Biofuels Research in Brazil: a perspective

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MOTIVATION TO DO RESEARCH AND USE BIOENERGY

Energy Security

Global Climate Change
BIOENERGY: what is it?

...renewable energy made available from materials derived from biological sources
THE SCIENCE FOR BIOENERGY: THE FUTURE AND IN THE PRESENT
Tailoring biomass to fit the biofuels pipeline

Center for direct catalytic conversion of biomass to biofuels (C3Bio)
Conversion technologies for next-generation biofuels

Biomass → catalytic conversion → Sugar → Fermentation

Biomass → catalytic conversion → Syn gas → Fischer-Tropsch

Biomass → catalytic conversion → Pyrolysis → Catalytic upgrading

Fuel + High-Value Organics
The maize and sorghum genomes are engines of discovery for improvement of bioenergy grasses

- Close evolutionary relationship to the future bioenergy grasses
- The cell walls of maize and sorghum and its gene networks for wall biogenesis are characteristic of all grasses
- Complex genomes similar to other C4 energy grasses
- Their genetic diversity gives great potential for improved agricultural traits of interest
- Long history of genetic discoveries and breeding success
- A wealth of genetic tools that is ever growing
- Now completed genome sequences

Tropical maize and sweet sorghum could also become transitional if not terminal bioenergy crops

Maize and sorghum can serve as good models for sugarcane, as the latter is an octaploid with very complex genetic problems to be solved

Schnable et al. (2009) *Science* 326, 1112-1115
THE GENERATIONS OF SUGAR CANE BIOETHANOL

- Cane genome
- Cell Wall
- Fungal genome
- Enzymes
- Termochemical Route (gasification, pyrolysis)
- Enzyme structure
- Green gasoline
- Cane
- Sucrose
- Acid
- Glucose, xylose, and arabinose
- Bioethanol

Rotas para o etanol celulósico - Marcos Buckeridge, msbuck@usp.br
SUGAR CANE AND ETHANOL IN BRAZIL
IS IT WORTHWHILE?
Domestication and early evolution of sugarcane

Saccharum officinarum
Saccharum sinense
Saccharum barberi
(crosses to wild relatives
natural hybrids)

Sugar extraction
Manufacturing
Cottage industries

8000 BC
1000-1500 BC
500 AD
6th-8th Century
15th Century
16th Century
19th Century

SE Asia
Pacific Islands
Intertropics
Persia
Mediterranean
Spain
Canary
Madeira
West Africa
Dominican
Republic
Brasil
Java
India

Sugar extraction
Manufacturing
Cottage industries

Modern Breeding

Modern sugarcane cultivars

S. officinarum x S. spontaneum
(interspecific hybrids)
The use of ethanol in Brazil started in the Northeast at the beginning of the 20th Century.

In April 1933, there were ethanol pumps serving cars in several cities in the Northeast of Brazil: 3 in Recife; 1 in Caruaru, 1 in Garanhuns, 2 in Maceió, 1 in Serra Grande, 1 in União dos Palmares.
Cars selling of light vehicles in Brazil (1979-2007)

- Corrosion
- Optimization of combustion
- Proalcohol
- Flex engines

Graph showing the sales of different types of cars from 1979 to 2007. The graph includes three categories: 100% Ethanol Cars, Gasoline Cars, and FlexFuel Cars.
Processamento em uma usina sucro-alcoleira
ACTIVE BIOENERGY RESEARCH PROGRAMS IN BRAZIL

CeProBIO
A INTERNATIONAL RESEARCH NETWORK IS NOW BEING ASSEMBLED

PURDUE, CCRC

FAPESP
CNPQ
NSF
BBSRC
FULBRIGHT

FP7
CeProBio

BIOEN, CTBE
INCT
INDUSTRY

SIBRATEC
US$ 5 mi

Pilot Plant
CTBE
US$ 40 mi

CTBE

INCT BIOETANOL
US$ 3 mi

Centros Paulistas de Bioenergia
US$ 10 mi

Embrapa
US$ 47 mi

TOTAL: US$ 120 mi
Science and technologies for bioethanol production
STATEGIES TO IMPROVE SUGARCANE ETHANOL SUSTAINABILITY

IMPROVING PRODUCTIVITY
- Average today: 80 t/ha
- Goal: 120 t/ha
- There are records of >300 t/ha
- We continue to develop more productive varieties
- Photosynthesis can be improved

IMPROVING 1st GEN ETOH
- We can still improve sucrose in Brazilian varieties.
- Engineering can improve process efficiency, especially the fermentation step

DEVELOPING 2nd GEN ETOH
- 2/3 of the energy in sugarcane is in the cell walls
- Part of it is used for bioelectricity
- Biorefinery can be developed

- GENETICALLY MODIFIED PLANTS FOR HIGHER SUCROSE
- YEAST SYNTHETIC BIOLOGY

-CELL WALL ARCHITECTURE
-PRETREATMENT
-HYDROLYSIS
-PENTOSE FERMENTATION

IMPROVE EFFICIENCY OF COMBUSTION OF ETHANOL IN ENGINES

Using the CO₂ produced during the process to empower algae to make biodiesel could be a great help to decrease CO₂ emissions
Sugarcane leaves performe $C_4$ photosynthesis

Amanda Souza & Marcos Buckeridge – Photosynthesis in Sugarcane, Cortez, L. 2010
THE ARCHITECTURE OF SUGARCANE CELL WALL

Dos Santos, Pimentel & Buckeridge, Unpublished

Primary walls: Cell Suspension

Cell wall of stem
Augusto Crivellari & Marcos Buckeridge – unpublished results
Aspergillus niger, one of the model fungi species under study at the INCT

Photos: Gustavo Goldman
Heterologous expression of hydrolases
Biodiversidade

Structural studies

Kinetic studies

Scaling up to Industrial process

Bioinformatics and Systems Biology

Genomic studies

Figure: Igor Polikarpov
PE-2 and CAT-1: Fungal-type cell wall organization

Figure: Gustavo Goldman
e-Science: we are flooded with information

The human dimension of biofuels
IMPORTANT ISSUES
GHG LCA analysis
Social impacts
Economical impacts
Potential of different areas for production of sugarcane in Brazil based on soil and climate without irrigation.

- **High**
- **Average**
- **Low (World average)**
- **Inappropriate**

**Areas**:
- Amazon Rainforest
- Pantanal
- Atlantic Forest
- Other important preservation areas
- Above 12% slope
Controlled Traffic Structure (CTS): to be used for precision agriculture
Feedstock production (sugar cane)

Green water: evapotranspiration - “water footprint”

Brazil – more than 75% of sugar cane is rainfed

Gerbens-Leenes et al. (2008)
de Faiture and Berndes (2009)
Strategies to reduce impacts on water resources

- **Control use of herbicides**, pesticides and other chemicals on sugarcane crops.
- Avoid expansion of sugarcane crops to areas devoid of riparian buffers.
- **Monitor use of water resources** and impacts to water quality.
- Promote industrial practices that **reduce use of water and recycle**. (e.g. *Project for water use reduction in the sugarcane industry created by the Sugarcane Technology Center (CTC) Sao Paulo – Brazil and more recently Dedini Company*).
- **Implement public policies to promote reduction in water use** (e.g. charging for water use in the state of Sao Paulo is showing positive results).
- **Enforce laws** to protect and restore riparian buffers.
Cost versus production of ethanol in Brazil

http://www.biodieselbr.com/energia/alcool/etanol.htm
Ethanol resists to fluctuations in prices of oil
Complex themes require inter and transdisciplinary approaches

- **The natural sciences**: biology or life sciences, chemistry, earth sciences, mathematics and physics
- **The social sciences**: anthropology, economics, political science, psychology, and sociology
- **The humanities**: art and art history, history, philosophy, and religious studies;
- **The applied professions**: business, communications, criminal justice, education, engineering, law, social work, and medicine.
Although denotations of these terms look similar to the layperson, one should not mix them:

**Multidisciplinary:** disciplines run in parallel, **WITHOUT** interaction;

**Interdisciplinary:** disciplines run in parallel, **WITH** interaction;

**Transdisciplinary:** interdisciplinary actions with the participation of society.
TRANSDISCIPLINARY APPROACH IN BIOFUELS RESEARCH
SCIENCE OF COMPLEXITY!
CONNECTING BASIC SCIENCE WITH TECHNOLOGY PRODUCTION
Precision agriculture

Pilot Plant

7,000 m², with two floors, several labs and one pilot plant, CTBE wants to have, in one place a transdisciplinary institutions with national and international connections.

The aim: improve technologies for ethanol production
MEGAEXPERIMENT

Marcos Buckeridge
Basic Science
WHAT IS IT?
The MEGAEXPERIMENT is a group of parallel scaling up experiments that integrate different parts of the 2\textsuperscript{nd} process aiming to improve the process of production of lignocellulosic ethanol from sugarcane
General Strategy

Evaluate the status of the following steps of ethanol production:
1) Source and quality of biomass
2) Pre-treatment
3) Hydrolysis
4) Fermentation
5) Distillation
THANK YOU

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