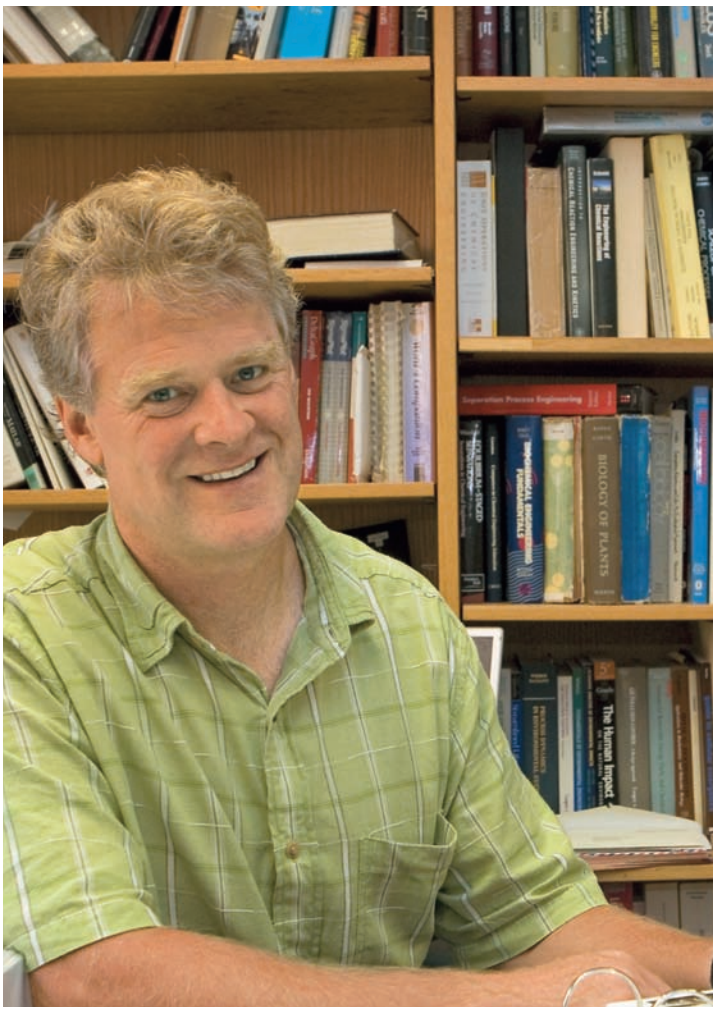
INTERVIEW WITH LEE LYND

The transition will be smooth

The US researcher says that cellulose ethanol and sugar cane ethanol promise to be more complementary than competitive

Published in September 2009



DARTMOUTH COLLEGE

Lee Rybeck Lynd is a pioneering researcher in the field of biomass used for the production of energy. His interest in this matter began in the late 1970s, when the possibility of converting cellulose into biofuels inspired his graduate course dissertation – and this interest has never waned. For the last 22 years, this professor of engineering and biology has led a research group at the Thayer School of Engineering, at Dartmouth College, a 240-year old university located in Hanover, New Hampshire. His team has already produced more than one hundred scientific articles and a dozen patents; this team is responsible for an important part of US research studies on second generation ethanol, extracted from cellulose, which includes the promise of producing biofuels from wood, agricultural residues and various kinds of plants, without jeopardizing the production of food.

While most biological routes being studied for the processing of cellulosic biomass focused on the separate production of enzymes, in a process which comprised several stages, Lynd's group identified a simpler and potentially less expensive manner of achieving the same result by using another technique. The name of this process is consolidated bioprocessing (CBP), in which the four transformations involved in the production of bioethanol (production of enzymes, saccharification, fermentation of hexoses and fermentation of pentoses) take place in a single phase. In this technique, microorganisms produce anaerobically complex enzymes with higher activity than the enzymes used by other processes. Lynd's group is one of the world's most active groups using this approach.

In 2005, the researcher partnered with venture capital investors to create Mascoma, a company in the field of biofuel research; investment capital was provided by such

investors as Vinod Khosla, the founder of Sun Microsystems. The company owns the patent on enzyme producing microbes and, according to Lynd, will soon receive commercial application for this process.

In addition to his work as a researcher and entrepreneur, Lynd also acts as an advisor to government authorities. He testified at a congressional hearing on biofuels at the US Senate and was a member of the committee on biofuels during the Clinton Administration. He has also prepared reports together with non-governmental organizations, such as the Natural Resources Defense Council. His latest venture is acting as one of the leaders of the Global Sustainable Bioenergy: Feasibility and Implementation Paths, an international team of scientists who plan to explore the possibilities of using biofuels on a global level and on a large scale in order to achieve scientific consensus on the matter. The group will meet in five different countries – the United States, South Africa, Malaysia, Holland and Brazil (*see* Pesquisa FAPESP *nº 162*). Physicists José Goldemberg, former dean of the University of São Paulo (USP), from 1986 and 1990, and Carlos Henrique de Brito Cruz, scientific director of FAPESP, are members of the committee that organizes the project's meetings. This study is important for Brazil because it provides an opportunity to discuss scientific evidence on the feasibility of producing biofuels on a large scale, including sugar cane ethanol, a field in which Brazil is the leader, and cellulose ethanol, which could put other countries on the biofuels map.

The keynote speaker at a workshop organized by the Programa FAPESP de Pesquisa em Bioenergia, Bioenergy Research Program, scheduled for September 10, Lynd gave the following interview to *Pesquisa FAPESP*:

■ *How close are we to producing cellulosic ethanol on a large scale? What are the major technical challenges that remain to be solved?*

— The purchase price of cellulosic biomass at anticipated prices, about US$ 60/tonne, is competitive on an energy basis with oil at U$ 20/barrel. Thus, the obstacle is the cost of processing, rather than the cost of raw material. Conversion of sugars to ethanol is done now at a very low cost using mature technology on a large scale in both Brazil and the US, so that is not the barrier. A cellulosic ethanol industry would exist today if it were not for the difficulty of producing reactive intermediates, notably sugars, from this low-cost starting material. Low cost technology to overcome the recalcitrance of cellulosic biomass is the key, with the cost of cellulase enzymes the single largest component. Very recently, Mascoma Corporation has shown that the requirement for added cellulase can be reduced several fold, and eliminated for some cellulosic feedstocks, using an approach called consolidated bioprocessing or CBP. In light of this advance, I believe it is now clear that the recalcitrance barrier will fall, leading to a commercial cellulosic biofuel industry. There are paths by which this could occur quite quickly, but this will require alignment of interests and resources involving multiple parties.

■ *What are the most viable resources for lignocellulose conversion? What about sugar cane bagasse?*

— A broad range of lignocellulosic feedstocks are potentially attractive for conversion to ethanol, including grasses and other herbaceous plants, woody plants, and various process residues. Bagasse is one of the most attractive feedstocks for the emergent cellulosic biofuels industry as it is available precollected in large quantities and could be processed using infrastructure available at an existing mill producing cane ethanol and/or sugar. Bagasse, of course, has value now as a source of heat and, increasingly, electricity. Incorporating biofuels needs to add value beyond current options for baggase processing. Although I have not analyzed this in detail, my preliminary assessment and that of others with relevant expertise with whom I have spoken is that this is probably achievable. Conversion of sugar cane trash is another potential opportunity for lignocellulose processing that is worthy of evaluation.

■ *Why do you believe that consolidated bioprocessing (CBP) is better than other routes to obtain cellulosic ethanol? Could you explain the advantages?*

— The CBP strategy achieves low operating and capital costs through elimination of costly added enzymes and process simplification, resulting in less equipment. As stated by an expert panel convened by the US Department of Energy (DOE Joint Task Force – 2006), CBP is "widely considered the ultimate low-cost configuration for

WIKIMEDIA COMMONS

Ethanol producing unit in the USA: Option for corn is being questioned

cellulose hydrolysis and fermentation." Although there is broad agreement on the transformative benefits of CBP, there has been until recently a greater diversity of opinion on whether CBP represents a prospect for the near term or long-term. In CBP, cellulase enzymes are produced by the same microbe that ferments sugars to ethanol so that all biologically-mediated processes occur in a single process step. Because CBP is carried out under anaerobic conditions, costly and energy-intensive aeration is avoided and the metabolic energy for cellulase production is provided by fermentation resulting in ethanol. With CBP, producing ethanol from lignocellulose looks a lot like ethanol production from cane, except that pretreated lignocellulose is fed to cellulose-fermenting microbes instead of cane juice being fed to sugar-fermenting microbes. Alternative biological routes to cellulosic ethanol other than CBP involve multiple process steps with one of these devoted to cellulase production, and require aerobic cellulase production in which the metabolic energy for cellulase production is provided by respiration resulting in CO_2, water, and loss of feedstock heating value as heat. There are non-biological ways to overcome the recalcitrance of cellulosis biomass, such as acid hydrolysis or gasification. Whereas CBP is enabled by transformative emergent advances in biotechnology and has only recently been demonstrated for the first time under near-industrial conditions, acid hydrolysis and gasification have been practiced industrially for decades and I have never seen a case for innovation-driven advances for these technologies with impacts comparable to CBP.

■ *Did your senior thesis already suggest this solution?*

— CBP was the central focus of my senior thesis completed as an undergraduate in 1979, although this processing strategy was referred to by a different name then, and I have been working on it ever since. I am delighted that this long journey appears close to fruition.

■ *What is the forecast for the technology patented by Mascoma? Is venture capital helping foster research for cellulosic ethanol?*

Bagasse is used as a source of heat and electricity. It is necessary to aggregate value beyond these options, in order to incorporate it to the production of biofuels

— I anticipate that Mascoma's CBP technology, including both in-hand advances as well as those in the pipeline, will enable commercial cellulosic ethanol plants in the near future, while also providing a new value proposition for farmers and a platform from which to produce a diversity of products from lignocellulosic feedstocks. It is important to realize that the CBP approach is enabling for production of all fuels and commodity products from cellulosic biomass, and not only for ethanol. Venture capital has played a vital role in bringing Mascoma to where it is today, and I expect Mascoma's early investors to reap handsome rewards. Looking forward, I anticipate further investment from strategic partners and institutional investors as well as VCs. Mascoma favors a "franchise" business model where we take an equity stake in a plant owned and operated by partners as opposed to a "build-own-and-operate" model. For this reason, as well as opportunities stemming from linking Mascoma's front-end technology with expertise of others involving conversion of sugars to a variety of products, strategic partnerships represent a natural and promising strategy by which to achieve a rapid market impact.

■ *Sugar cane has a good energetic balance and its production could expand in degraded lands or pastures in Brazil and in Africa. Its productivity has raised 4% per year in the last 30 years in Brazil. What, in your opinion, will be the future of sugar cane ethanol? Why not keep on investing in first generation ethanol research?*

— The growing worldwide demand for renewable, low GHG fuels necessitates that we explore and develop multiple feedstocks, including those that readily yield simple sugars and those that do not. Feedstock diversification will improve the overall business predictability for ethanol producers, by mitigating the impact of price fluctuations for feedstocks, such as cane sugar, that have alternative markets – witness the recent doubling of worldwide sugar prices. Sugar cane ethanol is increasingly recognized as combining low greenhouse gas emissions, high fuel yields per hectare, and modest impacts on water pollution to a greater extent than other established biofuels. Cane ethanol will thus be among the leading options considered by countries looking to increase biofuel production. Cane ethanol and experience gained from its production is also important with respect to emergent technologies that produce biofuels from lignocellulose. Sugar cane bagasse is a logical point of entry and proving ground for such technologies. As well, close relatives of sugar cane including but not limited to Miscanthus have potential as feedstocks for lignocellulose conversion and can be produced in temperate climates where cane is not grown today. In addition to the broad collective geographical range of cellulosic feedstocks, a further driving force for cellulosic biofuel feedstocks in some parts of the world is the range of opportunities they offer for addressing concerns over land availability. However lignocellulose processing will need to advance a lot before it is cost competitive with cane ethanol production. For the near term, cellulosic ethanol and cane ethanol are much more likely to be complimentary than competitive. In the longer term, any transition to cellulosic ethanol from

cane ethanol is likely to be smooth rather than disruptive and to occur only to the extent that processes and feedstocks offer improvements over current practice. As far as research, clearly we need to improve worthy things we are doing now while we also enable worthy things we are not yet doing. Consistent with this, it makes sense to continue research on cane ethanol, but also to include aggressive research to establish lignocellulosic ethanol, especially now that commercial implementation is within reach.

■ *In an article written by you and Nathanael Greene, you stated that "Biofuels are a modest part of the food price picture, consuming only 4% of world grain, and there is little evidence that food prices would be much lower if we did not produce biofuels." What is the real size of the risk regarding food security?*

— Although issues involving food security, biofuels and their interaction are complex, some salient observations can be made. I see increasingly compelling evidence supporting a recent statement made by a diverse group in *Science* that "We cannot afford to miss out on the global greenhouse benefits and the local environmental and societal benefits realizable through biofuels done right. But we also should not accept the undesirable impacts of biofuels done wrong." It is particularly important in this context to understand two points: 1) land use and environmental risks associated with biofuels done wrong are avoidable rather than necessary consequences of biofuel production; and 2) there are risks to the environment and other important interests associated with not pursuing biofuels. With respect to the latter, likely results of not pursuing biofuels include increased production of petroleum from shale oil and tar sands, diversion of green electricity away from coal displacement, and lost opportunities in rural economic development and energy security. Because of the dearth of foreseeable alternatives to liquid fuels for heavy-duty vehicles, achieving a sustainable transportation sector without biofuels is substantially easier with biofuels than without them.

■ *What do you expect from the Global Sustainable Bioenergy (GSB) project?*

"Perhaps the ambivalence towards bioenergy is leading us to invest less in its potential than its merits recommend

What contribution could researchers from Brazil, the Netherlands, South Africa and Malaysia offer?

— There is currently great confusion and uncertainty about whether the world should look to bioenergy (biofuels, electricity) to play a prominent role in the future and, if so, what policy frameworks are needed to ensure a sustainable result. This is too bad, because it means that we are either distracted by an inflated view of the potential of bioenergy, or our ambivalence is causing us to under-invest in bioenergy relative to its merits, or – in light of the diversity of bioenergy technologies – both. At the most general level, I hope that the GSB project will bring clarity and consensus to these issues. A key focus of the project, and stage 2 in particular, is to actively look for future land use scenarios that are not continuous with current trends. Such scenarios are, by definition, improbable today. However, currently improbable futures are exactly what is needed, since we cannot expect to achieve a sustainable and secure world by continuing the practices that have resulted in the unsustainable and insecure present. Motivated and informed by analysis of the possibility of bioenergy-intensive futures carried out in stage 2, stage 3 of the GSB project will work back to the present, addressing transition paths and policies, ethical and equity issues, and local-scale analysis. To achieve global viability, relevance and impact, it is essential that the GSB project involve analysts and reach decision makers from around the world.

■ *What contribution can the Brazilian researchers give to the project?*

— Brazilian participation in the Global Sustainable Bioenergy (GSB) project is important for several reasons. First, Brazil has a lot to teach the world in light of its trail-blazing role in the biofuels field, leading to a larger share of transport fuel coming from biomass in Brazil than in any other country. Second, in the course of informal discussions associated with planning the GSB project, knowledgeable persons from Brazil have commented: "Concern over land availability is a distinctive concern to persons in the US and EU, but the world looks much different from the perspective of those of us in South America and Africa' and 'The issues of ultimate resource availability and domestic energy security are easily and often mistaken for one another. We need to develop better clarity on the relative importance of national and global concerns, and realities, with respect to biomass resource availability.' Clearly, perspectives such as these are essential to include in order for the objectives of the GSB project to be realized. Finally, as a country that combines a large biofuels industry, a modern infrastructure and a substantial poor population, Brazil is in a distinctive position to provide much-needed understanding and experience relative to the important matter of the impact of biofuels on the world's poor and poverty alleviation efforts.

■ *Will the group analyze only second generation technologies or will it also evaluate the progress in first generation technologies? Which resources will be considered?*

— The project will take a feedstock-neutral, performance-based approach, considering first generation feedstocks and technologies, to the extent that they are responsive to project objectives. Decisions have not been made with respect to specific feedstocks.

■ *Will the group evaluate gas emissions and other problems related to the "land use changes"?*
— In contrast to many other studies, our primary emphasis will be on avoiding undesirable impacts associated with indirect land use change assuming motivation to do so rather than quantifying such changes assuming the absence of such motivation.

■ *What are your expectations about investments and advances for green technologies, like cellulosic ethanol, in president Obama's government?*
— As a result of both their insight and the times in which they find themselves, President Obama, Energy Secretary Steven Chu and others in the administration have given a higher priority to green technologies than prior administrations. How this will be translated into action remains to be seen, but I am hopeful , based on the administration's awareness of the importance of renewable energy as well as on positive initial steps, such as US$ 2 billion in stimulus money devoted to supporting research on sustainable energy production and energy conservation. I believe that the US, and other developed countries have both a moral obligation and a pragmatic interest in modifying our resource use toward practices that would be viable if emulated by the developing world.

■ *What is your opinion about new approaches to obtain biofuels, like green gasoline?*
— In general, I believe that we need to consider all conversion technologies that are capable of producing acceptable transportation fuels so long as they pass the 'sniff test' of potential for being cost-effective and scaleable. There clearly is interest from multiple parties, including multinational oil companies, in developing biofuels for both light duty and heavy duty vehicles. Indeed, I think a stronger long-term case can be made for the necessity of biofuels for the heavy duty sector as compared to personal vehicles. Compatibility with the existing petroleum fuel infrastructure is an important consideration, although price and performance will be the deciding factors in the long run. Elaborating on this a bit, I think that a three-step approach makes sense with respect to new energy technologies. Step one is a 'sniff test' to determine whether the idea has potential to be cost-effective and scaleable. We want technologies to pass the sniff test, because we need multiple paths to success. However, we should avoid pursuing ideas that do not have any realistic hope of making a significant impact. In my opinion, not all energy technologies that are currently being pursued by both governments and the private sector have passed this test. In step 2, innovation-focused activities should be supported pursuant to a very broad range of technologies that pass the sniff test. Like the successful venture capitalist, we need a diversified portfolio such that, of ten investments, five might fail utterly, three might succeed marginally, and two would succeed such that they pay for all the rest. Wringing our hands over single options we can afford to invest in is not the best way to ensure successful navigation of the sustainable resource transition. Following broad investment in innovation, the winners that are adopted on a large scale should be determined by consumers in response to performance and price dictated by both cost of production and also governmental policies to capture societal values that would not otherwise be represented by market forces.

■ *You once said that "It seems to me that when, in a few hundred years, people look back on our time, one of the very key things that they will judge us on is how well we did or did not deal with that transition. So I can't think of anything more important to devote my professional life to." Are we doing fine? Are you optimistic?*
— Well, I think our situation is still grim in absolute terms but the trend with respect to increased awareness and urgency is positive. Currently probable trajectories are not sustainable, and we must thus we must look beyond these trajectories to find viable futures. In this context, we need to realize that "business as usual," although a term of art in scenario planning, is in fact a fantasy rather than a baseline. The first step toward realizing currently improbable futures is to show that they are possible. I am devoting my career to developing this understanding of possibility at the level of both technology as well as resource and environmental issues. ■

Fabrício Marques

INRA LILLE/S. CADOUX

Miscanthus, the option chosen by the Americans for the production of cellulose ethanol