SIAGRO 2019
Sao Carlos
December 3, 2019

Bioproducts, Bioeconomy and Sustainable Development of Renewable Resources

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Acknowledgements

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College of Agriculture

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EMBRAPA

Cristiane Farinas (Research Leader)

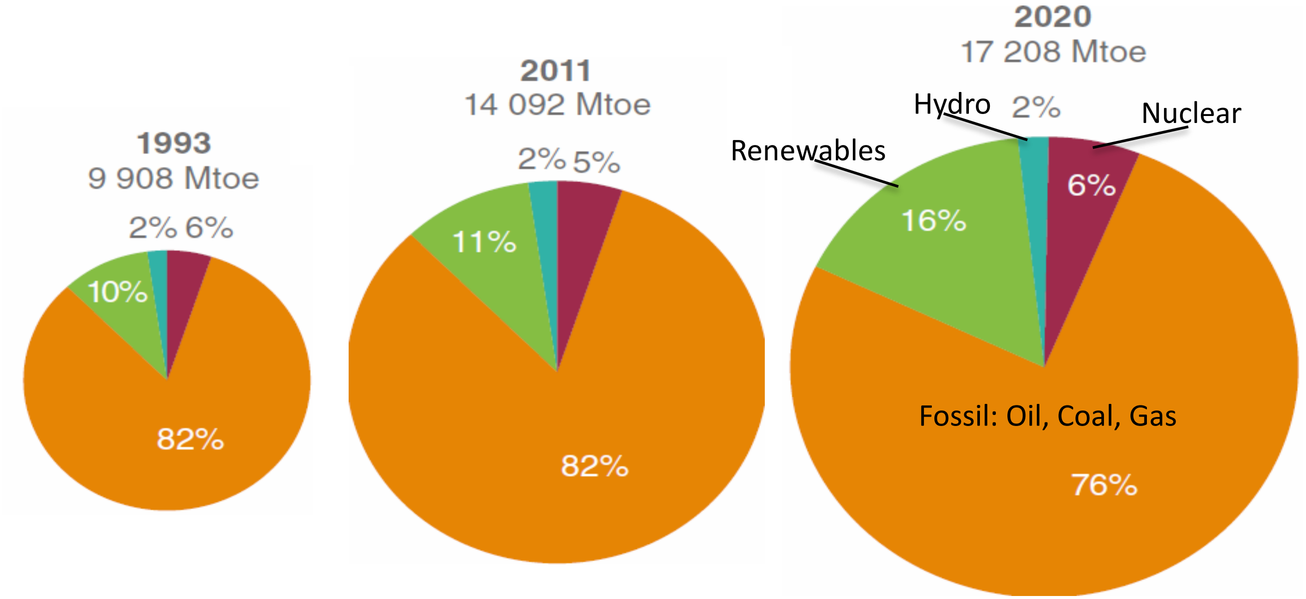
João Naime – Chefe Geral Embrapa Instrumentação

Ladislau Martin Neto, Chairman do Siagro 2019

Outline

- Bioenergy, New Materials and Sustainable Biorefineries
  - Technology
  - Feedstocks (sugar cane bagasse, leaves)
  - Costs
- Role of Bio-products / On-site Enzyme Production
  - Use of captive co-products
  - Role of Bioprocessing
  - Examples
    - Biodegradable adsorbents
    - Nanocellulose
    - Enzymes
- Conclusions

Global Energy Sources (and Consumption) are Increasing



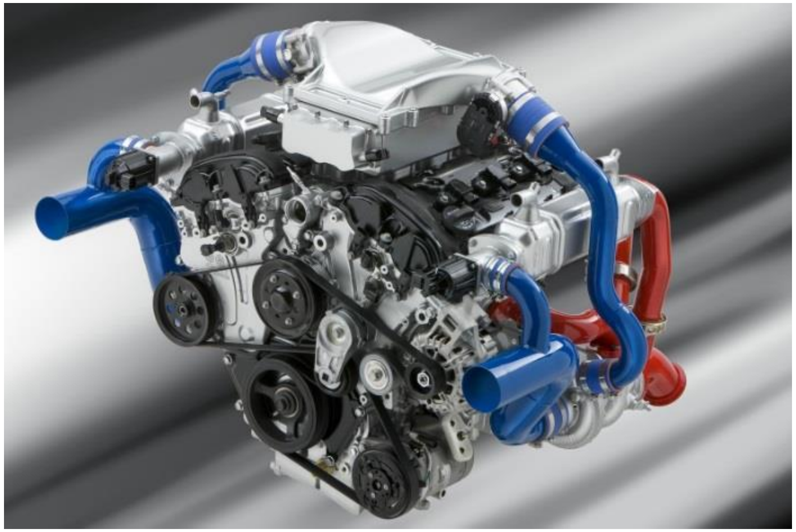
TPES = total primary energy supply
Mtoe = millions of tons of oil equivalent
Renewables = wind, solar, PV, biomass
"Negajoule" = energy saved

World Energy Council, 2013

Two Approaches to Reduce Emissions

More fuel with less carbon –
advanced low carbon biofuels

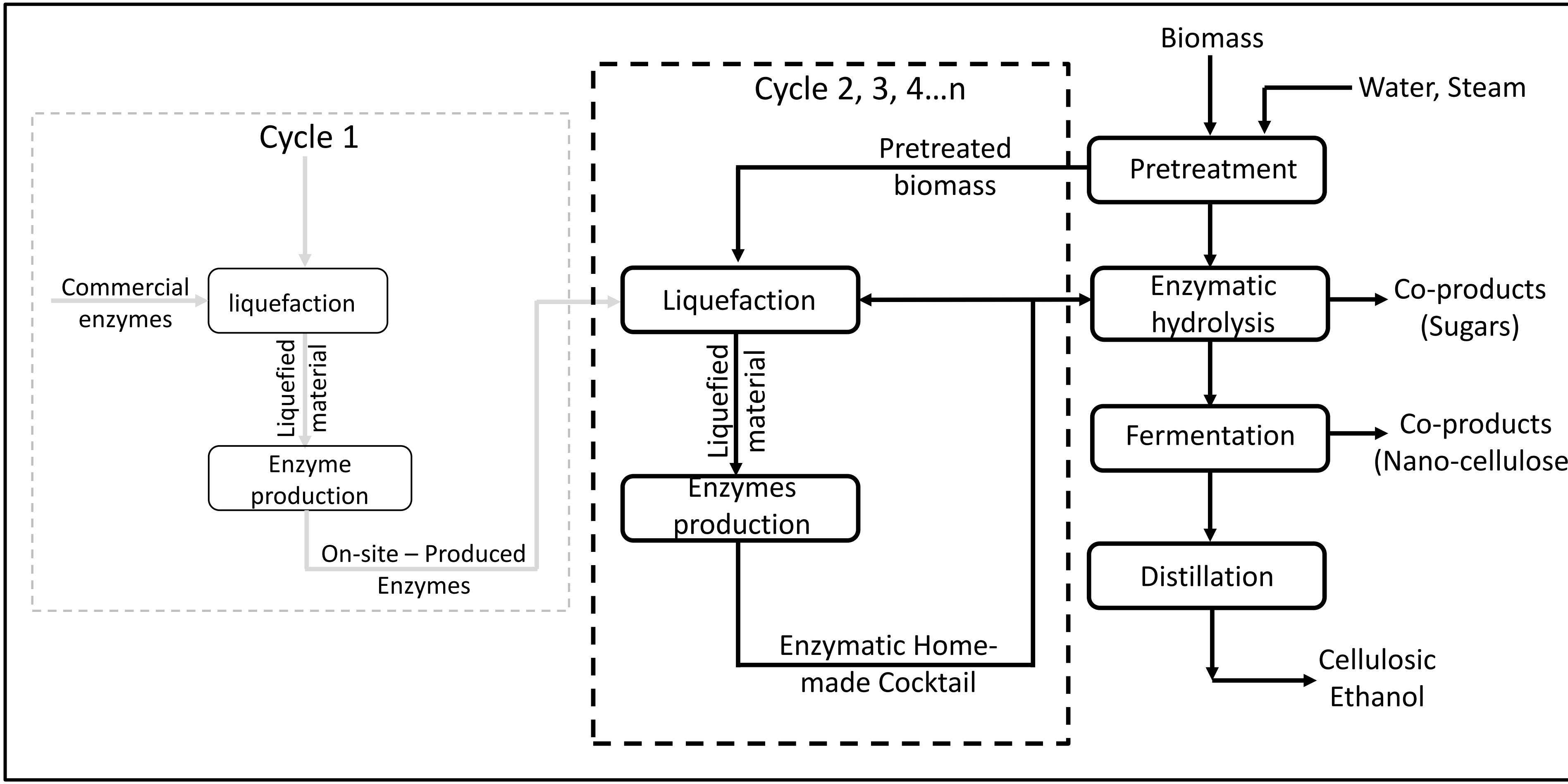
Engine Technology
More miles with less fuel



Cellulosic materials: low carbon and with long term sustainability. Combined with efficient biofuel engines, emission reductions result.

Shaver, 2014, Kakosimos, 2016; Allen, 2015

Closed-loop strategy to produce the cellulolytic enzymes using sugarcane bagasse liquefied by a home-made enzymatic cocktail



Squinca et al., 2018

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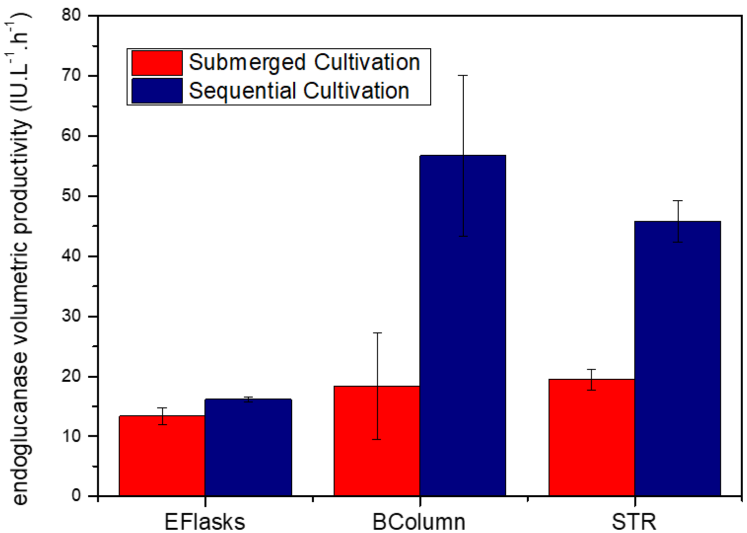
Sequential Fermentation

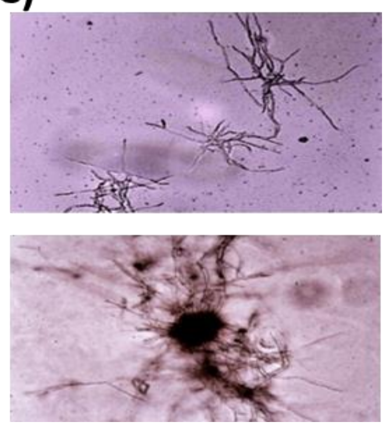
A)

SmF

B)



C)



The sequential fermentation (SeqF) is proposed as the combination of the SSF and SmF cultivation techniques.

(a) *A. niger* cultivated in sugarcane bagasse under SSF followed by SmF in a column bubble bioreactor;

(b) endoglucanase productivity under Seq and conventional SmF in different bioreactors;

(c) *A. niger* morphology under Seq and SmF systems

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Liquefaction at High Solids

Needed to achieve smooth operation of plant

Sugarcane bagasse 30% (w/w)

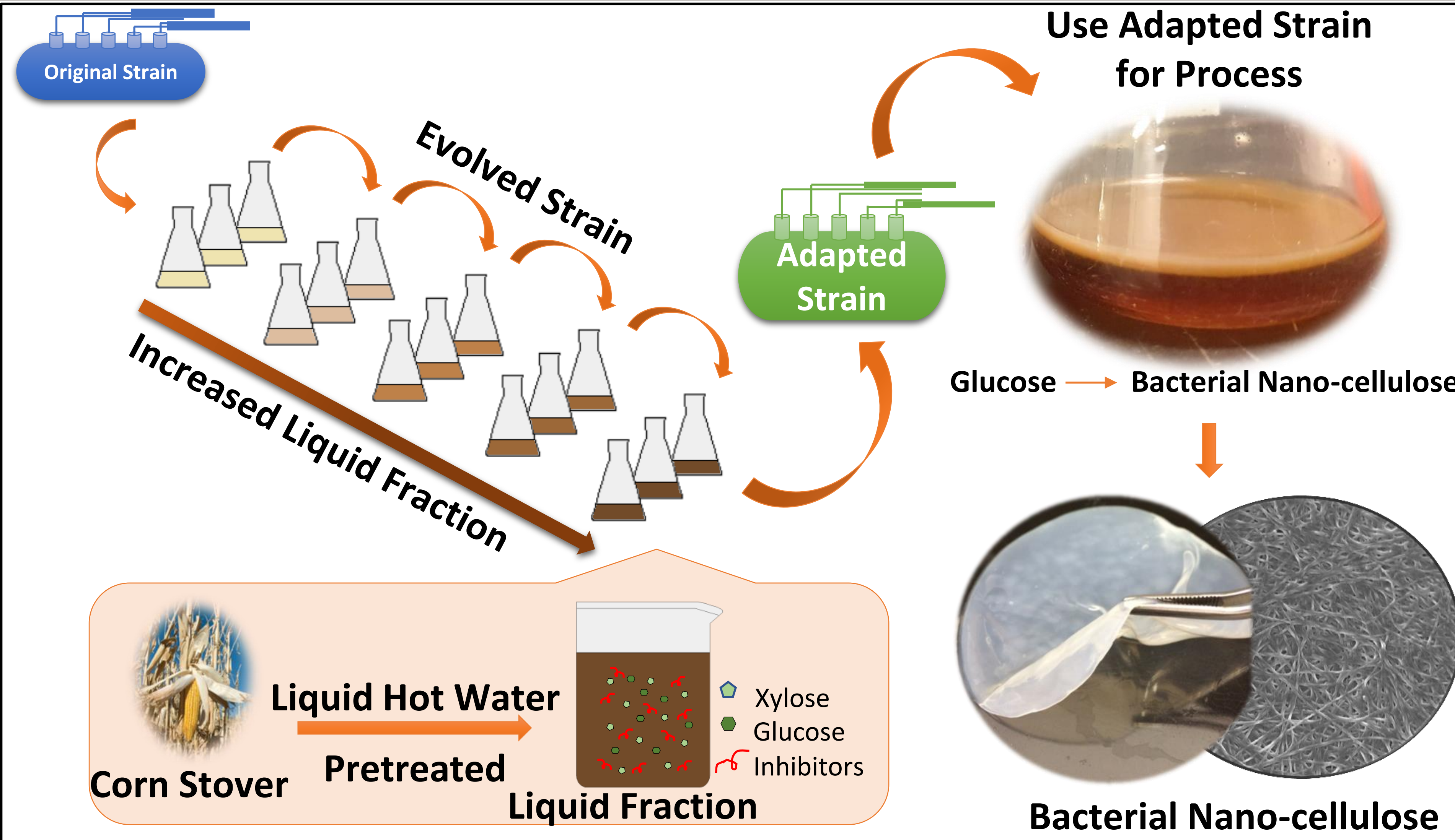
Before Liquefaction

After Liquefaction

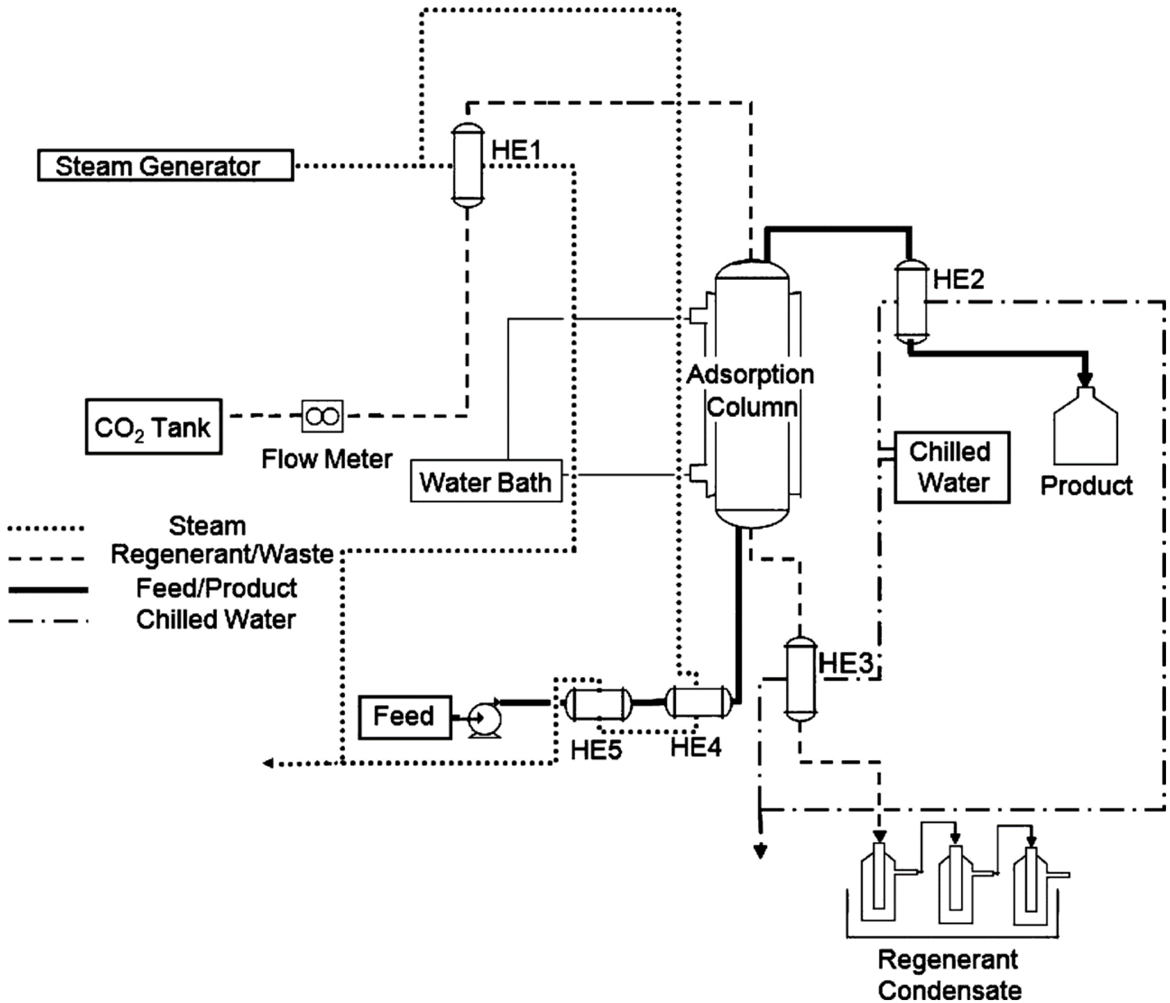
Cunha, F.*, T. Kreke, A. Badino, C. Farinas, E. Ximenes, and M. Ladisch, “Liquefaction of Sugarcane Bagasse for Enzyme Production,” *Bioresource Technology*, 172, 249-252 (2014);

Ladisch, M. R., E. Ximenes, T. R. Kreke, A. C. Badino, F. da Cunha, C. S. Farinas, “Liquefied Cellulosic Biomass for Enzyme Production,” US 10,072,253 B2 (September 11, 2018).

Bacterial Nanocellulose Production Using the Liquid Fraction of Liquid Hot Water Pretreated Corn Stover



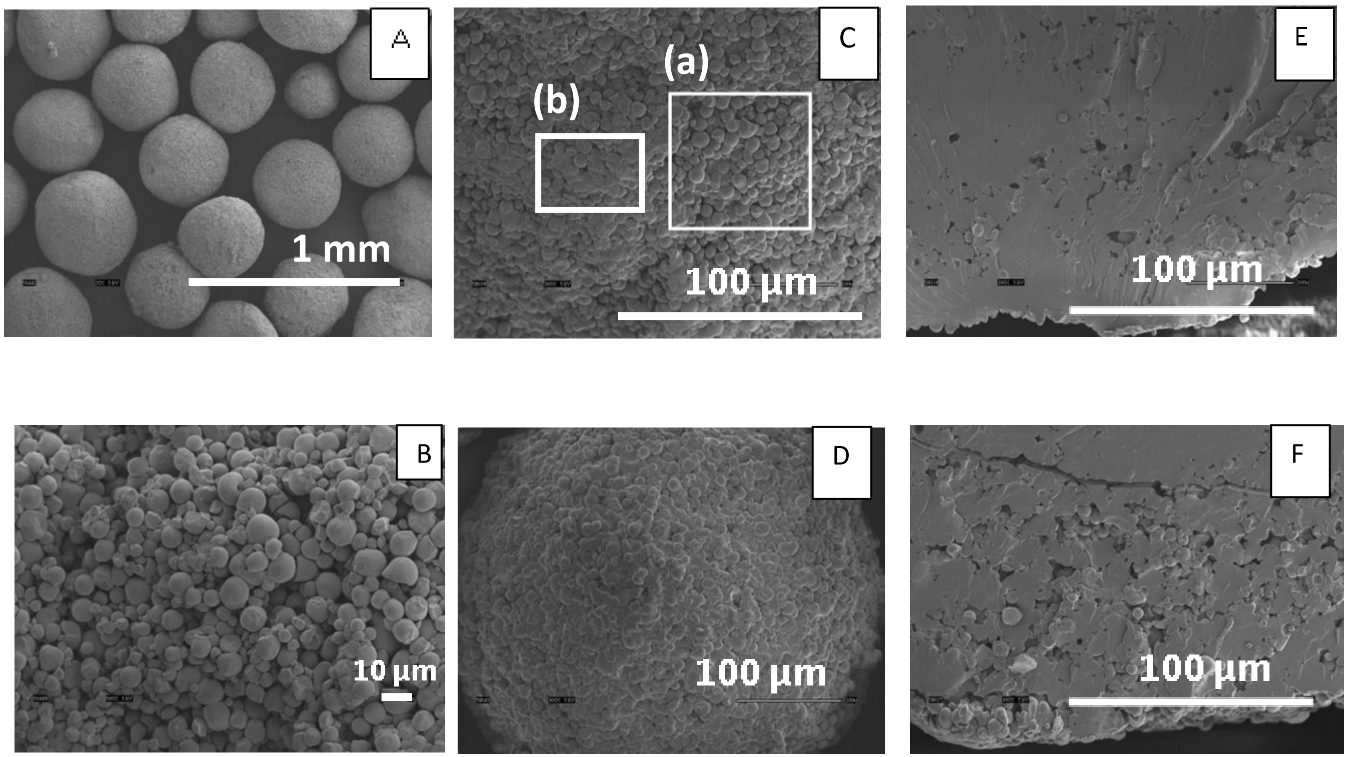
Process for Drying Fuel Ethanol



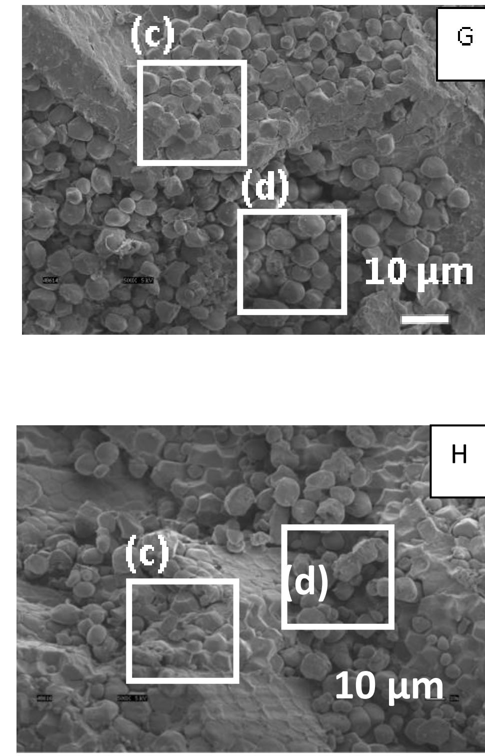
Starch Adsorbents for Drying Ethanol

Used for Energy Efficient Drying of Fuel Ethanol

Cassava Pearls



Corn



Ladisch, M., Y. Kim, N. Mosier, R. Hendrickson, A. Hilaly (ADM), "Drying of Fuel Ethanol Using Tapioca Pearls" (February 5, 2010)
Kim, Y., R. L. Hendrickson, N. Mosier, and M. R. Ladisch, "Methods and Systems Useful for Drying Ethanol," US8,921,648 (Dec 29, 2015).

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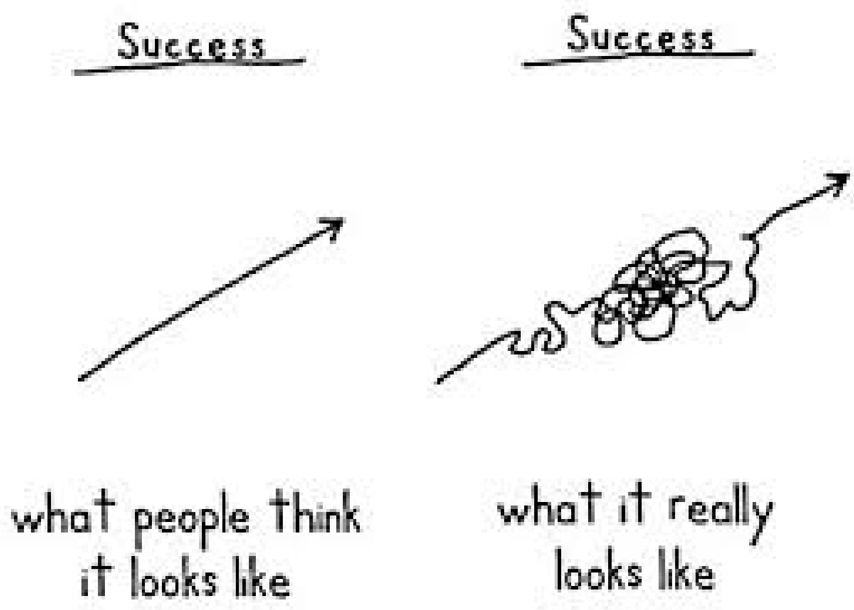
The **Reality**



Alignment of…
People
Talent
Perseverance
Advisors
Time
Timing
Money
Technology
Intellectual Property
Operations
Manufacturing
Pricing
Marketing
Customers
Competitors

Productive academics are entrepreneurs

	Academic	Entrepreneur
Ideas/Innovation	Meet needs or wants	Meet needs or wants
Raises capital	Research funding	Venture funding
Promote their ideas	Publications, presentations	Marketing, advertising
Plan their work	Proposals	Business plans
Need partners and networks	Needs advisors, colleagues, collaborators	Needs advisors, partners, suppliers
Build a team	Graduate students	Employees
Build an entity	Research program	Business

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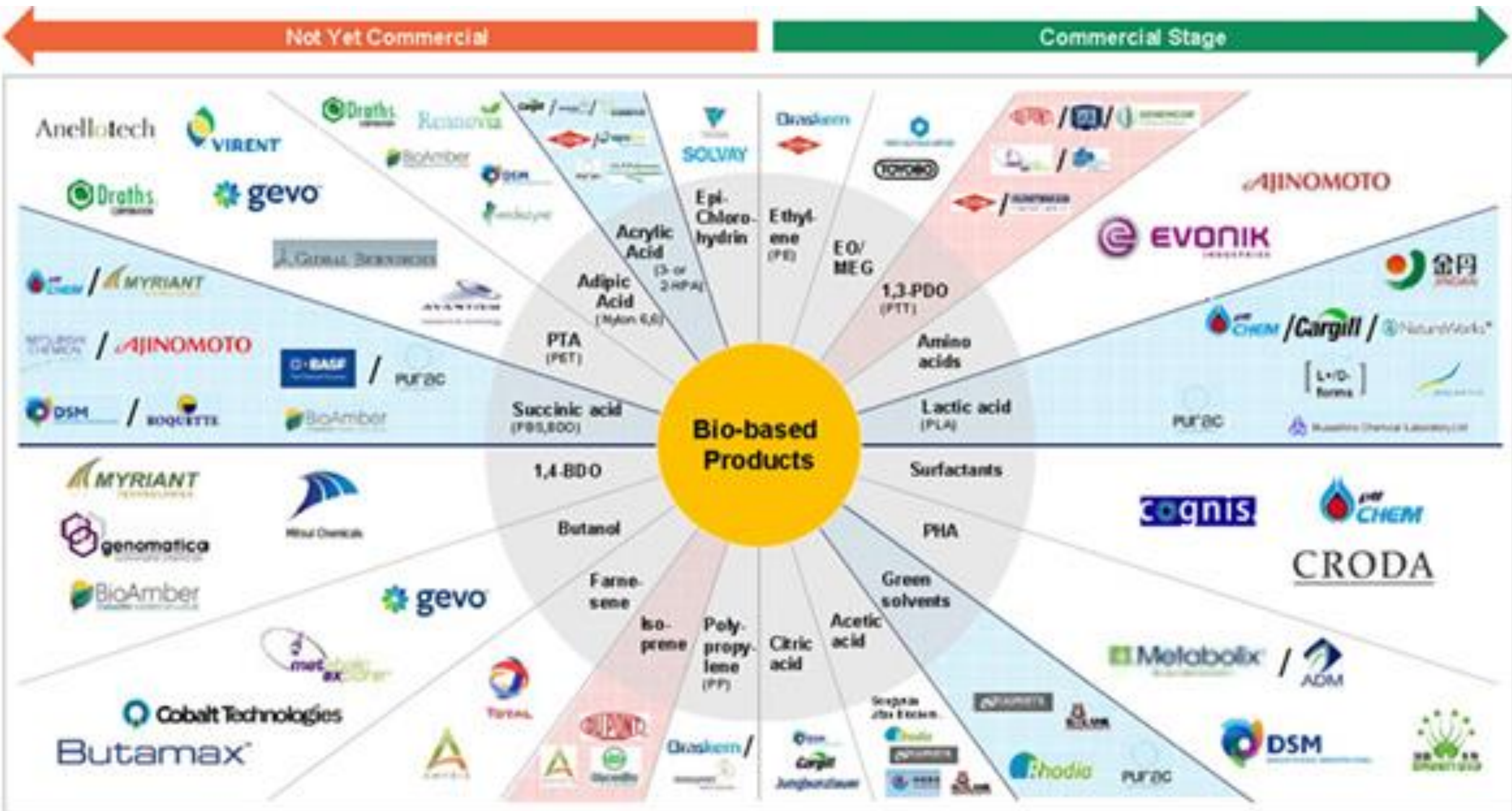
Biomaterials Competitive Landscape



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14 Factors©

1. Role of proof of concept vs. actual prototypes
2. Impact of timing: when to move up and when to move on; how long does this take?
3. Need for Research discipline to achieve reproducibility of results and product robustness
4. Building/finding business team to move from prototype to product (revenues)
5. Defining pathway (license vs. start-up), markets, resources
6. Freedom to operate analysis
7. Sources of corporate and project capital vs organic growth

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14 Factors©

8. Disclosures, provisional patents, patents, publications (the need for speed)
9. Understanding investors
10. Role of networking and entrepreneurial eco-system (professors, students, alumni)
11. Managing conflicts of interest
12. Financial and personal costs (and benefits) to founders of new venture
13. Effective Communication
14. Leadership

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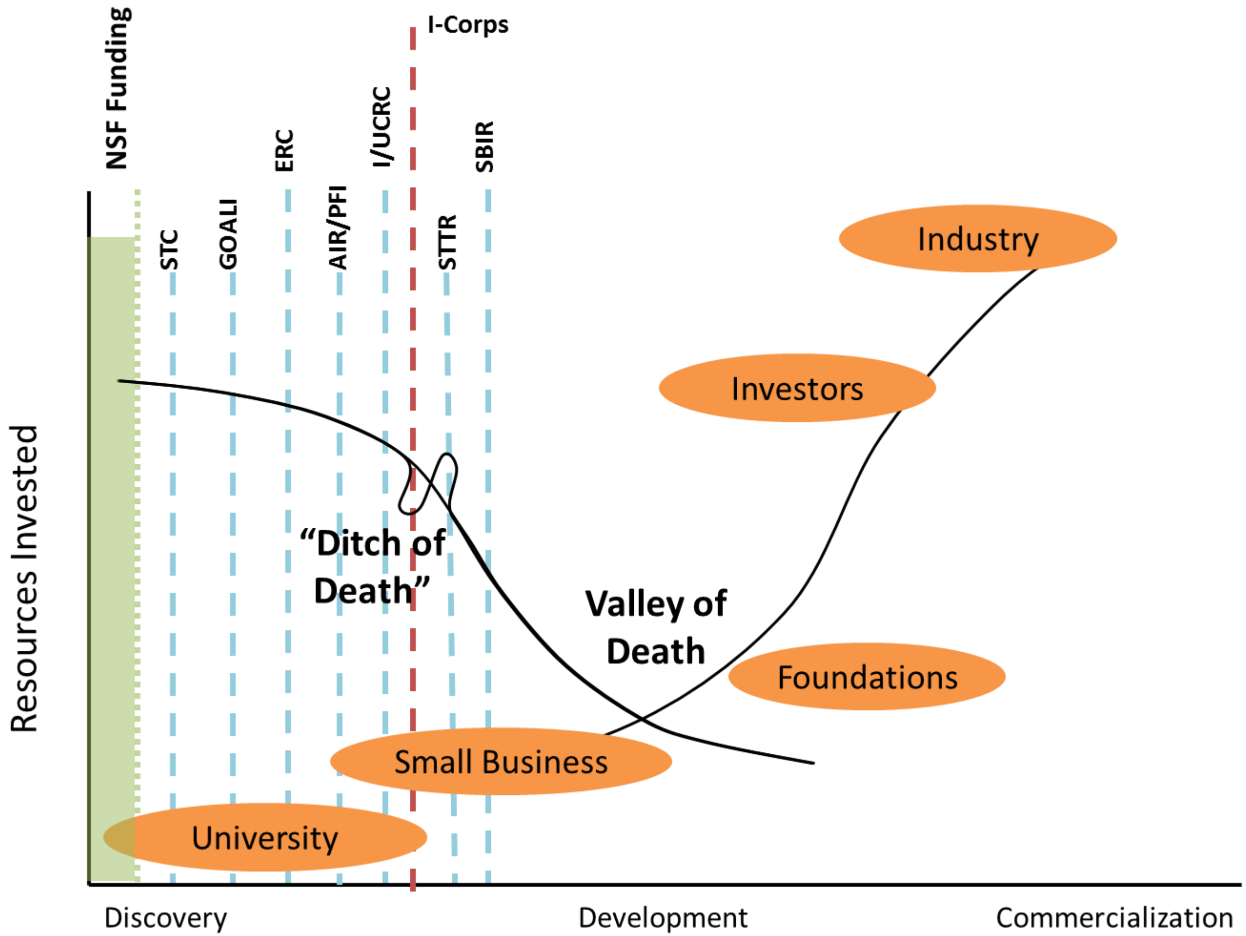
Stages to Commercialization

University commercialization/entrepreneurship is complex



PROGRAMS SUCH AS NSF I-CORPS

- Leverages NSF investments in research -- lineage of previous support ($7B)
- $50K grants per team
- Projects are team-based -- commercialization is team effort
- Process-oriented
- Go/no-go decision

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Is there a system or approach?

An Algorithm for Discovery

Slow down to explore.

Read, but not too much.

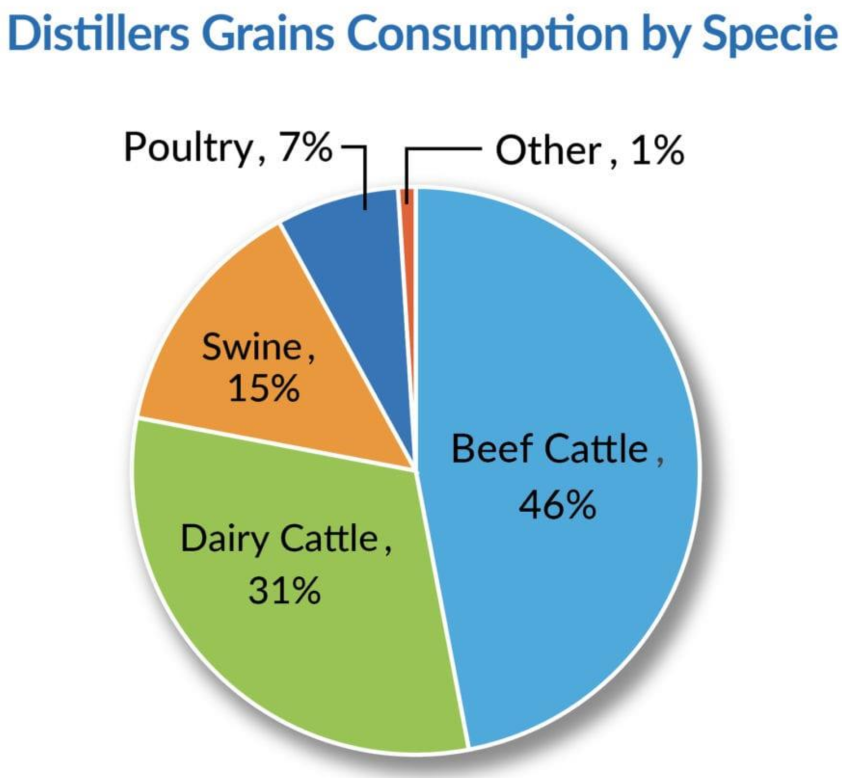
Pursue quality for its own sake.

Look at the raw data.

Cultivate smart friends.

Paydarfer and Schwartz, Science, 2001

Co-products are key to economic fuel ethanol production



Source: Distillers grains marketing companies

Ethanol Industry
Co-product Animal Feed Output

Year	Million Metric Tons (mmt)
2007	15.60
2008	22.59
2009	27.12
2010	33.04
2011	34.21
2012	32.06
2013	32.34
2014	34.80
2015	35.52
2016	36.21

Source: RFA and U.S. Dept. of Agriculture

RFA, 2019