Agricultural Waste Utilization Systems

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Goal of biomass conversion : Enhance renewable C utilisation

Such goal is influenced by:

- Nature of the biomass
  - Homogeneous
  - Quasi-homogeneous
  - Non-homogeneous
- Cost of the biomass (fob plant)
- CAPEX and OPEX of the primary conversion process
- Purification of intermediates and further upgrading

Biomass

- <u>Homogeneous biomass</u>
  ≥100 USD/tonne (dry basis)
- Uniform and of high quality
- With already sizeable markets
- Examples:
  – Grain
  – Structural wood
  – Wood chips for pulp

Biomass

- <u>Quasi-homogeneous biomass</u>
  ≥30 and ≤80 USD/tonne
- Typically « residues » from forest and agricultural operations: comprise single and mixed species
- Even if there are markets for these residues, they are abundant across Canada
- Plantation biomass (or energy crops) on marginal lands are also part of this category.
  – Examples: willows, switchgrass, etc.

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Biomass

- Non-homogeneous biomass
  ≤ 30 USD/tonne
- Usually comprised of postconsumer residues
- They may carry a tipping fee
- Examples are all urban wastes (= « urban biomass »)
  - Residential MSW after sorting and biotreatment
  - Institutional, commercial and small industry wastes (ICI)
  - Construction and demolition wood
  - Dewatered sludges from WWT plants

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Dealing with supplies

Availability of Feedstocks

Even if abundant, when financing a project, the first question is : how much biomass is secured contractually an for how long?

- Large residual biomass quantities (> 200,000 t/y , anhydrous basis) are available only in areas dedicated to large forest and agricultural operations.

  Contracts need to be negotiated with Governments and/or large corporations

- Unused residual biomass is readily available, throughout many regions in the world, in quantities ranging from 25 000 to 200 000 t/y , anhydrous basis.

  Contracts are negotiated with local suppliers (counties/municipalities or private)

- Urban biomass [MSW+ICI] ≈ 2.0 kg per person * day: a population of 100 000, will generate about 73 000 t/y. After mechanical sorting and biotreatment, 29 200 t/y on an anhydrous basis (or 40%), is the "available residual non-homogeneous biomass".

  Contracts negotiated with municipalities

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Challenges

The challenges for developing a second generation bioenergy, biofuels and biomass-derived co-products industrial sector (i.e., biorefineries) are:

• to use quasi- homogeneous and non-homogeous biomass as affordable feedstocks

• to develop processes that are compatible with availabilities of feedstock: 50 000 to 200 000 tonnes (dry basis) per year being a practical range

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Strategies for quasi-homogeneous biomass

- Composed of lignocellulosic tissues
  – Forest or agricultural
- Typical composition:
  – Extractives + Hemicelluloses + Cellulose + Lignin
- Conversion processes :
  - Pretreatment + Fermentation
  - Fractionation in its various configurations
  - Pyrolysis

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Conversion approach

- Our work has focused on « Sequential Fractionation » to produce, in high yields primary intermediates which are then individually upgraded to marketable products
- Heat and power for the « energy self sufficient » process are provided by cogeneration using the process residues and local non-homogeneous biomass as feedstocks.
- The overall process can be adapted to diversified feedstocks
- Companies developing and marketing the technology are CRB and Enerkem, spin offs of our lab

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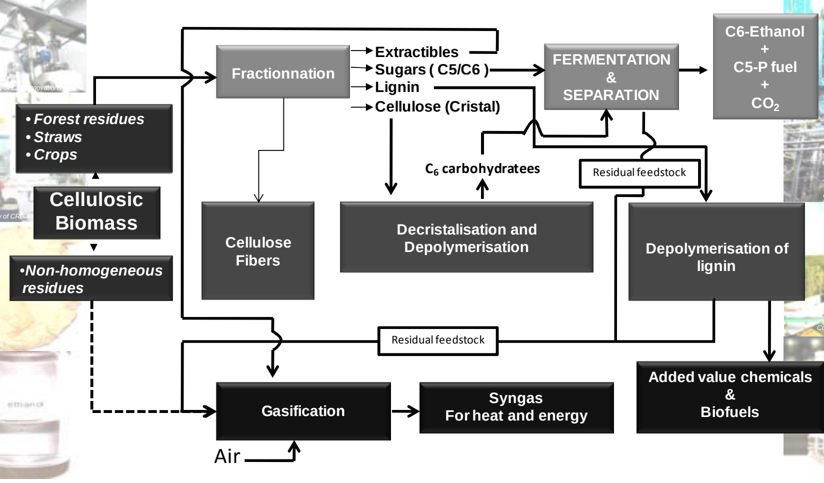
The « Feedstock Impregnation and Rapid and Sequential Fractionation » (FIRSST) approach and its integration with cogeneration via gasification



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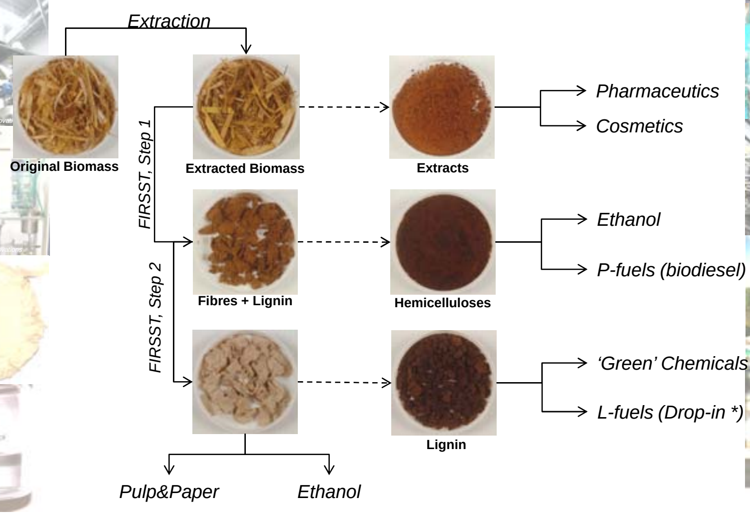
Example → converting corn stover



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1 step / 2 steps

- Both one steps and two steps steam treatment have been used to fractionate residual lignocellulosic biomass
- While the 1 step process requires less energy, the two step process require less purification

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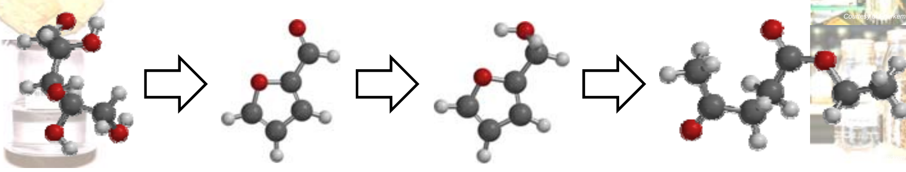
Hemicellulose conversion

- Fermentation used as purification
- C_6 content is fermented to EtOH
- C_5 are not converted by classical yeast
- EtOH removed via distillation
- C_5 dehydrated to furfural



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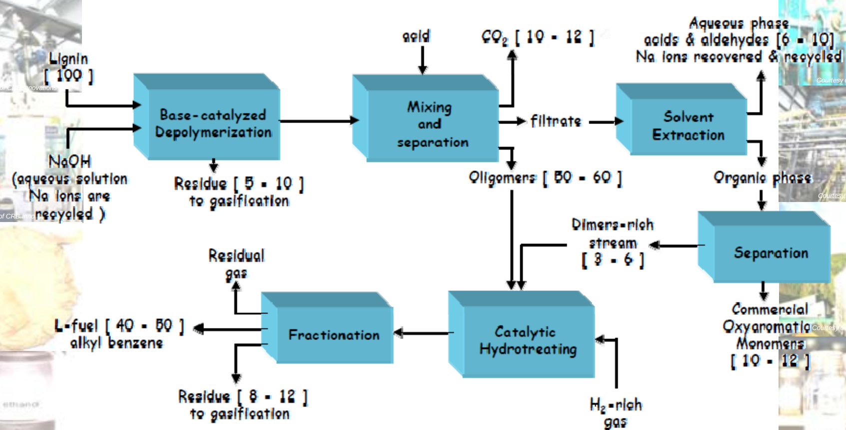
Lignin conversion



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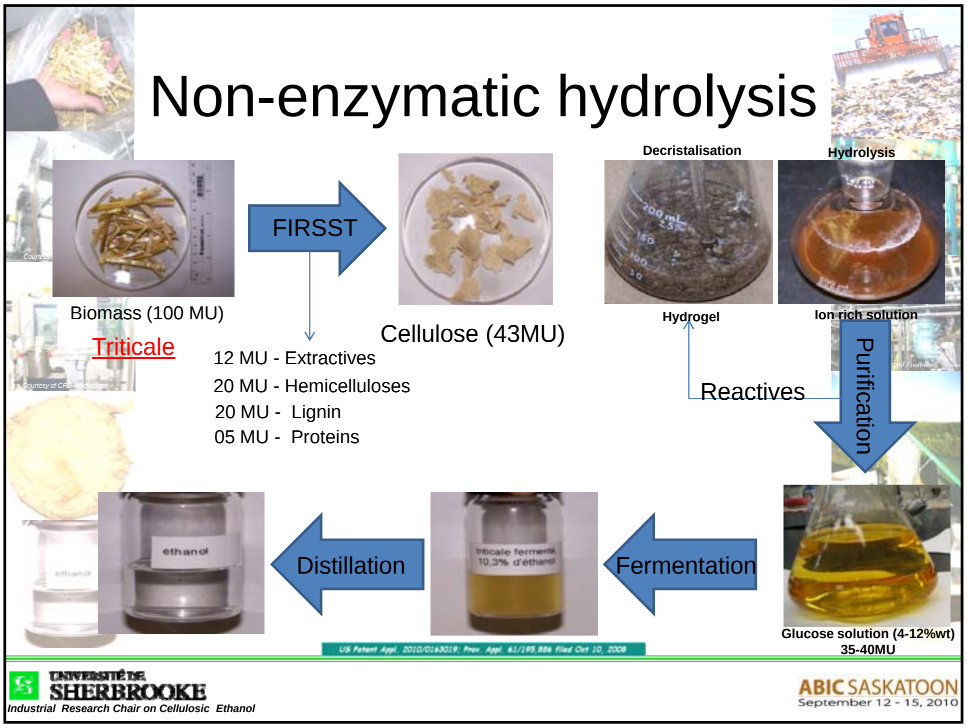

Upgrading intermediates from FIRSST

- Non-enzymatic cellulose hydrolysis -> high yield of sugars:
  - Using ionic solutions: U de S + CRB + LTE-HQ
- Fermentation of C_6 from hemicelluloses and cellulose:
  - Using yeasts: U de S + CRB + Ethanol Greenfield-Varennes
- Conversion on hemicellulose and lignin to biodiesel and jet fuel respectively:
  - Lignin: U de S + CRB + NRCan
  - Hemicelluloses (C5): U de S + CRB

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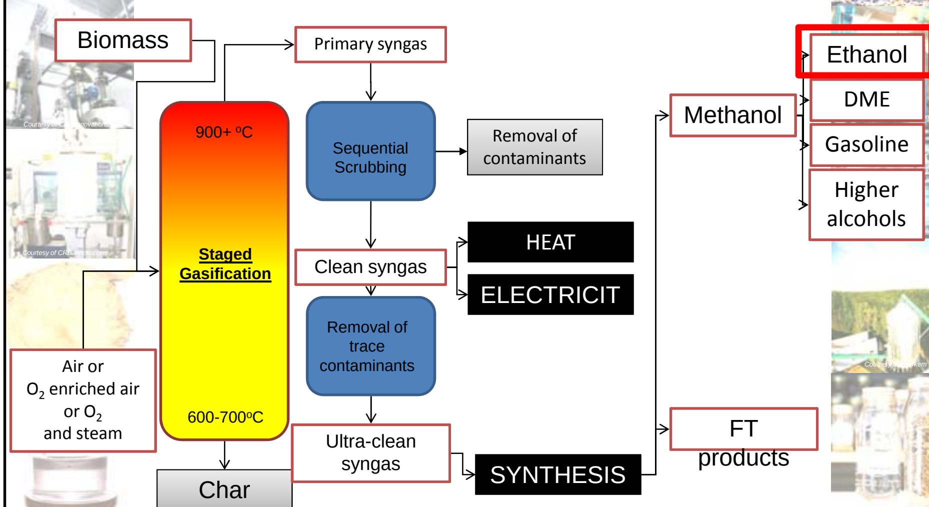
Non-homogeneous biomass

- Unexpensive (it normally has a « tipping fee »)
- Readily available from municipalities
  - 1.5 - 2.0 kg /person*day in North-America
- Composed of different macromolecules: lignocellulosics, plastics, proteins, lipids, inorganics (ash) can reach 20 wt%
- Fractionation is not a viable option
- Gasification converts the feedstock into a synthetic gas having a rather uniform composition

Gasification approach



Syngas composition

Gas Component	Air gasification, low severity	Air gasification, low severity + steam reforming	O_2 / steam gasification, low severity
N_2	55.8	35.5	0.5
Ar	0.8	0.5	0.3
H_2	9.5	35.2	11.8
CO	10.3	17.9	20.4
CO_2	14.1	10.9	41.1
CH_4	4.2	0.5	10.0
C_2H_4	2.2	-	8.6
C_2 - C_5	2.1	-	6.6
C_6 - C_{10}	1.0	-	0.7

Composition can be varied by adjusting the reforming step with steam and CO_2 for specific applications.

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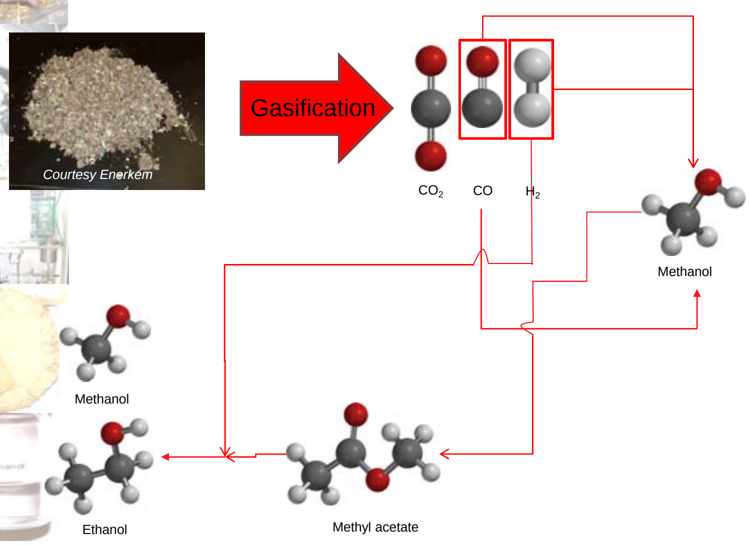
Synthetic pathway



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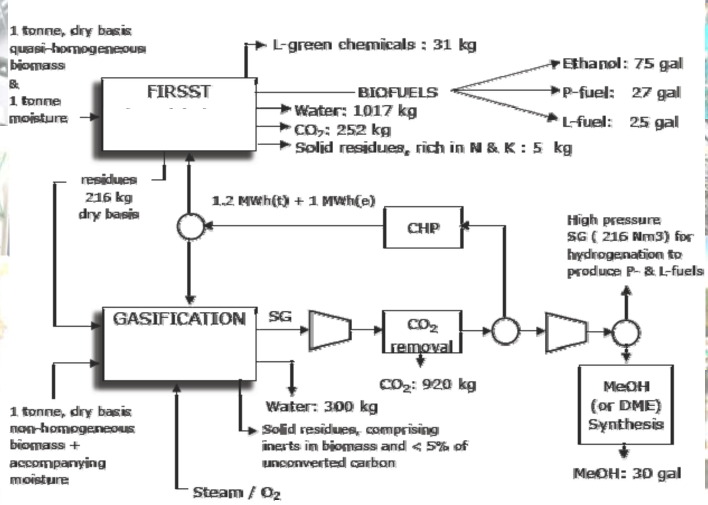
Specifics

- Synthesis of MeOH
  - 1 kg MeOH/(kg catalyst * h)
  - Available commercial catalysts
- Carbonylation
  - Directed towards Methyl Acetate production
- Hydrogenolysis of the ester -> ethanol
- Overall production:

  360L EtOH/tonne of fluff (dry basis)

Synergistic approach



Energy efficiency

		Litres	kg	GJ	MWh
Inputs:					
	1 t, quasi-homogeneous biomass, dry basis			18	5.0
	0.7 t, non-homogeneous biomass, dry basis			14	3.9
	TOTAL biomass input, t = tonne			32	8.9
Outputs					
	Ethanol	283	222	6.6	1.83
	P-fuel: Methyl furan	102	95	3.3	0.93
	L-fuel: Alkyl benzene	94	66	2.8	0.77
	Residual Syngas				0.3
	L-chemicals (catechols)		31		0.2
	TOTAL outputs				4.03

Process Energy Efficiency (HHV) : 4.03/8.9 = 0.45 (45%)

Note: non-homogeneous biomass considered to have HHV of 20 GJ/t

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Industrial Research Chair Cellulosic Ethanol

- Located at Université de Sherbrooke
- Funded by:
  - Greenfield Ethanol, Enerkem and CRB
  - Government of Quebec
- Interactive projects carried out in synergy with funding companies
- Providing fundamental understanding and state of the art analytical information to ongoing:
  - Pilot and Demo Gasification + Synthesis project
  - Bench and Pilot Fractionation and Fermentation projects
  - New basic studies on CO_2 conversion

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A perspective on the development of gasification and synthesis: a rigorous path towards commercialization

R&D (1999 on)
Sherbrooke

Pilot Plant
(2003)
Sherbrooke

Feedstock: multiple
(up to 200 kg/h)
> 4500 h of testing

Commercial Demonstration Plant
(2009-11) Westbury

Feedstock: used electricity poles
Capacity: 1.3 millions gallons / yr
Gasification: Summer 09
Methanol: Fall 10
Ethanol: Winter 11

Commercial MSW-to-Ethanol Plant (2010-11) Edmonton

Feedstock: sorted municipal solid waste
Capacity: 10 millions gallons / yr
Project permitted
Financial closing (Fall 09)
Construction begun (Aug 10)

Commercial Waste-to-Ethanol and/or Electricity Plants (2012-on)

Feedstock: flexible
Capacities: multiple trains (10 millions gallons / yr per train)
3 Projects are under development
at the time of this presentation (Sept 10).
One of the projects (ELSEF Bioessence, UK) is permitted. It aims at electricity production.
Second project is in Miss (USA) and will produce EtOH
Third project, in Canada, is to be announced in Fall 11. It will produce EtOH

Acknowledgements

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- ABIN
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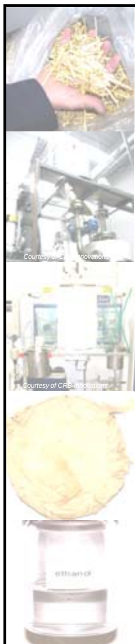

Merci

Discussing research strategies at the Chair