Alternative Feed-stocks for Bioconversion to Ethanol: *a techno-commercial appraisal*

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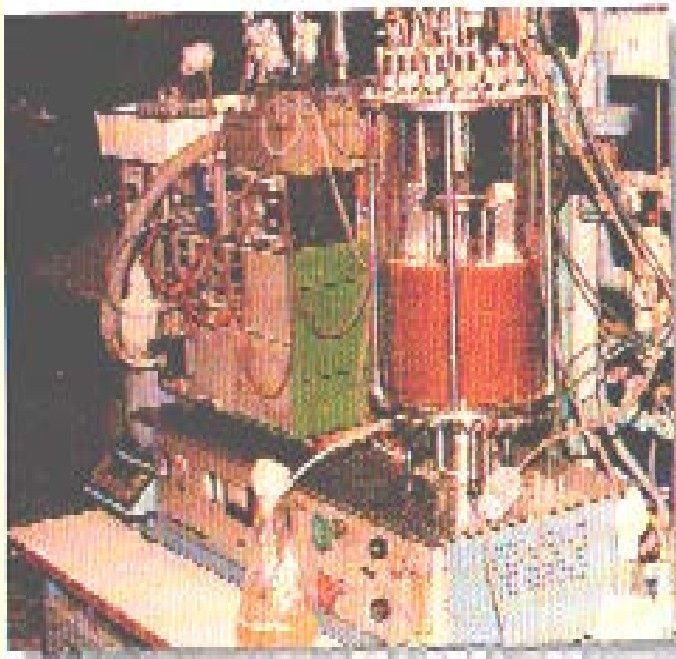


Ethanol as a Chemical Feedstock - *Characteristic Features*:

- **Bioconversion route *vs* Chemical Synthesis**
- **Represents highest product concentration among microbial products**
- **Application sectors**
- **Biphasic demand curve**
- **Challenges**

Chemical *vs* Biochemical Routes

Chemical Synthesis:

$CH_2= CH_2 + H_2O \longrightarrow C_2H_5OH$

- K_{eq}= 0.15 at 30^{0}C and 70 atm. Pressure
- 100 % carbon conversion (recycling)
- 0.61 kg C_2H_4/kg ethanol

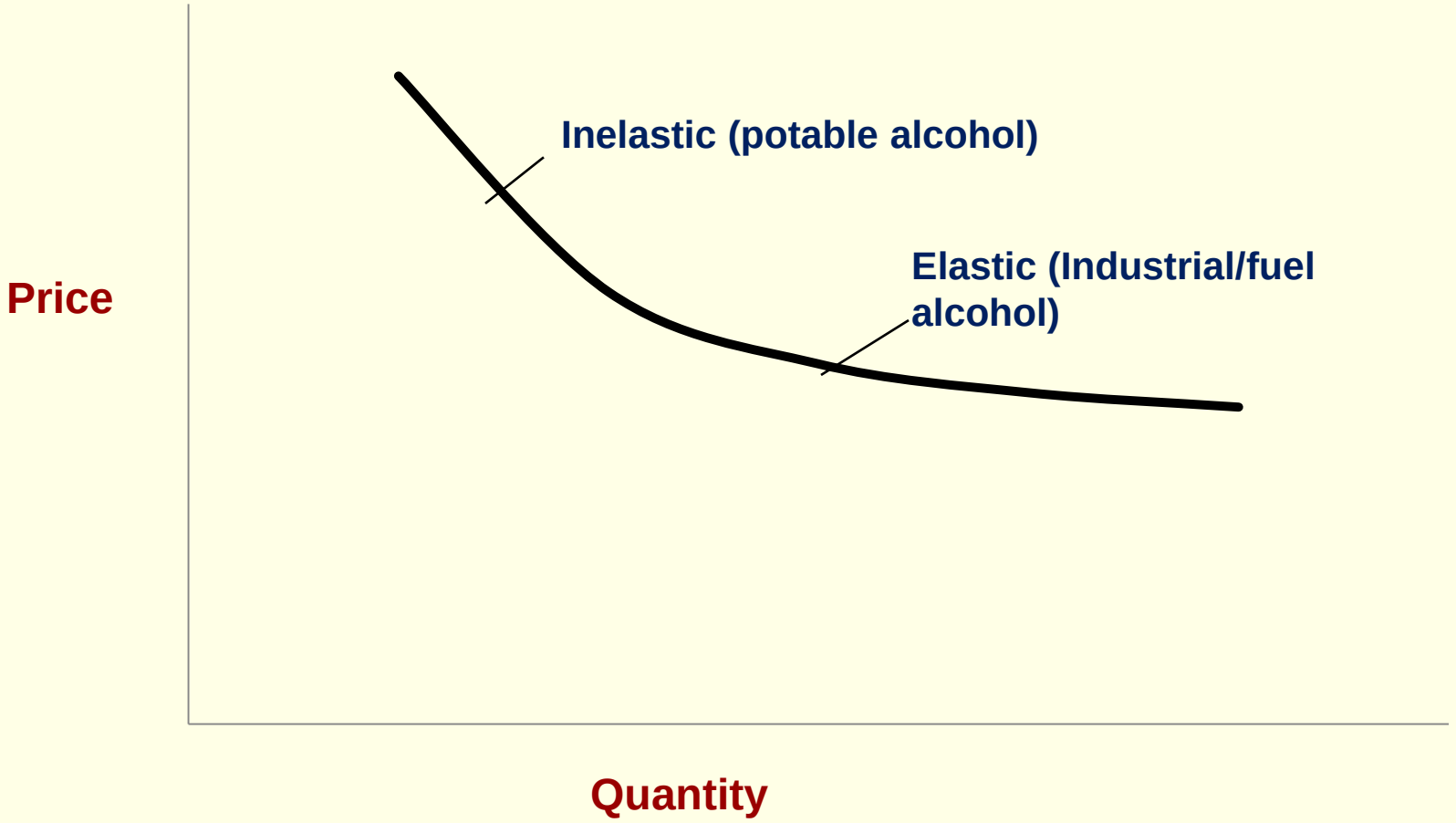
Bioconversion:

$C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + 2CO_2$

(Yeast/ Bacteria)

- Carbon conversion : 66.7%
- Fermentation efficiency>85%
- Glucose required / kg ethanol: 1.96 kg
- Raw Materials: molasses, sugar cane juice, corn, agro-residues (lignocellulosics) etc.
- Uses biomass based renewable feed stocks

Biphasic demand curve



Potential feedstocks for bio-conversion to ethanol

1. Sugar containing raw materials
   - Sugarcane juice
   - Molasses
   - Mahua flowers
   - Sugar beets

2. Starch based raw materials
   - Cereal grains (corn, spoiled wheat / rice)
   - Tubers (potatoes, cassava)

3. Lignocellulosic Agro-residues:

   Wheat / Rice Straw, Bagasse etc.

Alternative uses (?)

Bioprocess criteria:

Raw Material (s)

Biocatalyst

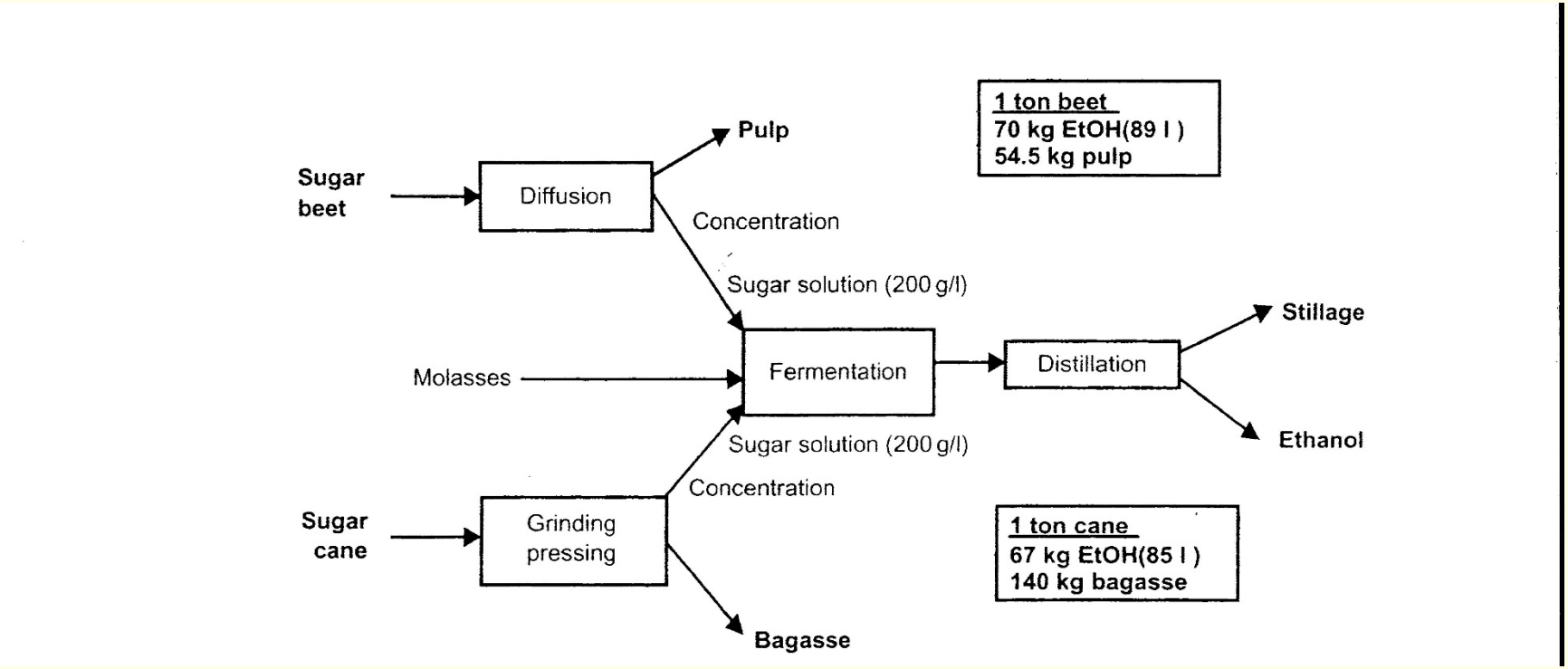
- **High rate of substrate utilization**
- **High ethanol productivity**
- **Ethanol concentration in the brew > 8.5%**
- **Reduction in the volume and strength of effluent**
- **Automation and reduction in down time**

Bioprocess Technology

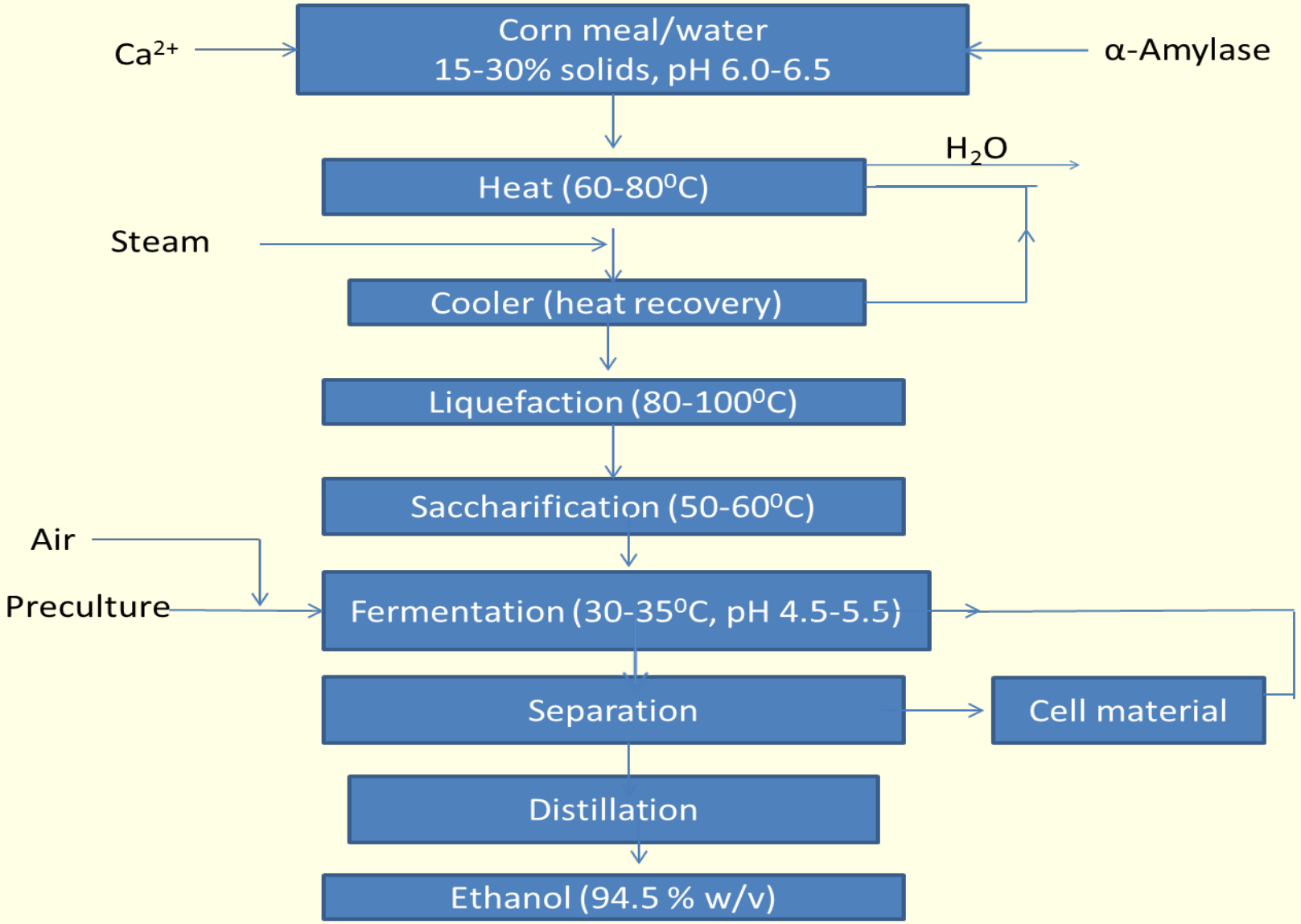
Distillation

Effluent treatment and water recycling

Ethanol from Saccharine Feedstocks



Ethanol production from substrates containing starch



(Misselhorn, K. 1979 in Dellweg, H (ed), 4th Symposium Technische Microbiologie Berlin

Energy (MJ/l of pure ethanol) required to produce absolute alcohol…(Misselhorn, 1979)

Process stage	Substrate		
	Beets	Cane	Starchy raw materials
Digestion/Hydrolysis			
Batch	4-5	-	7-8
Continuous	-	-	2
Cane Mill	-	1.1-1.5	-
Extraction	0.8-1	2-3	-
Fermentation			
Batch	0.06	0.06	0.06
Continuous	0.1	0.1	0.1
Distillation			
Single-staged	10-13	10-13	10-13
Optimized	5-7	5-7	5-7
Process			
Conventional	16	13	19
Optimized	7	7	8

(Misselhorn, K. 1979 in Dellweg, H (ed), 4th Symposium Technische Microbiologie Berlin

Bioconversion of Lignocellulosics to Ethanol

- Selection of Appropriate Feedstock
- Pretreatment and Delignification
- Saccharification / Hydrolysis
- Fermentation to Ethanol
- Recovery and Purification
- Process Integration, Techno-economic evaluation and Scale Up

Bioconversion of different raw materials to ethanol

Raw material	Crop yield T/ ha./yr.	Alcohol yield L/T	Productivity L/ha/yr
-Sugarcane	60-100	60-80	5000-6000
-Sugar beet	30-60	50-110	3000-4000
-Molasses	--	225-300	--
-Potato	15-30	80-120	2000-3000
-Cassava	10-20	150-200	2000-3000
-Sorghum (dry)	2-5.5	340-400	1000-2000
-Corn (dry)	3-7.5	360-400	1500-2000

Parameters affecting choice of Raw Materials

- Biochemical availability
- Concentration
- Quality
- Location
- Seasonality
- Alternative uses
- Local technology potential

Sweet Sorghum- a potential crop

- An alternative to sugar cane
- Production of high biomass yield
- High %age of fermentable sugars and organics
- Shorter growth period
- Tolerance to draught stress
- Low fertilizer requirement
- Provides grains for additional ethanol productivity

Sweet Sorghum (*Sorghum bicolor* L.)

SSG 601 **PC 009** **PCH 106** **PC 121** **PC 023**

- **Released by IARI in 1996; single cut variety ; 120-150 days cycle time (mid June – Oct end) ; rain fed & requires low fertilizers input.**
- **Total plant biomass yield : 620 Q /ha**
- **Dry matter : 35% w/w (217 Q /ha)**
- **Juice recovery : 27900 l/ha**
- **Total fermentable sugars : 15.8 % w/v (4408 kg/ha)**
- **Sorghum bagasse : 186 Q /ha (dry wt.)**
- **Sorghum grain : 12.5 Q /ha**

***** ***Courtesy Dr. S. Solomon , Dept. of Genetics IARI,New Delhi***

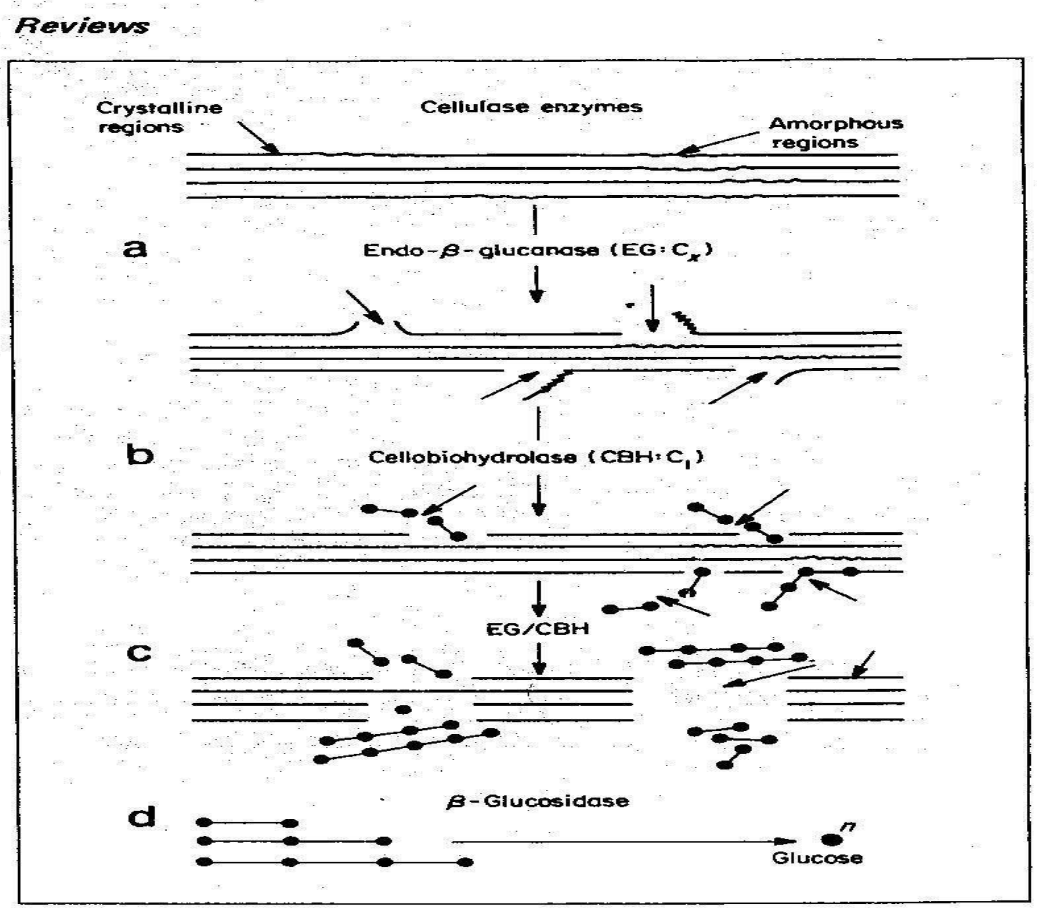
Sweet Sorghum:

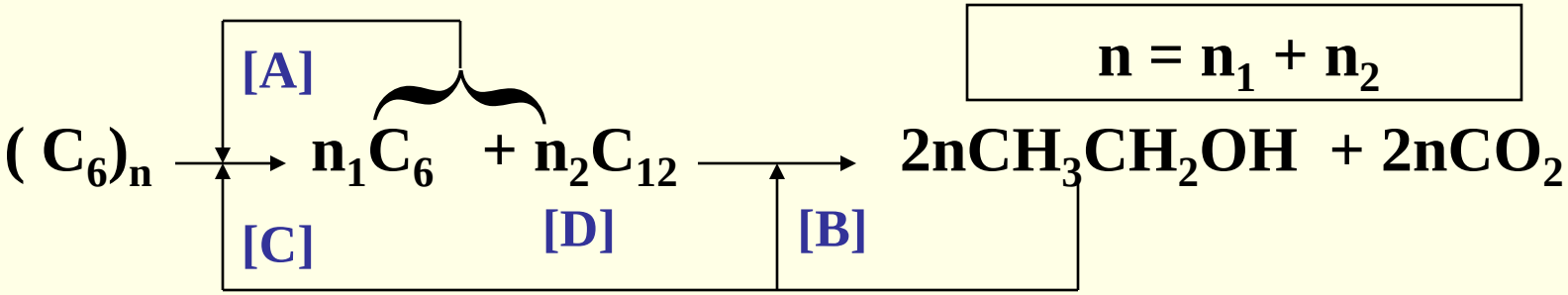
- Stalks → Juice → Ethanol

- Bagasse → SSF → Ethanol
  +
  Residues

- Grains → Liquefaction → Saccharification
  ↓
  Ethanol

Synergistic action of cellulase components





[A] :Sugars (Glucose & Cellobiose) inhibit cellulase enzyme (Saccharification)

[B] : Ethanol inhibits alcoholic fermentation

[C] : Ethanol inhibits cellulase enzyme (Saccharification)

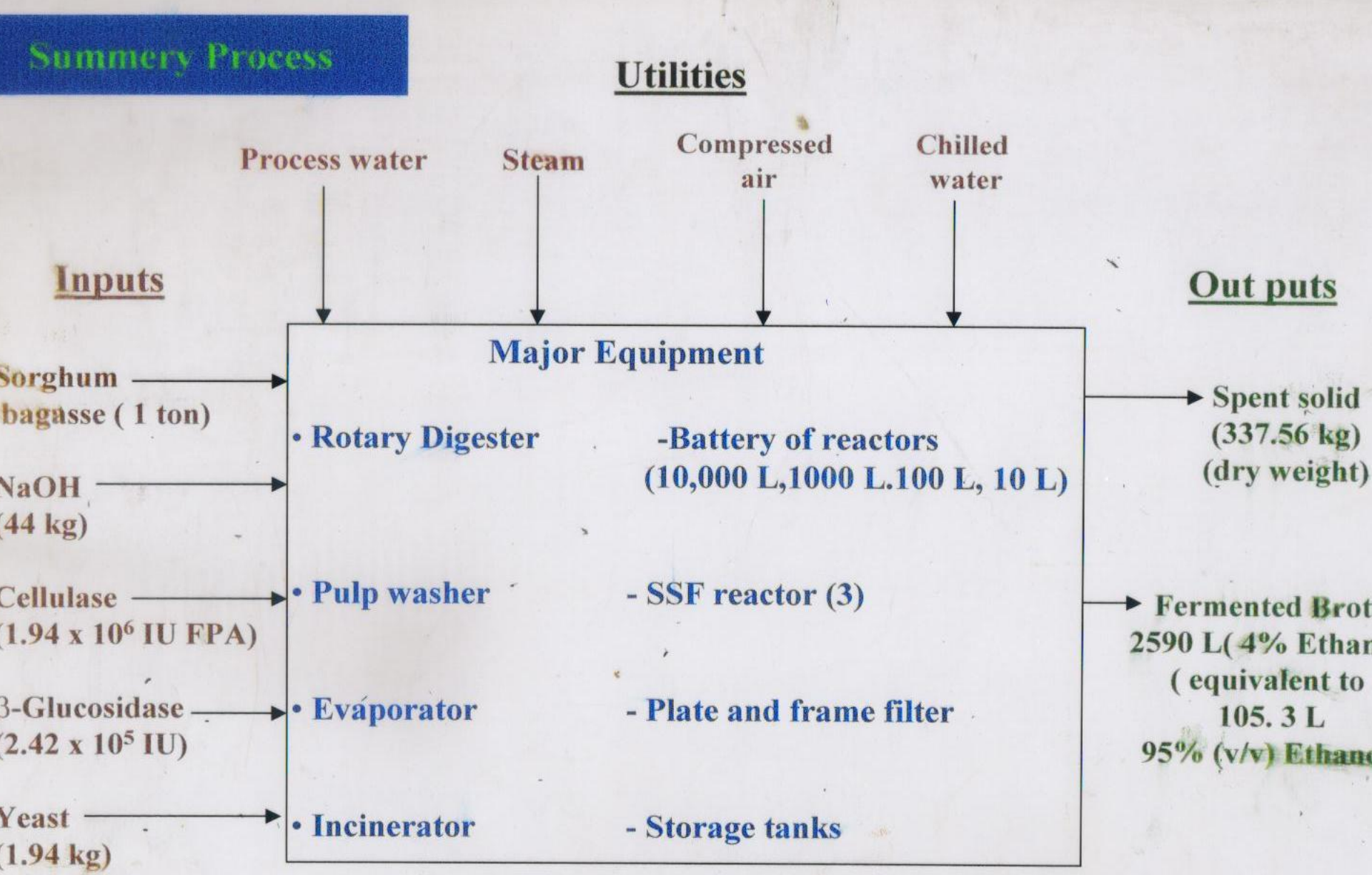
[D] : Accumulation of cellobiose reduces the yield of fermentable sugars.

Cellulose to ethanol : process inhibition pattern

Cellulase vs Glucoamylase

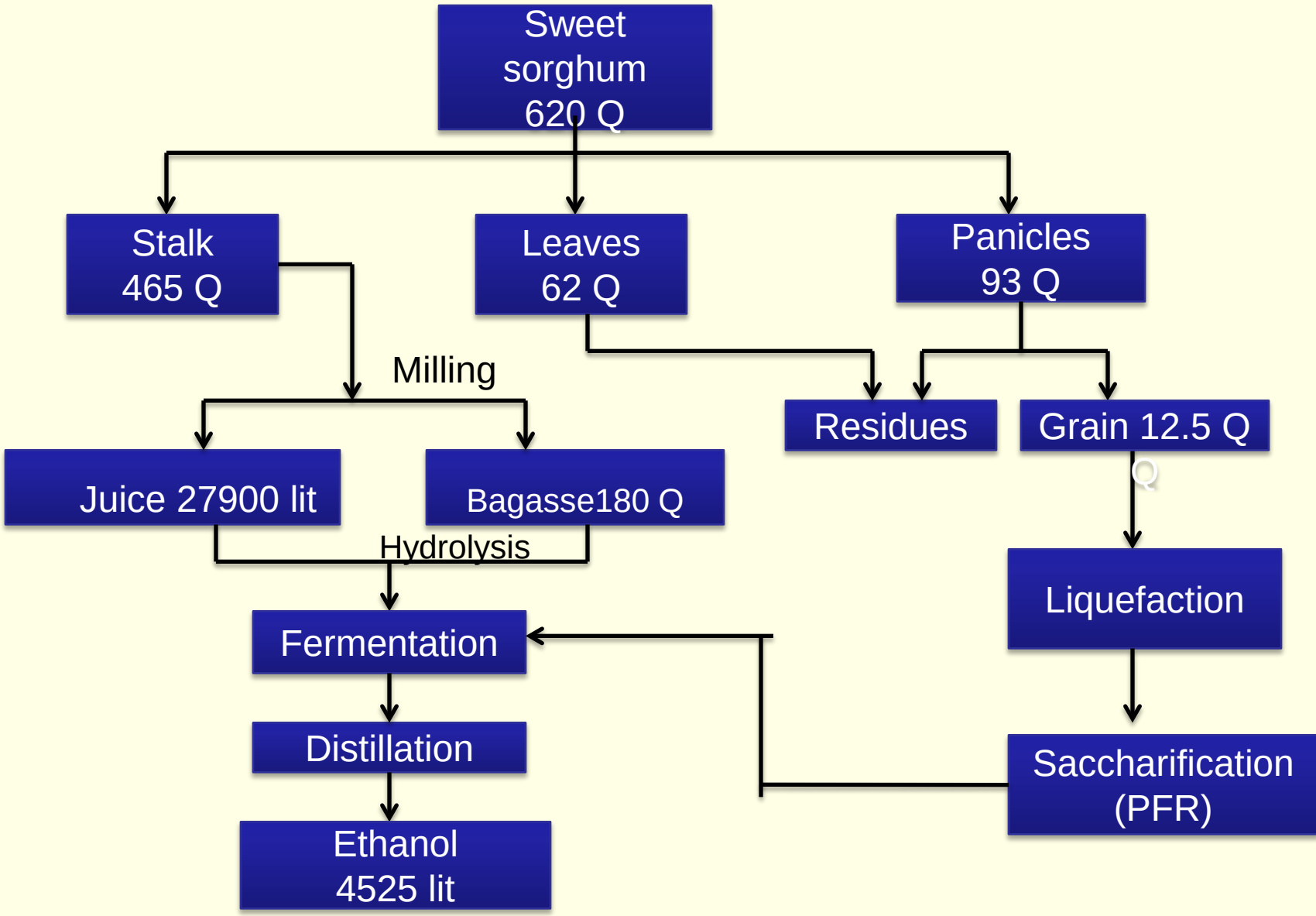
Enzyme	Sp. Activity (IU.mg-1protein)	Max. velocity (moles P/moleE.sec)
Cellulase		
- FPA	**0.6**	**0.5**
- EG	**70.0**	**58.0**
Glucoamylase	**~ 70.0**	**58.0**

Summery Process



Total Utilization of sweet sorghum for ethanol production

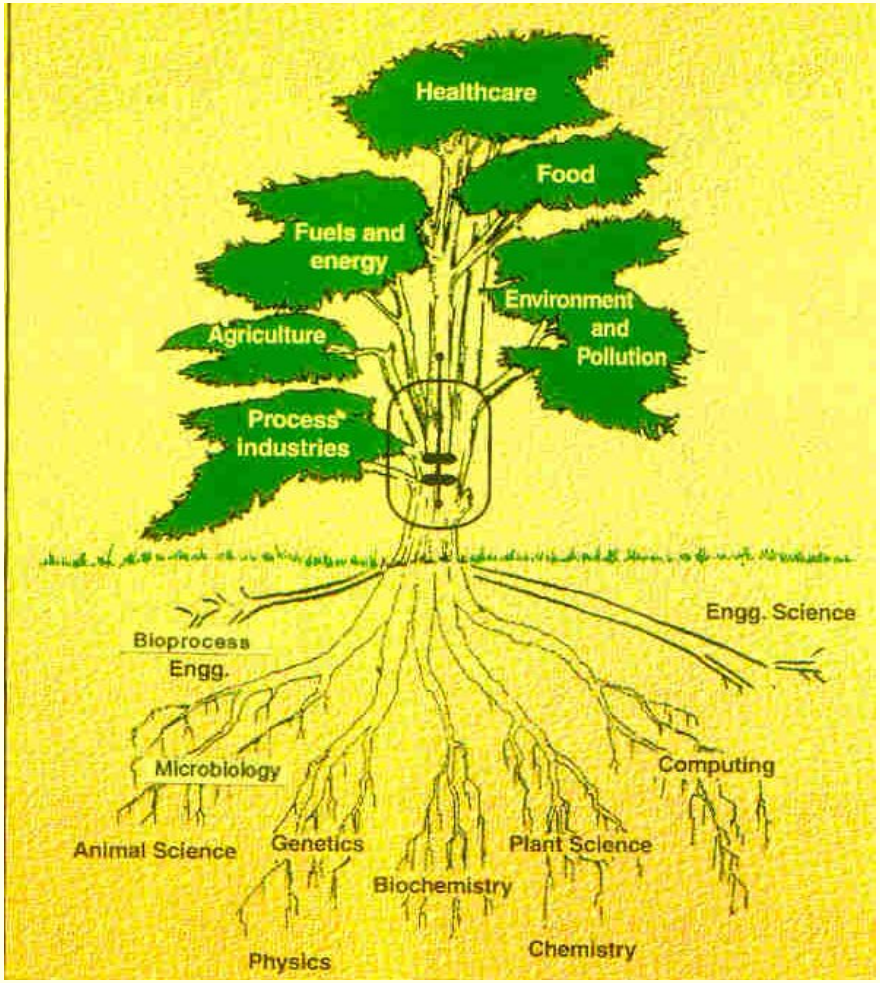
(Basis : 1 Hectare of Sweet Sorghum cultivation)



Waste Potatoes as additional feedstock

- **Potato production in India** **45.4 MT/Yr.**
- **Waste potato potential** **4.54 MT/Yr.**
- **Total ethanol potential from waste potatoes** **~ 373 M liters**
- **Affordable cost of waste potatoes** **~ Rs. 4.0/ kg**

Various alternative feed-stocks including a dedicated crop like sweet sorghum to ethanol and waste potatoes can provide a decentralized and sustainable solution to meet the growing needs of ethanol as a biofuel.



THANK YOU