article about what you learned.

Advanced Research Suggestions

- What does “biomass conversion” mean?
  - Give examples of processes used to convert biomass to biofuels.
  - Research current conversion rates for each of these technologies using different feedstocks.
  - Which are most efficient?
- What price should be paid to growers for various crops to assure that energy crops will be grown sustainably?
  - Analyze for areas in your state. Would there be different answers for growers in different areas? Different countries?

Advanced Research Suggestions

- Describe the kinds of sugars that can be derived from cellulose, hemicellulose, pectin and lignin, if any. Discuss what kinds of advanced biofuels could be developed from these sugars. Describe the process.
- Write an analysis of possible biofuels feedstock that could be grown in your area for an advanced biofuels refinery. Could your region produce enough to support building a biorefinery?