The CSI Process

Ambient Conditions Pretreatment for Plant Biomass Followed by Saccharification

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CSI has developed a new process for cellulose and biomass saccharification

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Applications in:

Cellulose-based industries

Biofuels and biobased chemicals

CSI Process

Room Temperature

- No heating or cooking means low energy costs

Ambient pressure

- No special alloys or expensive pressure vessels

Rapid

- Process takes less than 30 minutes

Simple

- No expensive or exotic chemicals used

Early development and roots

Cellulose has several recognized "polymorphs"

- Cellulose I, II, III, and IV
- Almost all native forms are Cellulose I
- Cellulose II, "mercerizing" or regeneration
- C-III – soaking C-I in liquid ammonia
- C-IV – cooking C-II at 200°-250° C (in glycerol)

Early development and roots

Developed out of research into the phenomenon of mercerization.

- Mercerization was developed in 1844
- Applied to cotton thread
- Mercerizing converts Cellulose I to Cellulose II
- Strong caustic in water
- **Washing with water completes transition**

Early development and roots

Developed out of research into the phenomenon of mercerization.

- CSI process stabilizes transition state between Cellulose I and Cellulose II
- A new *nanoporous* form of cellulose
- **Stable in aqueous medium**

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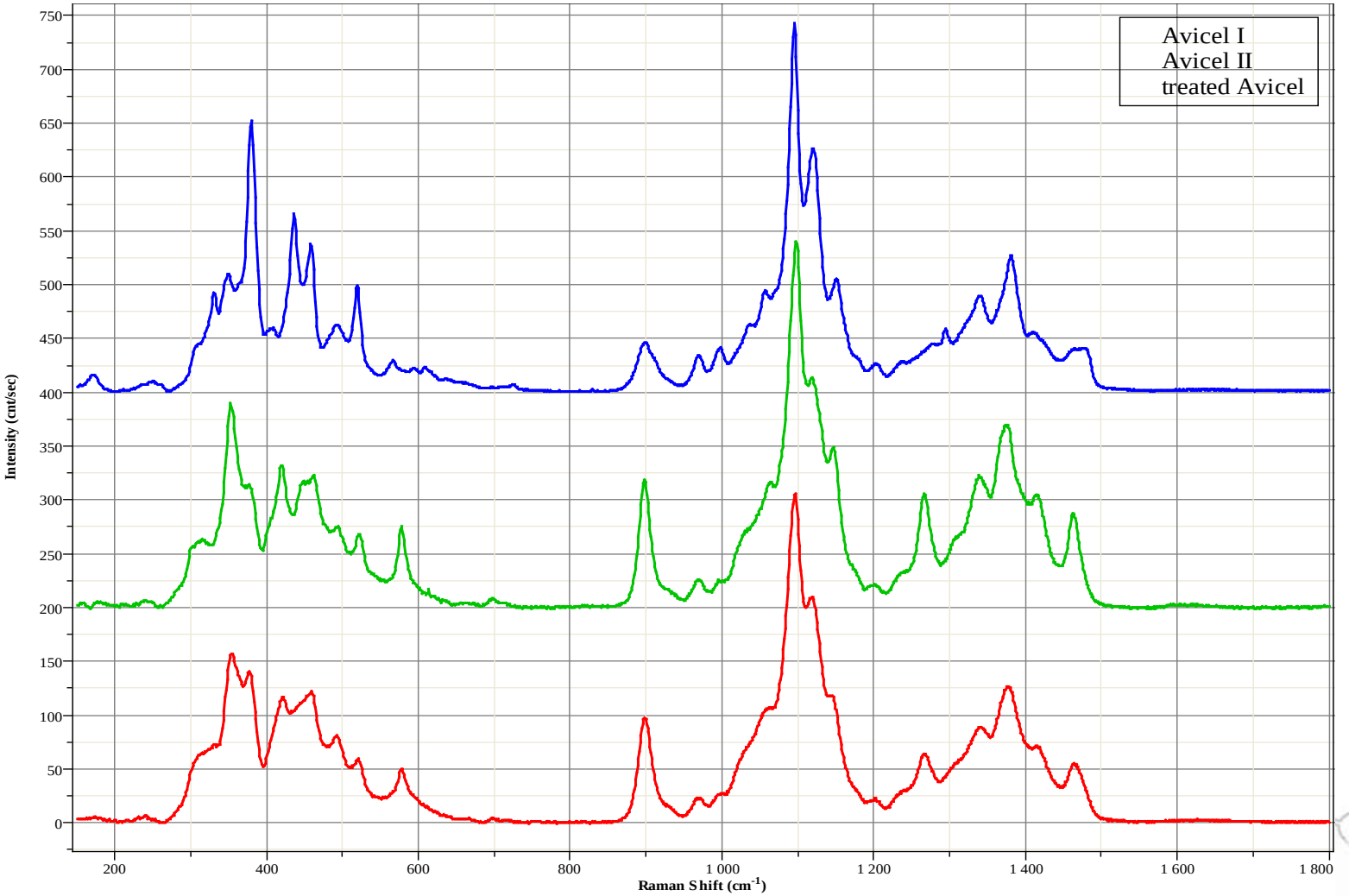
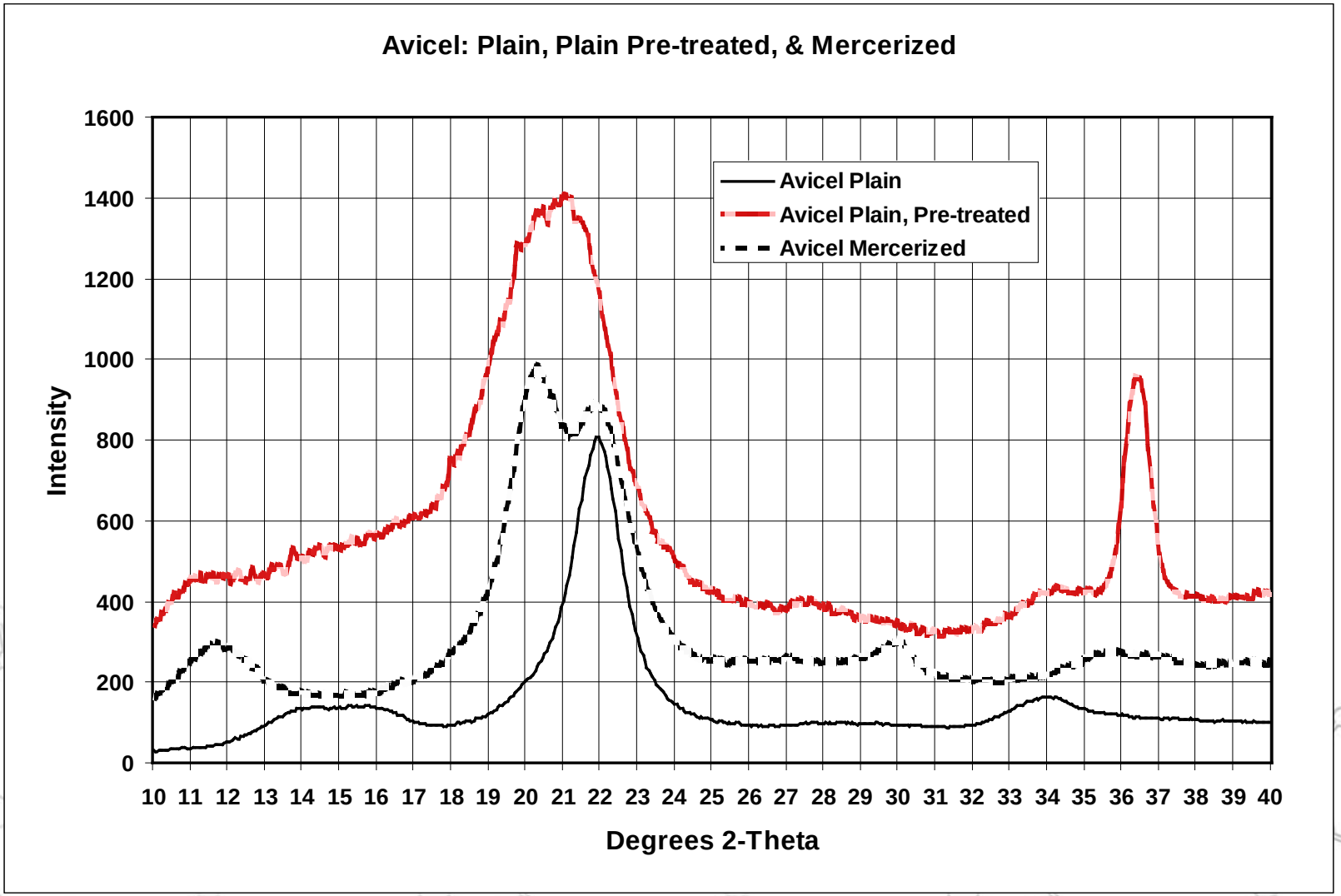
Applied to Cellulose Fibers

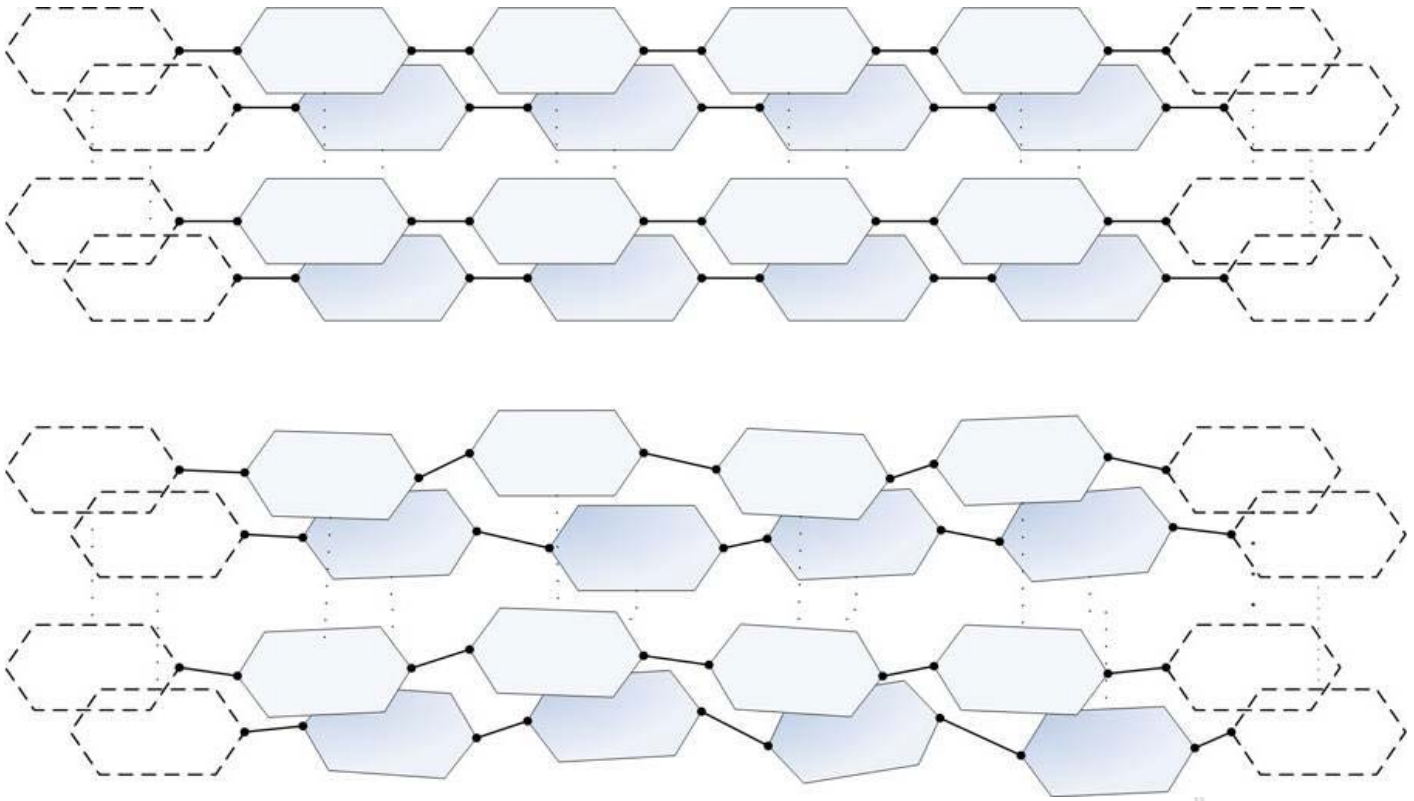
it produces

Nanoporous Celluloses



Raman Spectra


Avicel: Plain, Plain Pre-treated, & Mercerized
Avicel Plain
Avicel Plain, Pre-treated
Avicel Mercerized
Intensity
0
200
400
600
800
1000
1200
1400
1600
10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
Degrees 2-Theta



An abstraction at the nanoscale

- nano-scale disorder within chains
- increased spacing between the chains

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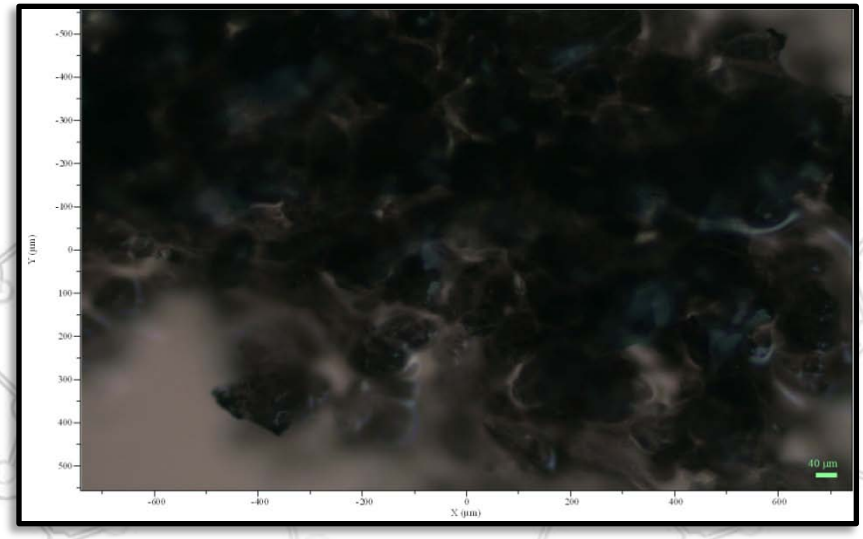
Avicel

Graff's C Stain
100X



Treated Avicel

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Nanoporous Cellulose Fibers

are

Much more elastic

and

Much less recalcitrant

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Enhances interaction between cellulose and hydrolytic enzymes

Faster hydrolysis at given enzyme dosage

Or

Reduced enzyme dosage per unit cellulose

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Accellerase applied to Avicel ~ 30 hours

sample	init. wt	final wt	% conv.
AC (ctrl-0.5ml)	1.000g	0.4897g	51.03%
A2 (0.5ml)	1.002g	0.0983	90.19%
A3 (0.25ml)	1.002g	0.1619g	83.84%
A4 (0.125ml)	1.000g	0.2878g	71.08%

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Works on all plant derived celluloses so far…

- Soy hull
- Soy stover
- Corn stover
- Corn bran
- Sorghum
- Switchgrass
- Bagasse
- Northern softwood
- Northern hardwood
- Southern pine
- Digester residue
- Cotton

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Applied to LignoCellulosics (biomass)

it results in

Simultaneous Delignification

and

Nanoporous Cellulose Production

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Overcomes both

Recalcitrance

And

Lignin and Toxin Inhibition

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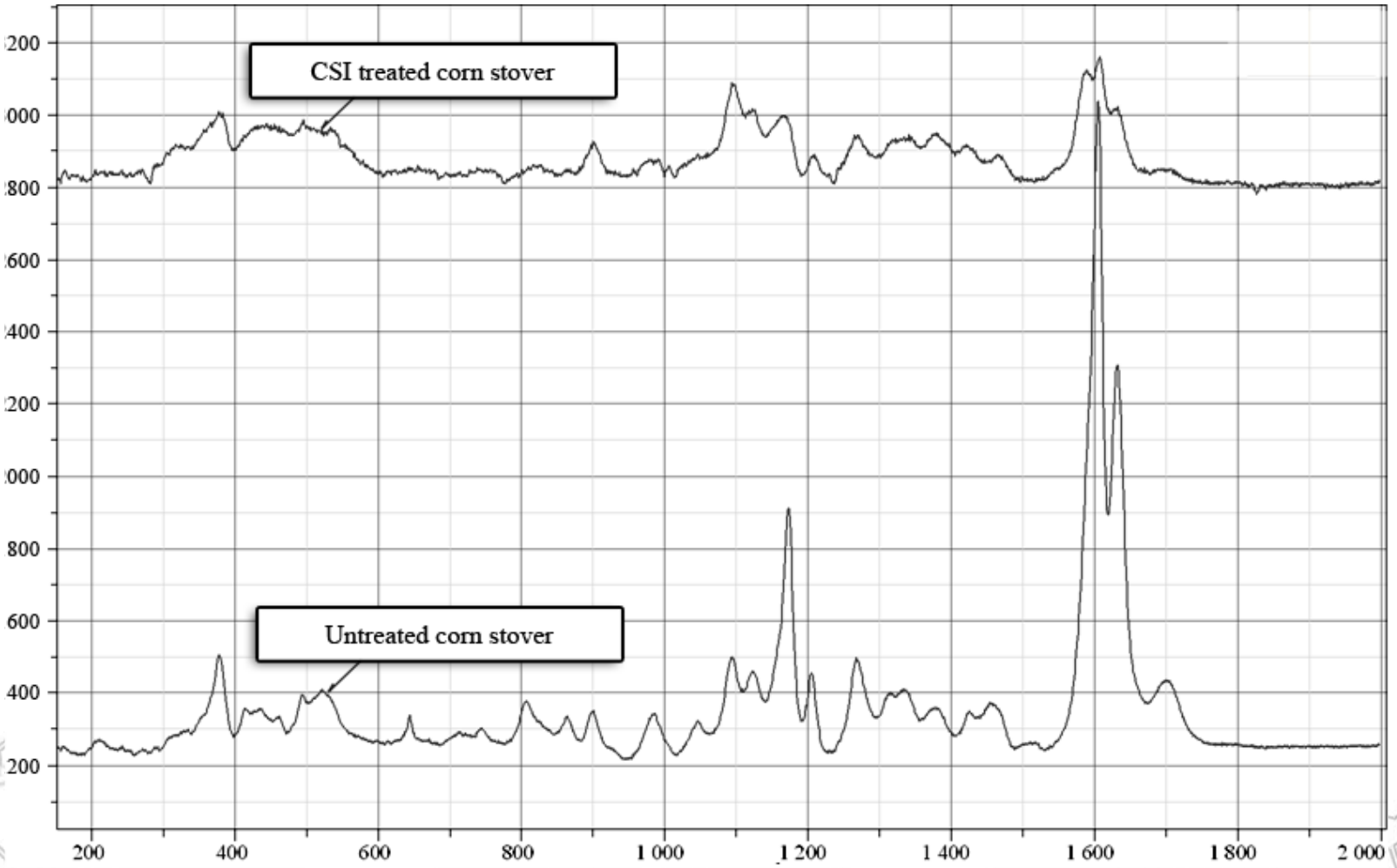
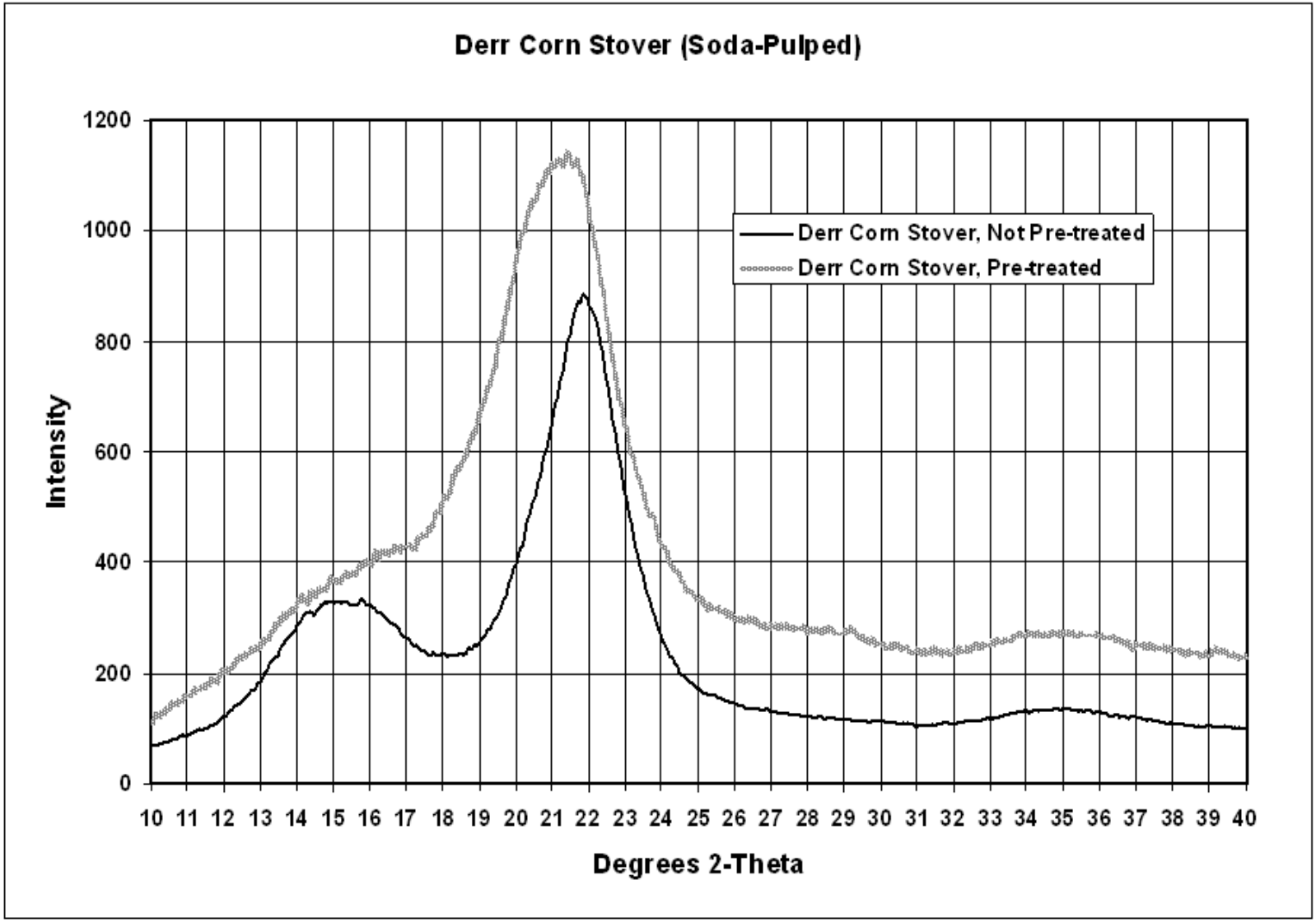


Raman Spectra


Derr Corn Stover (Soda-Pulped)
Intensity
1200
1000
800
600
400
200
0
10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
Degrees 2-Theta
Derr Corn Stover, Not Pre-treated
Derr Corn Stover, Pre-treated

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Comparing enzyme hydrolysis of ground, untreated stover vs CSI treated stover

(after 24 hours incubation)

77% for CSI treated stover

vs.

20% Untreated stover

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Steam exploded stover vs CSI treated stover

(after 19 hours incubation)

64% for CSI treated stover

vs.

35% Steam exploded stover

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We've also successfully treated several other feedstocks:

- Sugarcane bagasse
- Birch
- Southern pine
- Wood samples were Wiley milled (courtesy of FPL)

Validated by Novozymes

- Producer of commercial enzymes
- Evaluated treated corn stover
- “Excellent conversion at quite modest enzyme dosages”

CSI treatment works optimally on grassy plants

- The bonds between hemicelluloses and lignins are different from those in woody plants
- Process requires less size reduction

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Biomass conversion has two stages:

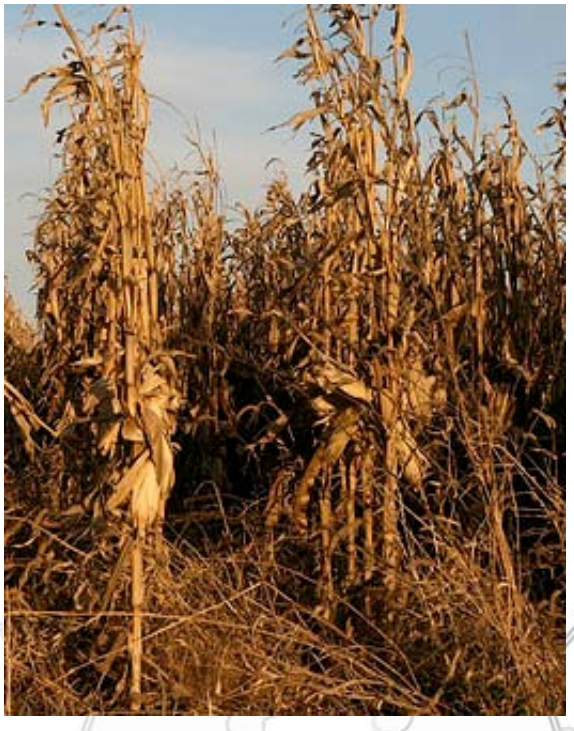
1. **Delignification and saccharification**

2. **Conversion of sugars to end products**

- **CSI's focus is on economically feasible first stage**

Biofuels and bio-based chemicals

- CSI Process makes biomass easier to hydrolyze
- Cellulose is nanoporous
- Toxins and inhibitors removed
- Enzymes have easier access



CSI Process

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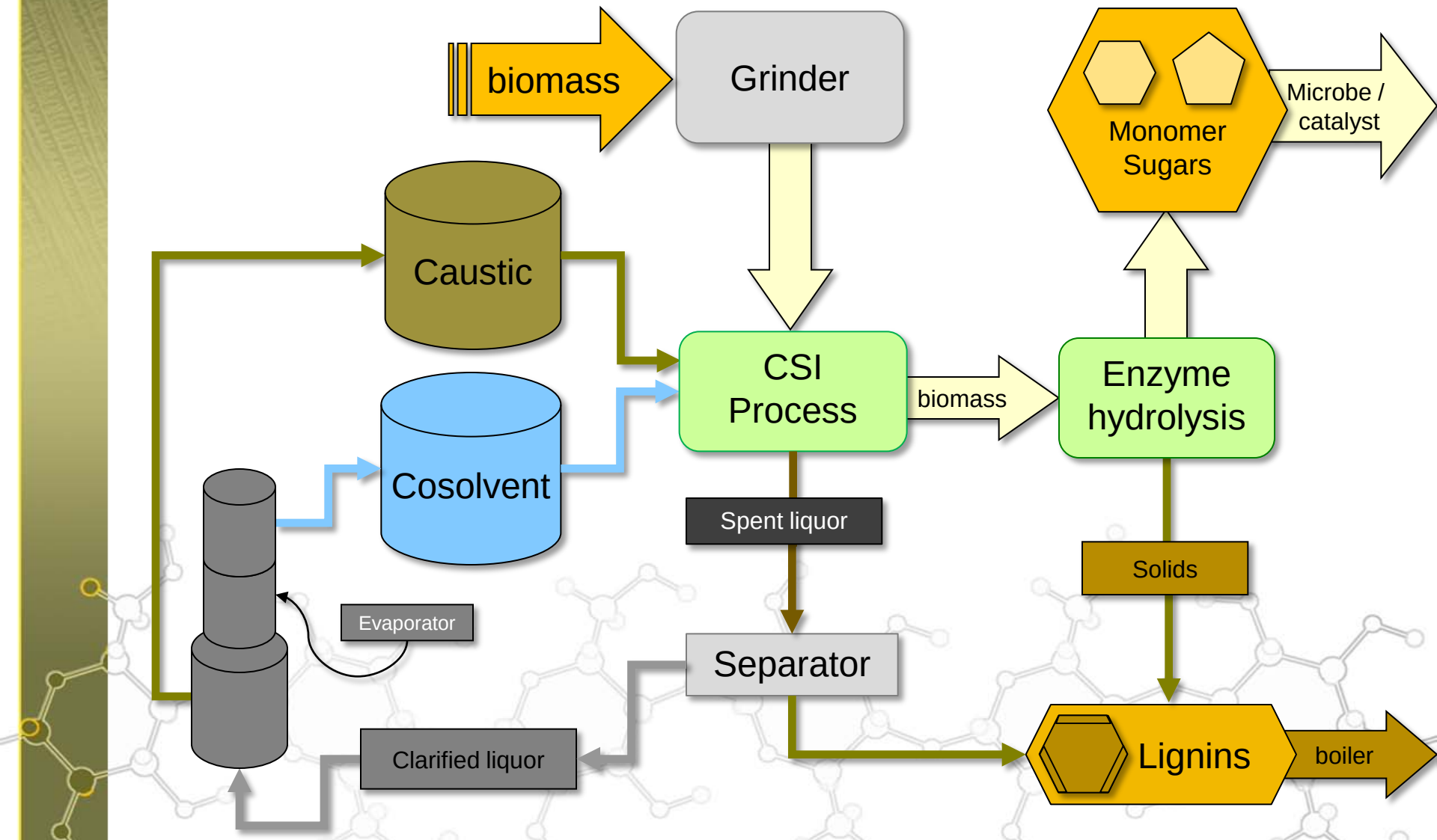
Simplified Process Diagram



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Benefits to biofuel and bio-based chem industries

- Allows efficient, low energy conversion of biomass to soluble sugars and raw lignin
- Enables, low-cost, low capital manufacturing of cellulosic ethanol
- Advantages extend to **next-gen biofuels** and **higher value bio-based chemicals**

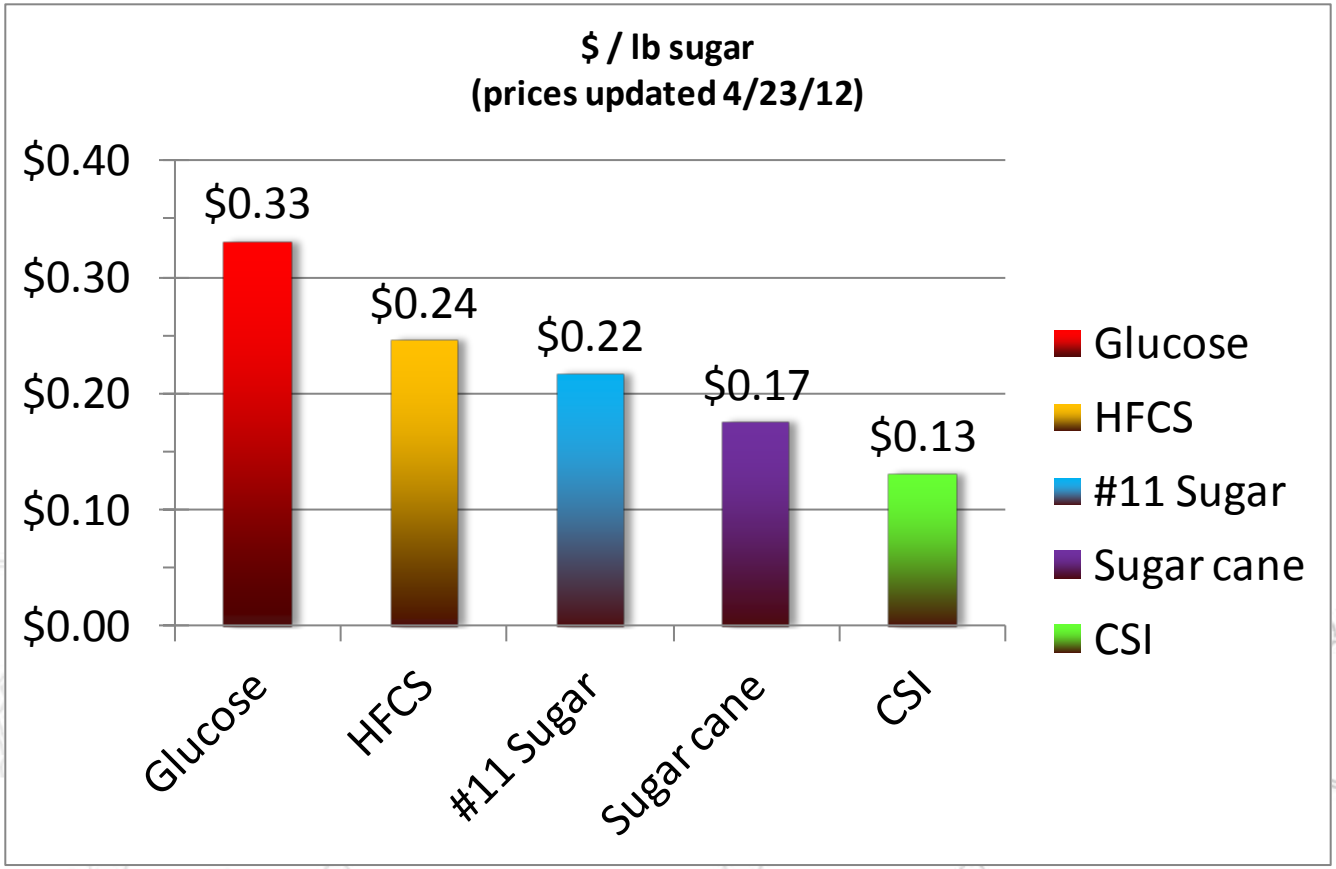
CSI Process
Biofuels and bio-based chemicals

- Less enzyme
- Less energy
- Lower operating cost
- Lower projected capital expense than other methods

Cost of sugars

Projected cost compared with current market prices

*includes feedstock, capital amortization and overhead



Current snapshot

IP position

4 patent applications filed

- Original process and composition-of-matter patent
  - Issued in S Africa
  - Notice of intent to grant from EU patent office
- Use of CSI treated fiber in wet- or dry-laid cellulosic networks (papermaking, tissue and towel, diapers)
- Simultaneous delignification and decrystallization of biomass
- Pretreatment of biomass for isolation of lignin

Commercialization

Collaboration with credible partners who:

- **recognize the opportunities our technology represents**

- **have the resources to develop its application in their fields**

Pilot development

Major Participant in the Forest Products Industry

Process to be integrated into existing facility

- Access to biomass
- Engineering support
- Recovery
- Wastewater

Initial capacity up to 100 TPD of biomass

Application to various woody and non-woody biomass

Supporters and Collaborators

BOLDT

Great Lakes Ag Energy, LLC

NREL

NSF

OFFICE OF ENERGY INDEPENDENCE

GREAT LAKES BIOENERGY RESEARCH CENTER

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Thank you

for your attention!

Questions?

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