Biomass based Biofuels Biological and Technological challenges

Purnendu Ghosh, Ph.D., FNAE
Vice President, Indian National Academy of Engineering
&
Executive Director
Birla Institute of Scientific Research
Statue Circle, Jaipur, India

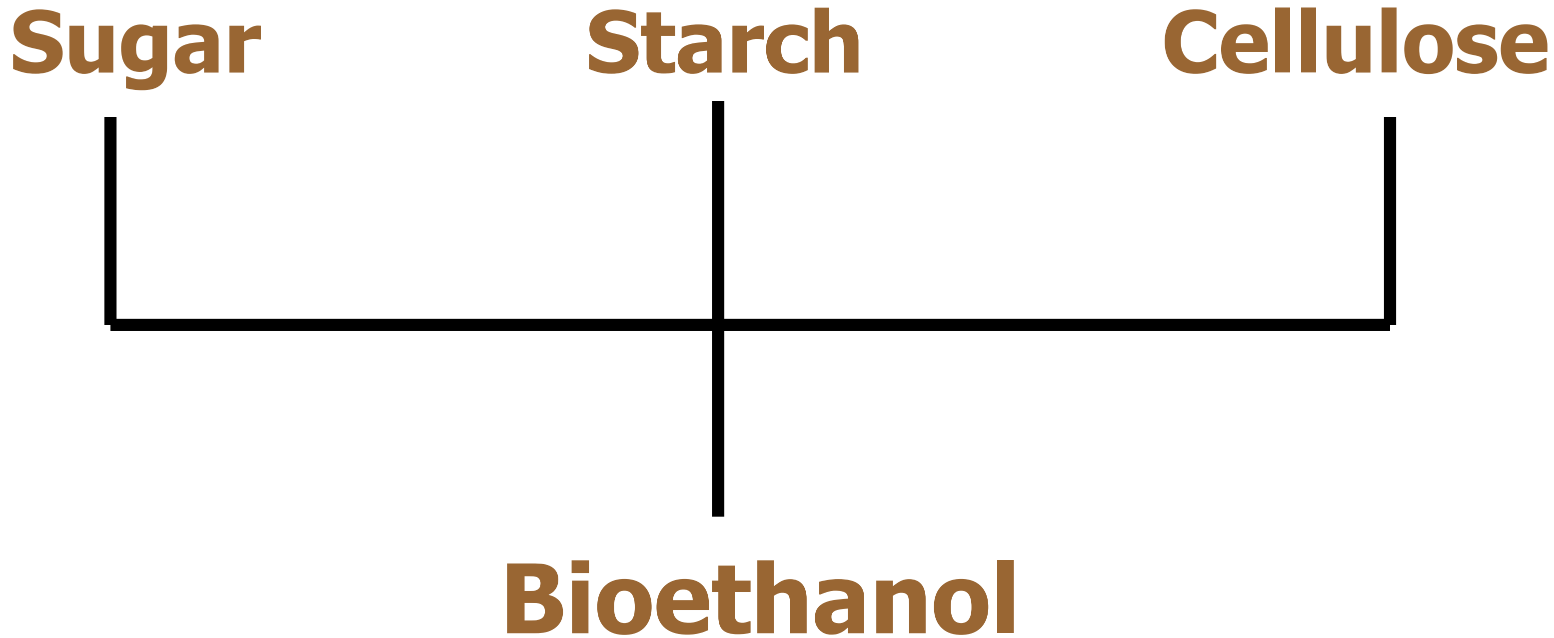
World Energy Sources

- Fossil 85%
- Nuclear 7%
- Renewable 8% ↑ 30% (2050)

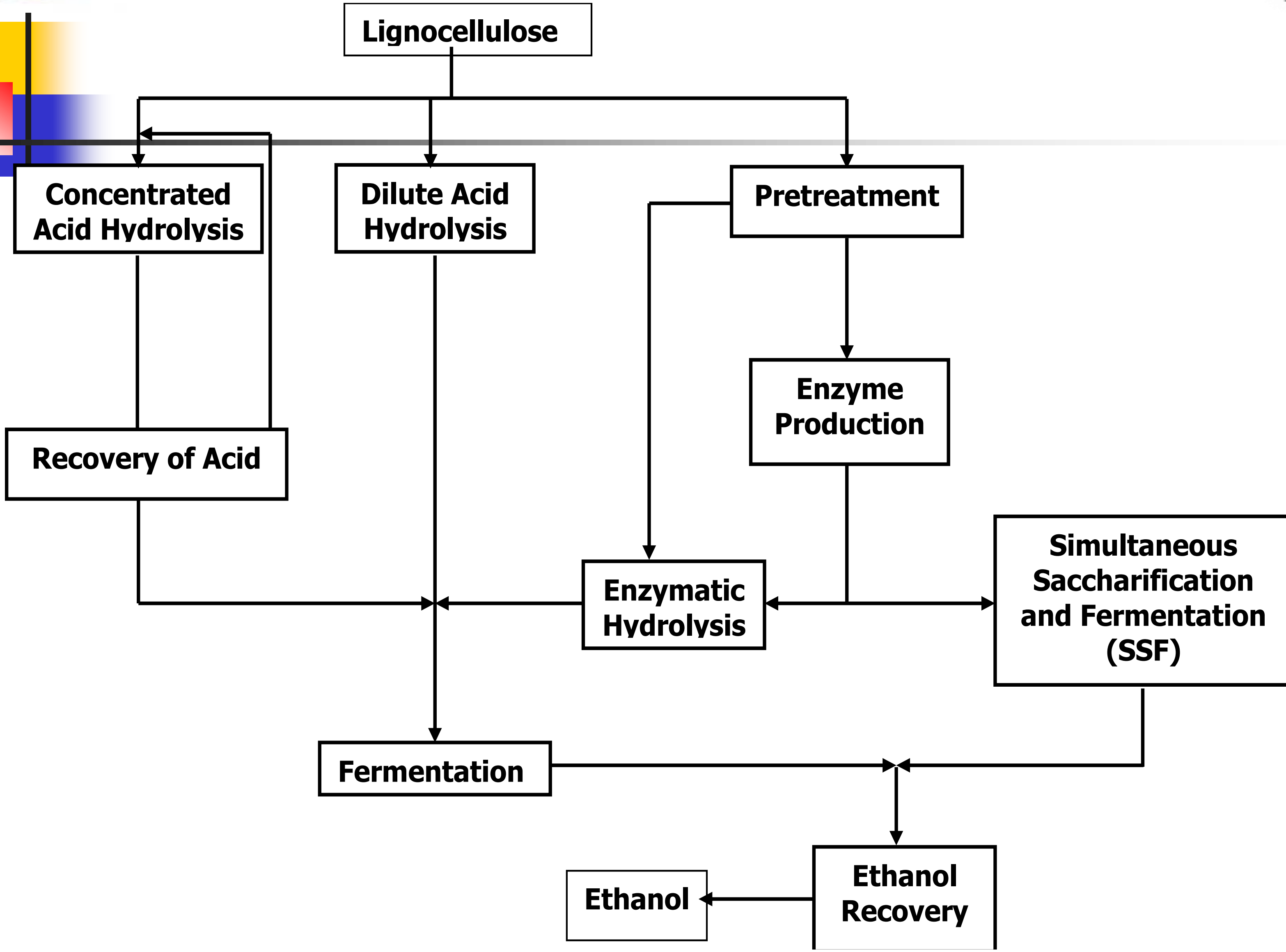
Oil Companies have acknowledged the need to develop energy sources to replace oil and the importance of reducing greenhouse gas emissions.

The ability to produce ethanol from low-cost biomass will be the key to making ethanol competitive with gasolene.

Bioethanol Feedstocks



Ethanol from Lignocellulose



LCB based Biofuel Technology

- Biomass availability
- Pretreatment technologies
- Efficient hydrolytic agents
- Availability of recombinant organisms
- Better co-product value.

Biomass Availability

- Increase in the efficiency of photosynthetic energy capture
- Improve biomass production and delivery system
- Alter carbohydrate composition

Pretreatment

Separate individual components of LCB with minimum component losses

Increase in surface area

Decrease in crystallinity

Pretreatment Approaches

Mechanical (*size reduction*)

Physical (*steam explosion*)

Chemical (*acid, alkali, solvent*)

Biological (*enzyme, whole organism*)

Combination of the above

Ideal Pretreatment Technology

- **Require little or no size-reduction**
- **Can be operated at high solid/liquid ratio**
- **Exhibit no significant inhibition of fermentation**

Cellulases

- *Desirable Attributes*
- Produce complete cellulase system
- Thermally stable
- Decreased susceptibility to product inhibition
- Selective adsorption on cellulose
- Ability to withstand shear forces

Cellulases

Improvement Strategies :

Discovering new enzymes through bioprospecting

Creating new/better mixture of enzymes

Developing improved expression systems through protein engineering

de-novo and in-silico designing of improved cellulases

Creating more effective cellulose binding domains in the enzyme molecule.

Ethanol Producer – Desirable Characteristics

High ethanol yield and productivity

High ethanol tolerance

Capability to ferment broad range of sugars

Resistance to inhibitory compounds present in the pretreatment/hydrolysis stream

Produces low levels by-products (e.g. acids, glycerol)

Can withstand high osmotic pressure, higher temperature and low pH

High cell viability and appropriate flocculation and sedimentation characteristics required for repeated cell recycling.

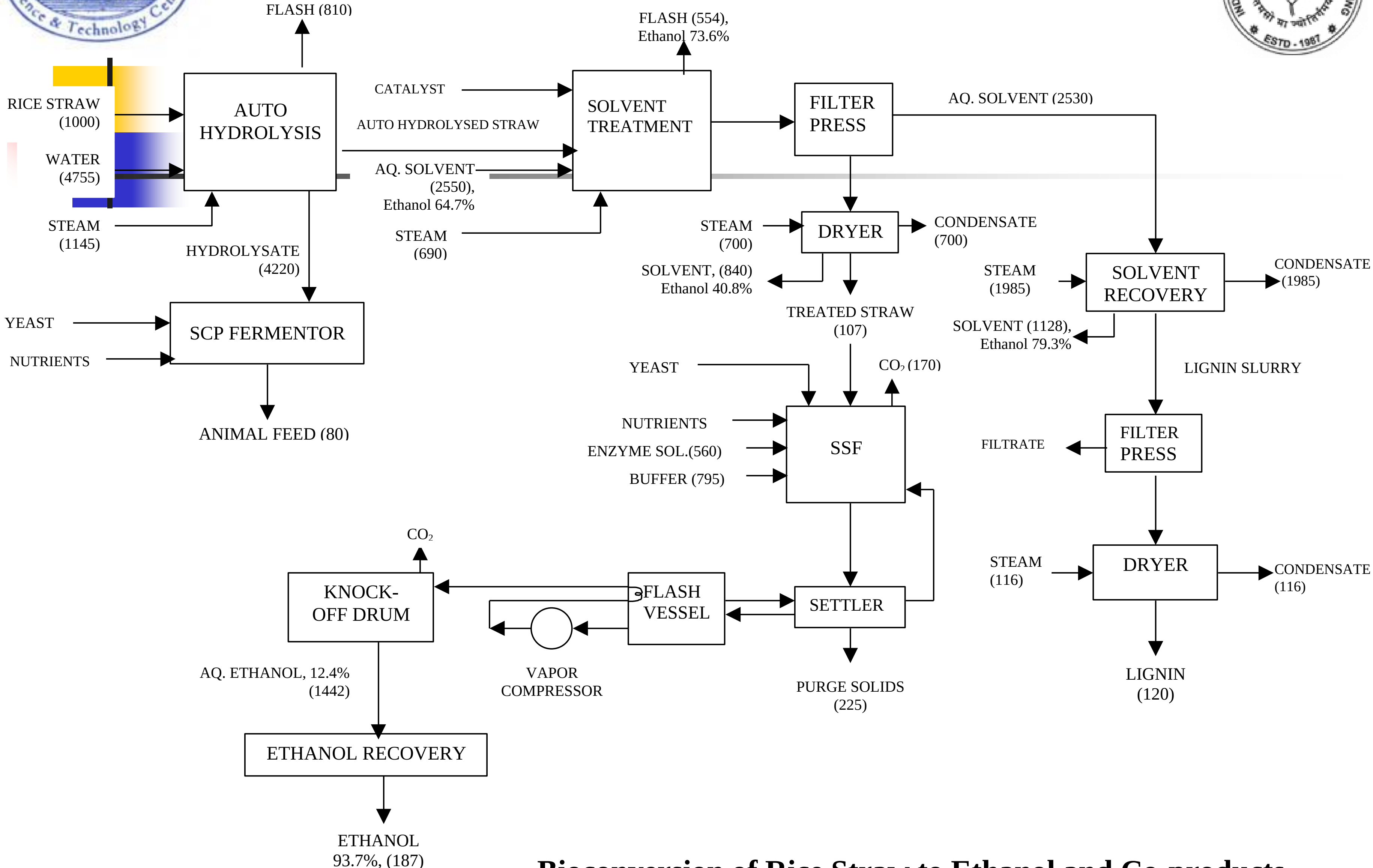
Recombinant Ethanol Producing Organisms

- **insertion of genes into a potential ethanol producing organism such as *Saccharomyces* and *Zymomonas* to enlarge substrate utilization range.**

- **insertion of ethanologenic traits into an organism capable of multiple substrate utilization e.g. *E.coli*.**

Rice Straw to Ethanol

Feedstock	**Rice Straw**
Pretreatment	**Autohydrolysis followed by solvent treatment**
Enzyme Source	**Mixed enzyme (*T.reesei* cellulase supplemented with *A.wentii* β-glucosidase)**
Enzyme Requirement (FPU/g cellulose)	**20**
Fermentation	***SSF with vacuum cycling and step feeding***
Ethanol yield (m^3/tonne LCB)	**0.23**
Byproducts	**Lignin, Animal feed**



Bioconversion of Rice Straw to Ethanol and Co-products

Technology Upgradation and Cost Reduction

Biomass

Cellulose	**42**	**-**	**51%**
Hemicellulose	**24**	**-**	**29%**
Lignin	**28**	**-**	**14%**
Ethanol yield	**250**	**-**	**370 l/t**

Cellulases

Productivity	**75**	**-**	**2000 FPU/l-h**
Yield	**200**	**-**	**2000FPU/g cellulose**

Fermentation

Temperature	**30**	**-**	**55^{o}C**
Residence Time	**7**	**-**	**2 days**
Contamination loss	**7**	**-**	**3%**

Research Priorities

- **Current pretreatment approaches either need high energy or chemical recovery costs or some undesirable component losses and presence of inhibitory products. Cost effective pretreatment technology is needed.**

- **Cellulases with characteristics such as increased thermal stability, decrease in feedback inhibition, enhancement in enzyme decrystallisation needed at a much reduced cost.**

- **Recombinant organism capable of co-fermenting whole range of sugars at a temperature compatible to optimum hydrolysis and better co-product value.**

Some Questions

Total process or cellulase enzyme production not on site or cellulase enzyme or site for use internally and also for sale to others

How can cellulase achieve required sales price and desired margin ?

Some Questions …..

Internal funding by a existing company or new venture with external funding ?

Who should be the major promoter of policy – Agricultural interests, sugar industry or petroleum industry

Necessity and cost of government support to make this technology viable ?

Genomic Prospective

Develop techniques to determine the genome structure and functional potential of plants, microbes, and microbial communities.

Functional Perspective

Develop methods and concepts needed to achieve a systems-level understanding of plants and microbial cell and community function, regulation, and dynamics.

Computing Perspective

Develop the knowledgebase, computational methods, and capabilities to advance understanding and prediction of complex biological systems.

India specific issues

India needs about 5000 million litres of ethanol to achieve its petrol blending targets of 5 percent, but the total ethanol production capacity in the country is 2650 million litres.

At the present levels of cane and sugar production (about 350 MMT & 26-28 MMT per annum respectively), molasses available is about 13 MMT, which is sufficient to produce about 3000 million litres of ethanol.

Assuming normal market conditions, ethanol imports will be 600 million liters in 2018.

At present, ethanol costs about Rs 40 per litre, which is about 60 percent of the price of a litre of petrol.

Crude oil required for indigenous consumption of petroleum products in 2017-18 is about 210 MMT. The domestic crude oil production is able to meet only about 17.9% of the demand.

Currently ethanol blending in petrol is around 2.0% and biodiesel blending percentage in diesel is less than 0.1%. An indicative target of 20% blending of ethanol in petrol and 5% blending of biodiesel in diesel is proposed by 2030.

Road transport sector accounts for 6.7% of India's GDP. Currently, diesel meets an estimated 72% of transportation fuel demand, petrol 23% and balance other fuels such as LPG etc.

What is required

Reduce Import Dependency:

Reduce greenhouse gas emission

Infrastructural investment in rural areas

Employment generation

National Policy on Biofuels - 2018

Expands the scope of raw material for ethanol production by allowing use of Sugarcane Juice, Sugar containing materials like Sugar Beet, Sweet Sorghum, Starch containing materials like Corn, Cassava, Damaged food grains like wheat, broken rice, Rotten Potatoes, etc.

Setting up of supply chain mechanisms for biodiesel production from non-edible oilseeds, Used Cooking Oil, short gestation crops.

Department of Biotechnology (DBT) Government of India

DBT Centres of Excellence

- DBT-ICT Centre for Energy Biosciences, Mumbai
- DBT-IOC Centre for Advanced Bioenergy Research, Faridabad
- DBT-ICGEB Centre for Advanced Bioenergy Research, New Delhi
- PAN IIT virtual centre for Bio-energy

DBT-ICT Centre for Energy Biosciences, Mumbai

Establish a biomass based Ethanol Technology demonstration facility.

DBT-IOC Centre for Advanced Bioenergy Research, Faridabad

Developed a process for CO_2 fermentation and conversion to lipids at the pilot scale.

DBT-ICGEB Centre for Advanced Bioenergy Research, New Delhi

Engineered bacteria for C5 fermentation to ethanol.

Engineered algae with enhanced CO2 sequestration.

PAN IIT virtual centre for Bio-energy

Network of IITs (Bombay, Kharagpur, Guwahati, Jodhpur and Roorkee)

To genetically engineer a microalgal strain to produce lipids and

Designing optimal photobioreactors and DSP system for the same.

Techno-economic feasibility of integrated biorefineries

Termites – The Walking Bioreactor

Termites love munching household timber silently and for this nuisance value we hate them.

We should love them precisely for this reason

The gut of a species of a termite from the rainforests of Costa Rica contains microbes and enzymes capable of breaking down cellulose present in woody fibre to biofuel.

Termites – The Walking Bioreactor ….

These species can munch 95 percent of cellulose present in wood to simple sugars within 24 hours.

Termites have a series of stomachs, each harbouring a distinct community of microbes under precisely defined conditions.

These 'bugs within bugs' are equipped with enzymes needed for metabolic pathways to digest cellulose to sugars, and then sugar to ethanol.

Termites – The Walking Bioreactor ….

There is hope.

Even and enemy can be a friend.

A waste can be a resource.

Thank you