BIOFUELS FOR BOLIVIA: A PROPOSED CONTECHS INITIATIVE

INTRODUCTION	The world needs to decrease its reliance on fossil energy reserves (e.g., petroleum, natural gas, and coal) by developing more sustainable, environmentally acceptable, and renewable energy sources with reduced greenhouse gas emissions. In response to this need, a modern biofuels industry has emerged within the past two decades, spearheaded by Brazil's success in fostering a fuel ethanol industry based on sugar cane. ConTechs Associates Inc. is a not-for-profit organization that facilitates the execution of societally meaningful engineering projects through the assembly of project teams comprised of engineering students in developing countries, their professors there, and experienced engineering volunteers from the U.S. and elsewhere. ConTechs now seeks to identify new programs and initiatives directed to the following ends: • development of *appropriate technologies for biofuels production* in developing countries, and • formation of *business ventures* to apply those technologies for the benefit of communities there.
CONTECHS' GENERAL OBJECTIVES	ConTechs seeks to identify and develop new programs/initiatives related to biofuels in developing countries that are consistent with its existing goals:[1] • to provide a compelling and meaningful volunteer experience for engineering professionals from developed countries; • to enhance the educational and employment opportunities available to engineering (and other) students in developing countries; • to bring additional educational resources to engineering professors in those countries; and • to benefit local communities by fostering projects with significant societal and economic impact. Thus far, ConTechs' activities have focused primarily on advising and supporting "Proyectos de Grado" performed by fifth-year chemical engineering students at Bolivian universities.[2] These studies have involved the conversion

	of Bolivian natural gas to diesel fuels via syngas formation, Fischer-Tropsch chemistry, and hydroprocessing – with particular emphasis on process and plant designs that reduce capital costs.[3]
SPECIFIC PROGRAM AIMS	ConTechs' new initiative in biofuels will have the following specific aims: • to design state-of-the-art process, plant, and equipment for ethanol (and perhaps biodiesel) production from plant resources available in Bolivia; • to develop financial models and business plans for sustainable biofuels businesses in Bolivia; • to conceive and evaluate *innovative* process technologies and designs well suited to dispersed and/or small-scale biofuels production; • to propose and develop *innovative* business models and businesses matched to those novel process technologies and designs; • to engage Bolivian university students in both the business-related and engineering aspects of producing and selling biofuels; • to create opportunities for employment of Bolivian university graduates in new biofuels companies; and • to promote businesses and technologies that will enable members of rural communities to participate in a Bolivian biofuels industry.
RATIONALE FOR BIOFUELS PRODUCTION IN BOLIVIA	Brazil leads the world in having nurtured and built a productive fuel ethanol industry based on sugarcane, albeit with the benefit of three decades of government subsidies. Certain regions of Bolivia enjoy agricultural conditions similar to those in Brazil, and Bolivia currently exports raw and refined sugar produced from sugarcane. Given that the economics of fuel ethanol are favorable in neighboring Brazil, it is reasonable to expect that ethanol production may be attractive in regions of Bolivia as well. Recently, the Worldwatch Institute reported that some 15 ethanol distilleries are under construction in Bolivia and that the government is contemplating authorization of E25 blends (25% ethanol in gasoline).[4]

	Worldwide, sugar cane is the dominant raw material from which ethanol is obtained, and Bolivia is a producer and exporter of raw and refined sugar. However, Bolivia also grows several other agricultural products that are potentially suitable for the production of fuel ethanol. These include such starchy crops and cereal grains as corn or maize, potatoes (including sweet potatoes), sorghum, wheat, rice, barley, and potentially (sugar) beets[5,6]; other potential bioethanol feedstocks include food byproducts like cane or beet molasses. Biodiesel can be obtained from palm, sunflower, and soybean oils. Although some of these are more readily and efficiently processed than others, the range of possibilities illustrates that several crops and regions of Bolivia might well participate in a Bolivian fuel ethanol industry.
PROCESS BASICS	The design of bioprocesses for ethanol production depends on many factors – most notably, the nature of the feedstock. The simplest process configurations correspond to feedstocks that require relatively little pre-processing and that contain simple mono- and di-saccharides like glucose and sucrose, respectively. Starchy feedstocks like corn or maize require additional physical and/or chemical/enzymatic pretreatment. Sugarcane, which contains 10% to 15% sucrose, is the preferred energy crop in Brazil, whereas the U.S. biofuels industry is currently based on corn. *Feedstock pretreatment and fermentation:* With sugarcane feedstocks, pretreatment consists simply of roller-pressing the harvested cane to produce a juice that can be fermented directly by a suitable yeast. With a starch-containing crop like corn, the feedstock is first ground and mixed with water and the enzyme alpha-amylase, which is then cooked to form a mash. A second enzyme, glucoamylase, is added to the cooled mash to further convert the liquefied starch to fermentable D-glucose or "dextrose". *Ethanol recovery and purification:* The ethanol concentration in fermentation broths depends on the feedstock, the fermentation process, and the particular microorganism involved. However, typical concentrations range from about 5 vol % ethanol (with sugarcane) to about 10 vol % (with corn). Distillation is invariably the first step in producing any of several ethanol-containing biofuels. So-called "flex-fuel" vehicles can operate either on gasoline or on "E85" – a blend of 85 vol % ethanol in gasoline. Because of

	E85's high concentration of ethanol, which acts as a cosolvent, a certain amount of water can be tolerated in the ethanol destined for mixing with gasoline, and so distillation need only approach the azeotropic composition of 96.5 vol % ethanol. However, if ethanol is to be used as an gasoline additive or extender in an unmodified gasoline engine, substantially anhydrous ethanol (99^+ vol %) is required for blending. Historically, anhydrous ethanol was produced by azeotropic distillation using benzene or other entrainers, but today dehydration can be performed more energy efficiently with molecular sieves. In the ConTechs initiative proposed here, teams of Bolivian students will design and evaluate conventional bioethanol processes that encompass both ethanol fermentation and ethanol recovery/purification in a single, integrated plant. However, ConTechs also envisions that these student teams will identify and evaluate more creative and innovative process configurations that may permit the fermentation step to be decoupled from recovery and purification operations – that is, separated either in time or in space as envisioned further below.
AN INNOVATIVE APPROACH?	Fermentation to produce dilute ethanol solutions is a relatively low-intensity, low-technology process that has been practiced for centuries by many cultures. Moreover, the process can be conducted on a small scale – e.g., at the level of local villages or even individual farms. The cost of transporting low-density feedstocks from the field to the fermentor often represents a significant fraction of the overall cost of biofuel production – a consideration that places an upper limit on the area of land that can economically supply a single fermentation facility. This, in turn, places a limit on fermentor capacity at a given site. In contrast, the recovery of fuel-grade ethanol from dilute solutions typically requires more complex technology and equipment, relatively high capital costs, and fairly skilled operators. Generally speaking, ethanol recovery and purification are best suited to centralized facilities capable of purifying relatively large amounts of ethanol on a continuous or semi-continuous basis. Economies of scale can be expected to apply. In view of the distinctive characteristics of these upstream and downstream operations – that is, upstream fermentation and downstream ethanol recovery -- it may be feasible to separate these two operations, either in time or in space. On the one hand, the fermentation step might be carried out on a small scale at many separate

	locations on a decentralized basis (i.e., close to the fuel crop fields), with the dilute ethanol product subsequently being trucked to a central ethanol recovery/purification facility operated by skilled personnel. Alternatively, the ethanol recovery/purification equipment might be skid-mounted on a truck that would travel from fermentation site to fermentation site in the manner of a packaged mobile "mini-plant". Such novel process concepts -- e.g., centralized ethanol purification facilities and/or mobile "mini-plants" for ethanol purification – might enable many Bolivians to participate in a biofuels industry who might otherwise be unable to do so. In this regard, we note that a Haitian-Dominican private sector consortium has recently proposed to deploy mobile sugarcane mills near the border between Haiti and the Dominican Republic in the context of a planned fuel ethanol project there.[7] Although details are sketchy, the notion is evidently to use mobile mills in order to manage infrastructure issues and to provide work for unemployed Haitians in their native communities. The ConTechs initiative proposed here has similar objectives and shares a common approach.
BUSINESS MODELS AND DESIGN COMPETITIONS	ConTechs seeks to foster the creation of biofuels businesses in Bolivia that meet the following three criteria: • leadership by Bolivian engineering and business students (both matriculated and graduated) as designers, entrepreneurs, and key personnel/employees in small-scale biofuels businesses; • engagement of rural/indigenous Bolivians in various aspects of biofuels production; and • business sustainability -- on either a non-profit or for-profit basis. One possible form this ConTechs initiative might take would entail its organization and sponsorship of two types of regional and/or national student competitions or "design challenges". One type of competition would focus on process technology and plant design, while the other would focus on planning for the business itself. Models for both sorts of competitions already exist[8,9], and ConTechs plans to adapt the most appropriate of these for present purposes and circumstances. These process and business design challenges will be closely linked with one another, inasmuch as neither business nor process can be designed independently of the other. ConTechs and its university partners (i.e., Bolivian professors) will need to coordinate these design and planning activities, given that participating students will be pursuing various academic degrees (e.g., business and technical) in various

	university faculties/departments. ConTechs hopes to use existing national student conferences as platforms for launching and hosting these competitions. To that end, in 2006 ConTechs co-sponsored CONEI-QAA – an annual national congress of students of chemical, environmental, and food engineering.[10] ConTechs fully expects that Bolivian university students, with advice from their professors and ConTechs' volunteer advisors where appropriate, will ultimately generate an array of creative and attractive process and business designs. One possible scenario might involve locating small-scale ethanol fermentors in numerous rural communities or villages, which would be visited periodically by trucks fitted with ethanol recovery and purification equipment operated by skilled personnel. In this way, a single mobile miniplant might efficiently service a number of fermentors, each located near the fields where its biofeedstock would be grown. In this particular scenario, the bioethanol business might rent or loan appropriate pre-treatment/fermentation equipment to members of rural communities who would commit to conducting these operations. The company would be paid in the form of the marketable bioethanol produced from the crops and efforts of the community -- while those involved in growing, harvesting, and/or fermenting the energy crop might be compensated either by direct payment, by profit sharing, or by retaining some portion of the recovered ethanol for their own use as fuel.
PARTICIPANTS/ STAKEHOLDERS	By design, the key participants involved in the initial stages of this ConTechs program will be identical to those whom the organization has sought to engage from the outset – namely, • enthusiastic students of engineering in developing countries; • university professors in those countries seeking to enrich their students' educational experiences and professional opportunities; and • experienced and motivated engineers in the U.S. with professional skills and a desire to contribute meaningfully as volunteers. Having said this, it should be noted that the business-oriented nature of this proposed biofuels initiative will require not only *engineering* expertise on the part of participating students, professors, and volunteers – but also

	management experience as well – i.e., experience in the planning, organizing, funding, and running of businesses. ConTechs' outreach will necessarily be broadened in this respect. Once the process design and business planning phases have been completed, projects will enter a start-up phase wherein actual businesses will be funded, staffed, and equipped. This operational phase will entail recruitment of Bolivian entrepreneurs, managers, staff, and operating personnel – most of whom will hopefully be recruited from the ranks of recent graduates of Bolivian universities. This phase will also entail recruitment and training of "mini-entrepreneurs" from local farming communities interested in growing, harvesting, and/or conducting fermentation operations. NGOs and microlenders operating in Bolivia will likely have important roles to play in establishing connections with people from rural and indigenous communities. In summary, this proposed initiative in Bolivian biofuels will require that ConTechs broaden its participant/ stakeholder base in two respects: first, to encompass participants with a managerial/business focus as well those with technical/engineering expertise; and secondly, to reach beyond Bolivian universities to other sectors of Bolivian society.
FUNDING	Thus far, ConTechs has focused on advising and supporting a handful of student projects and activities at just two Bolivian universities. Most of its activity is web-based and thus readily self-funded. Going forward, however, the biofuels initiative proposed here will require a more aggressive and comprehensive approach to funding projects, the program, and (eventually) biofuels businesses. Fortunately, these funding requirements will be phased – that is, the need for funding will grow as the new program grows. Initially, some up-front investment will have to be made in planning and preparing for this new biofuels program – e.g., for travel to/within Bolivia, expansion of ConTechs' website, promotional expenses like brochures, student conference sponsorship, etc. The biggest single expense associated with the process/business design challenges themselves is likely to take the form of the prizes awarded to the most successful student teams upon completion of their work. The monetary component of these prizes should be substantial – altogether, of the order of thousands of dollars, say – but the prizes can be linked to the start-up of commercial biofuels enterprises (e.g., in

	the manner of "seed capital"). Moreover, the monetary component can be augmented by the award of various business-related and/or technical services that ConTechs hopes to persuade Bolivian and/or U.S. firms to donate. Although ConTechs can self-fund much if not all of the above activity, subsequent phases of the program will require larger, external sources of support. In particular, the biofuels businesses that ConTechs hopes to promote will need start-up funding, which likely will come from a variety of sources – namely, entrepreneur/owners, "angel" and venture equity investors, banks and other lenders, providers of microcredit (especially to rural communities), and perhaps foundations. Microlenders might offer small loans to participants in rural communities for the planting and harvesting of suitable energy crops and/or for the financing of fermentation equipment. Once some initial success has been demonstrated, ConTechs will approach foundations for general support and scale-up of its biofuels program. Given the societal and political dimensions of the proposed initiative, it may also be appropriate to seek funding from U.S. and international development agencies.[7]