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The Increasing Multifunctionality of Agricultural Raw Materials: Three Dilemmas for Innovation and Adoption

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Abstract

Agricultural raw materials are increasingly being used for multiple industries or sectors beyond the traditional fiber and nutrition industries: energy in the form of ethanol and biodiesel, industrial products such as polymers and bio-based synthetic chemicals and fibers, and pharmaceutical/health products such as functional foods, growth hormones and organ transplants. A combination of the new science of biotechnology, the new potential end uses of the products of that science and the broadened social/public goals that these products can respond to surfaces at least three fundamental challenges or dilemmas: (1) the competing goals dilemma, (2) the incumbent vs. new entrant competition dilemma, and (3) the industry boundaries dilemma. This paper reviews the innovation and adoption research related to renewables and the bio-economy, and then frames the three dilemmas with the objective of identifying important research issues and the conceptual frameworks that might be useful to analyze these issues.

Keywords: Bio-economy, industry convergence, renewables, disruptive innovation, multifunctionality

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Introduction

The agricultural sector is increasingly becoming a source of raw materials for industries or sectors beyond the traditional fiber and nutrition industries: energy in the form of ethanol and biodiesel, industrial products such as polymers and bio-based synthetic chemicals and fibers, and pharmaceutical/health products such as functional foods, growth hormones and organ transplants. Technological developments and innovations in the bio-economy have important implications for the convergence between the previously relatively independent food, energy, industrial product and pharmaceutical industries. This may lead to severe competition in resource use, blurring of industry boundaries and dramatic changes in the competitive setting of down-stream markets. Hence, these new products and end-uses will have profound implications for the structure and operations of the supply chains in the agricultural industry as well. Hardy has suggested that "the bio-based economy can and should be to the 21st century what the fossil-based economy was to the 20th century" (Hardy 2002, 11).

More specifically, first generation bio-based energy in the form of ethanol from wheat, corn, sugarcane or sugar beet and bio-diesel from different raw material sources such as soybean and palm oil or rapeseed is now common-place in the market. Second generation biofuels from cellulosic material are under development. According to a USDA study the growth potential for bio-based chemicals is significant with the opportunity to move from a current market share of 20% in fine and specialty chemicals to a potential market share of 50% in 2025. Such products include cleaners, solvents, adhesives, industrial gums, and paints. Examples of bio-based polymers include plastics from corn starch. With consumption of renewable polymers projected to increase by 22 % annually in the U.S., the market size for biodegradable polymers generated from renewable natural sources, such as plant and animal biomass, is growing significantly (GIA, 2006). Other bio-based products include industrial enzymes, acidulants, amino acids, vitamins, food conditioners, nutraceuticals, pharmaceuticals, and cosmeceuticals. Moreover, edible vaccines are in efficacy and safety testing for human and domesticated animal diseases.

The different applications of agricultural resources leverages the importance of this industry becoming an input supplier for at least four different industries: (1) food and nutrition products, (2) energy, (3) industrial chemical products (including synthetic fibers, plastics, wall coverings, and other products that have historically been derived from the petrochemical industry), and (4) health and pharmaceutical products. Thus, agriculture is being transformed from an industry that produces and processes commodity products to one that biologically manufactures specific attribute raw materials for a broader set of end uses. The results of this transformation will not just be seen in the within-firm production, processing and marketing activities, but also in the creation of new value and supply chain relations leading to a redefinition of industry boundaries and structure as well as changing the competitive landscape. Hence, the process of technology-driven convergence—what we observe in other industries like telecommunication and electronics merging due to a fusion of technologies in line with digitalization of data (Kodama, 1992) which has led to "new competitive landscapes" (Bettis and Hitt 1995)— is part of the agri-food industry and related industries.

The purpose of this paper is to review the innovation and adoption research related to the bio-economy and renewables, and to frame three dilemmas with the objective of identifying some of the important researchable issues in this area and the conceptual frameworks that might be useful

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to analyze these issues. In this paper we seek to contribute to the evolving innovation management literature on convergence in particular (e.g. Curran et al. 2010) and apply it to the emerging industry sectors of the bio-economy.

The remainder of this paper is organized as follows; the brief introduction in this section is followed by a literature review focusing on innovation and adoption of innovations in the context of the bio-economy. This discussion also includes a closer look at patents in the bio-economy, to better illustrate what the bio-economy is really focused on and why agricultural raw materials are becoming increasingly multifunctional. Having elaborated on the context of the bio-economy, we then discuss three dilemmas associated with innovation and adoption in the bio-economy. This discussion of these dilemmas will emphasize the extant literature, connect different streams of theory and reflect these against the context of the bio-economy in order to derive and frame research questions. This is followed by final comments.

Innovation and Adoption in the Bio-economy

To account for the large variety of opportunities for innovation, we define innovation in the broad sense as proposed by Schumpeter (1934). Hence, innovation is a process of creative destruction, where the quest for profits pushes to innovate constantly, by breaking old rules to establish new ones. For Schumpeter, this implies not only the introduction of new products but also the successful commercialization of new combinations, based on the application of new materials and components, the introduction of new processes, the opening of new markets or the introduction of new organizational forms. The Schumpeterian definition of innovation is clearly applicable to the emerging bio-economy as so-called bio-renewables have the potential to break the rules of existing markets and to challenge established technological platforms such as petrochemicals (Nameroff et al. 2004).

Innovation is essential to respond to the critical concerns of society such as climate change and global warming, food/energy scarcity and security, and environmental challenges or resource use/sustainability. Many innovations will be in the form of products/services or processes that improve the effectiveness and efficiency of responding to these social/economic challenges (e.g., dealing with the measurement and mitigation of negative externalities). Others will be institutional innovations such as new markets for carbon sequestering or a cap and trade system to reduce greenhouse gas emissions, or new management systems such as lifecycle analysis to respond to resource constraints, environmental problems and sustainability issues. Some of these innovations will be in the form of creative public/private sector ventures such as the agreement between Novartis and the University of California for basic research in agricultural genomics (Klotz-Ingram and Day-Rubenstein 1999).

What kinds of innovations are likely to characterize the bio-economy? And which industry is most successfully developing these? First of all, patents are one indicator of innovation and R&D in this emerging field. Over 3200 green chemistry patents were granted in the U.S. patent system between 1983 and 2001, with most of them assigned to the chemical sector (Nameroff et al. 2004). A closer look at recent patents awarded in the U.S. and EU in the field of biofuels, bio-products and bio-energy between July and August 2009 reveals for instance, that the highest patenting activity could be observed in the field of bio-conversion and bio-production (see Figure 1, Garratt, 2009).

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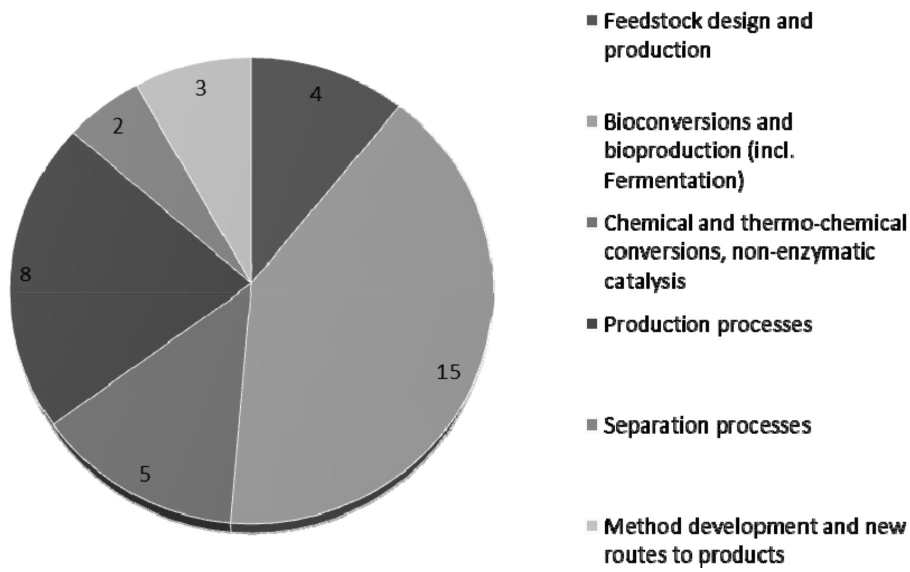

Figure 1. Level of grant and application activity in patenting in fields of the bio-economy
Source: Garratt (2009)

How, if and when will these patented inventions find their way to the market? Commercialization of innovation requires linking with complementary assets such as marketing expertise, brands, and logistics and supply chain networks, all in support of the innovation (Teece 1992). The extent to which a new product innovation can be mastered by existing complementary assets depends on the degree of innovativeness. Following Veryzer (1998), product innovations can be distinguished along the dimensions "technological capabilities" and "market capabilities." Depending on the degree to which an innovation requires new capabilities, it may create conflicts within the existing firm. This view can be extended to include the capability requirements of an innovation on the customer side, and even along the entire value chain (Bröring et al. 2006). The more disruptive an innovation is from a customer's view, the more assets need to be changed; hence, the less likely is the adoption of that innovation. This is because the customer may not want to invest in specific complementary assets to make adopting the innovation feasible (in case of B2B markets), or the customer may not want to invest in extra search and information costs (in case of B2C markets).

The market success of each innovation depends on its initial adoption and diffusion in the relevant markets (Rogers, 1983). However, adoption and diffusion may also be influenced by a number of external factors and they differ in B2B and B2C markets (Goshdal and Barlett 1988). Looking at the adoption of innovations in the bio-economy this differentiation becomes even more relevant as bio-technology has and still is facing multiple barriers for adoption (Klerck and Sweeney, 2007). In this regard, Verbeke (2007) investigated consumers' acceptance of the usage of biotechnology in bio-renewables. Consumers are increasingly interested in sustainability and more sustainable production methods but, especially in Europe, they have been quite critical toward particular applications of genetic modification (GM). While there is little doubt that the

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sustainability issue entails substantial opportunities for bio-renewables, the GM issue--posing either a threat or an opportunity -- is less straightforward (Verbeke 2007). Attitudes towards and acceptance of GM in the production of bio-renewable energy have not been investigated in depth thus far, leaving numerous questions unresolved.

At this stage it also remains unclear how the limited adoption of biotechnology by European consumers may impact the adoption rate on an industrial scale. This is because the management decision to adopt bio-renewables is a function of factors that maximize the expected benefits from adoption and minimize anticipated costs of adoption. Expectations (the likelihood of earning a given target return) and anticipations (the cost of process innovation adoption given the earning's expectation) are not directly controllable by the adopter. To conclude, the adoption of innovations in the realm of bio-renewables and in the bio-economy depends significantly on how decision makers frame and value the risks and rewards associated with it.

Dilemmas in Innovation and Adoption Associated with Agriculture's Increasing Multifunctional Role

The lynch-pin to the development of new end-uses for agricultural raw materials is the improved scientific base for understanding plant and animal product growth and processing. Genetic manipulation, enzyme development and biotechnology combined with traditional biological, chemical and engineering advances have resulted in innovations that are disruptive. A combination of the new science of biotechnology, the new potential end uses of the products of that science and the broadened social/public goals that these products can respond to surfaces at least three fundamental challenges or dilemmas:

(1) the competing goals dilemma,
(2) the incumbent vs. new entrant competition dilemma and
(3) the industry boundaries dilemma.

As concerning competing goals, the development of the bio-economy and the growing use of renewables have intensified the discussion of the complementary or competitive nature of the economic motivation of creating value and the "social motivation" of "environmental responsiveness and sustainability" (Shrivastava 1995). And as often occurs with disruptive innovations, new end-uses result in new customers that previously were not even recognized by incumbent firms, potentially enabling new entrants to be more successful in gaining market position and eventually dominating the traditional participants (Christensen and Raynor 2003). The third dilemma concerns the structural changes that will occur in the industries and firms involved in this "new" industry. This is because traditional supply chains no longer prevail as new value and supply chain structures are emerging in the bio-economy. Hence, previously relatively independent industries of agricultural/nutrition products, energy and industrial products and health/pharmaceutical products are now intersecting, industry boundaries are being blurred or redefined and the competitive landscape is being redefined (Bröring 2005).

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The Competing Goals Dilemma

The growing interest in renewables and the bio-economy is driven in part by the potential to respond to: 1) on the one hand the rising costs of fossil fuels and the growing market potential of biodegradable products (the economic motivation); and 2) on the other hand the increased concern about issues of sustainability and environmental challenges of continuing to be heavily dependent on fossil based raw materials (the social motivation).

Science and technology have powered the world's economy and economic progress in the recent decades, but along with wealth and prosperity they have caused unintended ecological problems including climate instability, ozone depletion, concerns about water and energy availability, declining biodiversity, and toxic waste (Shrivastava 1995). As natural resources become increasingly scarce, businesses can expect to encounter limited access to inputs and increased costs of those inputs.

Businesses, and specifically agribusinesses that rely heavily on natural resources, cannot ignore environmental and social issues that have become prevalent in today's society. Faced with increasing government regulations and strengthening public opinions, businesses are becoming more accountable for their impacts on society and more transparent in their activities as part of their corporate social responsibility. Thus, businesses are increasingly concerned about sustainability. But what is sustainability in detail? A plethora of different definitions of sustainability exist, but all share the common rationale as described in the *Brundtland Report of the World Council on Environment and Development* in 1987, "Sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs." On a more detailed level, the extant literature distinguishes different dimensions of sustainability (e.g. Andersson et al. 2005); they can be summarized in three major dimensions with different sub-categories as detailed in Figure 2 below.

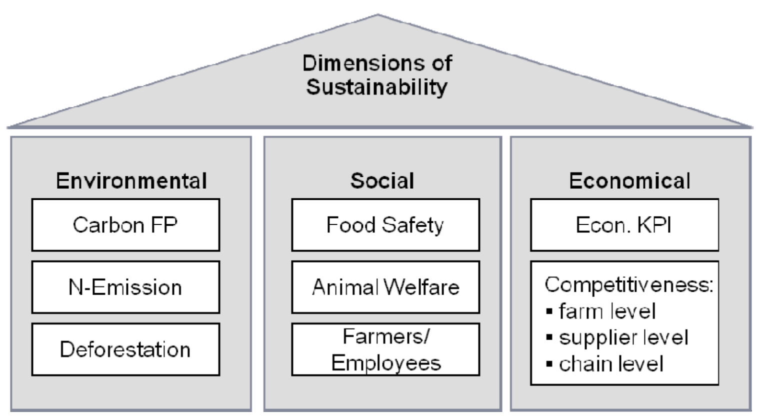

Figure 2. Dimensions of sustainability with different reinforcing or conflicting goals
Source: Bröring (2009)

An often expressed concern in the agricultural sector is the potential trade-offs between the three different dimensions as for instance a trade-off between environmental goals and economical goals (e.g. environmental sustainability and productivity). Companies and stakeholders often

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hold the belief that sustainability measures come at the expense of productivity and competitiveness within the industry. By taking into account environmental and social concerns, companies must internalize more costs and face additional constraints. Such arguments make it exceedingly difficult for management to receive the needed support for pursuing sustainability initiatives (de Voil et al. 2006).

In this context conventional industrial agriculture is being challenged to change its production, manufacturing, and distribution processes to be more environmentally or sustainability focused. Such challenges also provide new opportunities for implementing sustainable business strategies and entering market niches for environmentally-friendly products (Jansen and Vellema 2004). And bio-renewables are proposed and strongly promoted as such products. Those companies that see emerging environmental issues early and include them in their strategy have the potential to be perceived as more innovative and entrepreneurial than competitors. Consumers concerned with lowering their costs and environmental footprint often distinguish such companies as more prepared to deal with unpredictable market forces and more apt to meet customer needs. For instance, UK-based retailer TESCO and U.S. based Wal-Mart have launched a "carbon-foot-print" initiative, so that consumers get direct access to the CO^2 production involved with the products they purchase. The ability to acquire customer loyalty is essential for creating brand value, which in turn drives sales, premiums, and closer relationships with stakeholders (Esty and Winston 2006).

Technology and innovation in production processes and product development is at the core of environmental performance (Jansen and Vellema 2004). Increased pressures on natural resources and the threat of serious potential environmental effects add to the importance of the role technology can play. The vital role of science and technology in reducing the environmental footprints of companies and consumers relies on the ability to measure their impacts.

Increasingly, what have been perceived as conflicting goals are now being defined and repositioned as goals that are complementary. A recent survey by MIT's Sloan Management Review editors of 50 sustainability thought leaders and corporate CEO's indicated that 50% judged their company had a compelling business case for sustainability with the impact on the company's image and brand being the dominant component of that business case. Berns et al. (2009) present the business case arguments in terms of pricing power, cost savings, employee engagement, market share, new market entry, risk premiums and cost of capital as summarized in Figure 3. But other business leaders (including some in the same organizations as the thought leaders) are not convinced – only 10% of the 1500 business executives surveyed indicate that their company had a compelling business case for sustainability.

A second critical issue in responding to the potential economic vs. social motivation dilemma is that of adoption of innovations – both the rate/spread of adoption and the motivations for adoption. Kennedy and Fiss (2009) have expanded the classic two stage adoption/diffusion model of Tolbert and Zucker (1983) to include issue interpretation and decision logic. Issue interpretation in essence is whether an issue (and thus the change/innovation that will respond to that issue) is framed as an opportunity or a threat. Issues that are interpreted as opportunities imply that gain is possible, control can be exercised and thus there is increased potential to take action and to innovate and implement organizational change. In contrast issues that are interpreted as threats imply a loss, little control and resistance to innovation or change.

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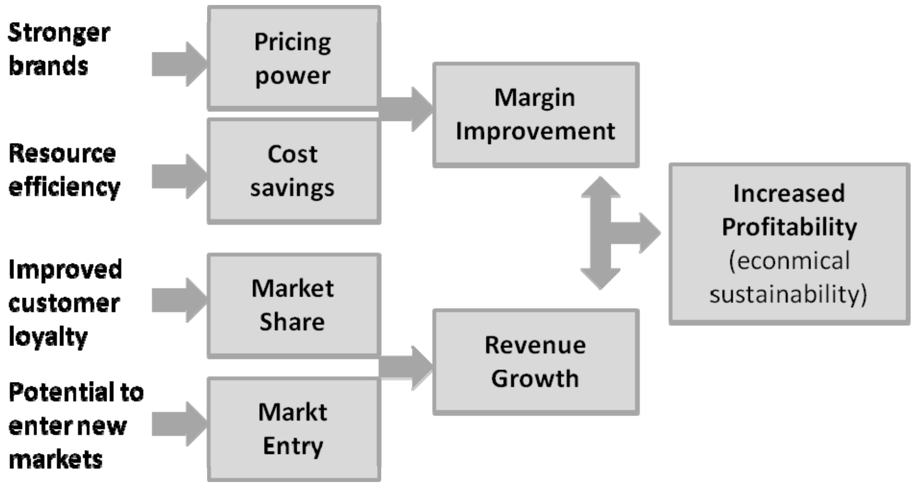

Figure 3. Creating goal conformity among social, environmental and economical goals of sustainability
Source: Adapted from Berns et al. (2009)

As to decision logic, Kennedy and Fiss (2009) focus on technical efficacy and social legitimacy. They argue that technical efficacy and efficiency gains incent more rapid adoption consistent with the logic of creating value. Social legitimacy is in essence an image or conformance decision logic – the desire to be perceived as "looking good" "politically correct" or not a laggard – to appear legitimate to both customers and competitors. Kennedy and Fiss (2009) summarize their analytical framework as in Figure 4 and conclude that early adopters will have framed the issue as an opportunity and use a combination of technical efficacy (creating value) and social legitimacy decision logic. In contrast, late adopters will frame the issue as a threat and use primarily technical efficacy (creating value) decision logic.

The implications of this analytical framework for innovation and adoption in the bio-economy and the resolution of the goals/motivations dilemma (value creation vs. sustainability) are straight forward: those firms that frame the issue of participation in this new market as an opportunity and use both technical efficacy and social legitimacy as decision logics in their strategic decision making will be more aggressive in innovation and institutional change and thus be leaders in the industry. Those who view the bio-economy developments as a threat and use primarily technically efficacy (creating value) as their decision logic will delay their innovation and participation in the bio-economy/renewables industry. A fundamental and critical research question is what industry and infra-firm characteristics and external forces and factors impact the issue interpretation and decision logic of firms in the agricultural and renewable industries. Additional research would focus on the financial performance of those who successfully resolve the motivations/goals dilemma compared to those who do not.

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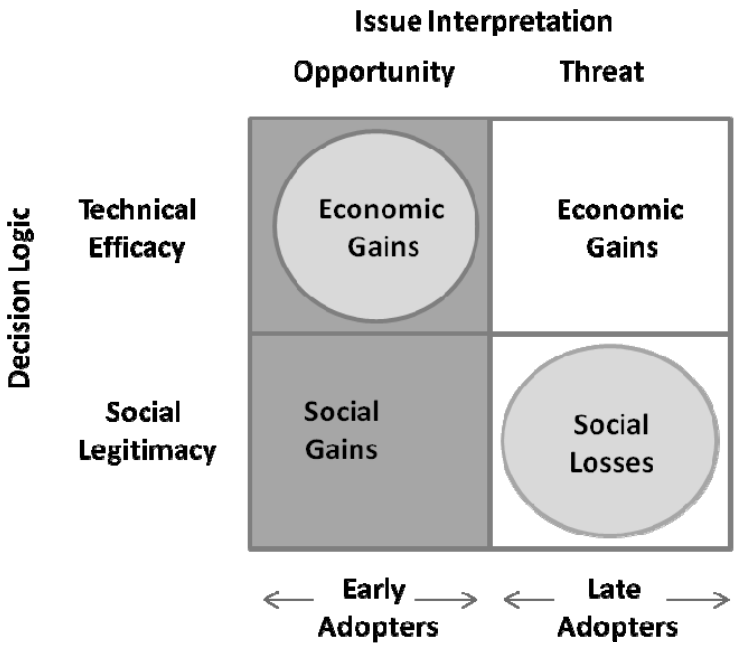

Figure 4. Motivations for adopting innovations
Source: Adapted from Kennedy and Fiss (2009)

The key researchable questions that might provide insight into the competing goals dilemma include the following:

1) What is the specific magnitude of the trade-offs (if any) of the economic and environmental goals for specific renewable products?
2) What strategies can firms embrace that will integrate the technical efficacy and social legitimacy decision logics to enhance their potential first mover/early adopter advantage?
3) What specific renewables innovations (both product and process) appeal to both the technical efficacy and social legitimacy decision logics and have the most potential for rapid adoption?
4) What strategies and decisions can be implemented to create value through sustainability initiatives in specific renewable markets?
5) What are the key determinants (firm characteristics, competitive conditions, regulatory regimes, etc.) of the issue interpretation and decision logic that will impact the speed of adoption of innovations in the renewable/bio-economy sector?

The Incumbent/New Entrant Dilemma

The second dilemma concerns the issue of the opportunity for new entrants to successfully enter the market and replace the incumbents who have been the dominant players in the industry. Bain's (1959) seminal analysis characterized the barriers to entry as structural or strategic -- structural resulting from natural costs or marketing advantages including those from regulation, and strategic resulting from deterring strategies of incumbents. Deterring strategies are typically in the form of price discounting and/or capacity expansion. More recent work has argued that the

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most effective and dominant entry barriers are a result of asymmetries between incumbents and new entrants –structural differences resulting from control of essential resources, economies of scale/scope/learning, and marketing advantages commonly referred to as the "umbrella effect" of branding which both increases switching costs of current customers and attracts new customers who respect the brand (Baumol et al. 1982). Innovation in both product and process can facilitate a new entrant's challenges of these structural entry barriers that favor the incumbent. The degree of innovativeness – "new to the world" products compared to incremental "repositioning" of products – has a significant impact on structural entry barriers. Disruptive/radical/discontinuous innovation by a new entrant can facilitate entry by: 1) use of new/different resources/inputs, thus challenging the incumbent's control of essential resources, 2) dramatically lowering the cost of production/distribution, and 3) introducing superior performing or lower cost products that offset the switching costs for current customers and attract non-customers.

In the context of disruptive or radical innovation as likely characterizes the bio-economy, Christensen and Raynor (2003) suggest that one potential characteristic of such innovations is that they frequently create the most value and thus are most attractive to non-customers, or those who are likely not the focus of the sales force and marketing strategy of incumbents. They classify such disruptive innovations as "new-market" disruptions. Such innovations "enable a whole new population to begin owning and using the product, and to do so in a more convenient setting …the disruptive innovation doesn't invade mainstream markets; rather it pulls customers out of the mainstream value network into the new one because these customers find it more convenient to use the new product" (p.45-46).

The implications of these arguments for the evolving nature of the bio-economy and the role of incumbents relative to new entrants in that sector are profound. As agricultural raw materials become increasingly important to new customers in the industrial product sectors and the health/pharmaceutical industries, the opportunity exists for new entrants to more effectively serve these new customers compared to incumbents. New participants in the bio-energy market such as POET that have challenged the market dominance of incumbents such as ADM are but one example. The longer-term implications are for significant challenges to incumbent agricultural production technology firms, as well as product processing firms, as renewable and biological based raw materials become the feedstock's not just for food and fiber end-users (the old customers), but for the health/pharmaceutical and industrial products end-users (the new customers) as well. And the resolution of this issue leads directly to the third dilemma – redefining industry boundaries to be discussed shortly.

Traditional Porter Five-Forces (Porter 1980) analysis frames rivalry and the threat of new entrants as a fundamental challenge to the market position of an incumbent and the competitive character and profitability of an industry. Such questions as: rate of industry growth; significant cost differences among firms; degree of product differentiation among sellers; buyers' costs of switching from one competitor to another; strength of exit barriers; importance of reputation or established brand loyalties in purchase decisions; entrants' access to distribution channels; entrants' access to raw materials; entrants' access to technology/know-how; entrants' access to favorable locations; experience-based advantages of incumbents; network externalities: demand-side advantages to incumbents from large installed base; government protection of incumbents;

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and perceptions of entrants about expected retaliation of incumbents provide specificity to the analysis of these forces (Besanko et al. 2007)). Assessing the evolving bio-economy from the perspective of these questions would provide some evidence of the competitive characteristics of the industry and the opportunities for new entrants to replace incumbents.

Recent analysis in the bio-energy industry by Ng and Goldsmith contributes analytically to this issue of incumbents vs. new entrants (Ng and Goldsmith 2010). They indicate that the arguments of the resource based view (RBV) of strategy focused on gains from unique sources of competitive advantage resulting in part from specialized assets must be combined with those from Organizational Ecology (OE) that emphasize market uncertainty and flexibility to understand the challenges (risk) and opportunities (first mover advantage) of market entry. More specifically, they argue and numerical evaluate the differences in entry strategies of firms in the traditional first-generation dry milling ethanol industry compared to the second-generation cellulosic ethanol industry, and conclude that market uncertainties combined with specialized assets in cellulosic ethanol production favors delayed entry compared to the earlier entry strategy for less specialized dry-milling technology participants in the market.

The key researchable questions that might provide insight into the incumbent/new entrant dilemma include the following:

1) What strategies should traditional downstream firms in the food/nutrition industry consider to compete successfully with new entrants from the energy/industrial products and health/pharmaceutical industries?
2) What specific dimensions of rivalry and threat of new entrants will be most impactive in determining the competitive position and success of incumbents versus new entrants in the renewables/bio-economy industries?
3) What are the key determinants of success in bringing disruptive innovations to market in the renewable sector/industry?
4) What are the opportunities for collaborative activities between leading firms in the agricultural industries and the industrial products or pharmaceutical industries to bring new renewable products to market?

The Industry Boundaries Dilemma

Industry convergence, which has been observed in various industries, plays an increasingly pivotal role in shaping markets and industry segments. In industries such as telecommunications, information technologies and electronics, formerly distinct sector boundaries have already largely faded (Gambardella and Torrisi 1998; Kodama 1992). More recently, this phenomenon can also be found in the emerging bio-economy or bio-renewables industry as different industry players are seeking to shape and benefit from this emerging sector. What are the implications of industry convergence? The process of convergence leads to “new competitive landscapes” (Bettis and Hitt 1995); actors from different formerly distinct industries are suddenly becoming competitors.

Moreover, value chains are becoming increasingly interlinked and interdependent. Even though agricultural raw materials still are the main starting point for the value chain of many sectors of

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the bio-economy, other industries such as energy or chemicals are entering the downstream stages of the value chain. For instance the chemicals industry that has exhausted to a high degree, classical levers for reducing costs and improving efficiency is devoting substantial R&D budget expenditures to bio-renewables in order to build more knowledge and potentially substitute bio-based feedstocks in petrochemical pathways (Lenk et al. 2007).

What are the consequences of the increasing interdependency of formerly distinct value chains for R&D and innovation? Cross-scientific research is increasingly enabling the chemical sector to utilize the technological developments in its neighboring scientific disciplines (e.g. biotechnology and agriculture). Strategic alliances between food and cosmetics and/or pharmaceutical companies are increasing in the emerging subsectors of the bio-economy. These are targeting foods with health benefitting characteristics leading to the production of Nutraceuticals and Functional Foods (NFF: a combination of nutrition and pharmaceuticals) (Bröring et al. 2006; Bröring 2005). But also the energy production sector is increasingly investing in the field of not only bio-energy, but also bio-based materials (Lenk et al. 2007). Thus, as Figure 5 depicts there are a number of established and previously distinct industries moving closer together due to fusing technology and resource platforms.

In addition, due to converging technology platforms new supply chains are emerging that are both complex and are with new unfamiliar industry players. This complexity is multiplied because there are sectoral systems of innovation that differ across industries (Malerba 2002). Cross-industry alliances are a precondition to successfully build new value chains in the bio-economy. Hence, innovation may necessitate the development of novel cross-chain relationships as well. For example, as illustrated in Figure 5 nutraceuticals and functional foods presents a new inter-industry segment between food and pharmaceuticals -- thus, a trend of convergence of food manufacturing and pharmaceutical industries. To exemplify the supply chain relationships, an innovative food manufacturer may rely on its ingredient supplier for technological application knowledge (Bröring et al. 2006).

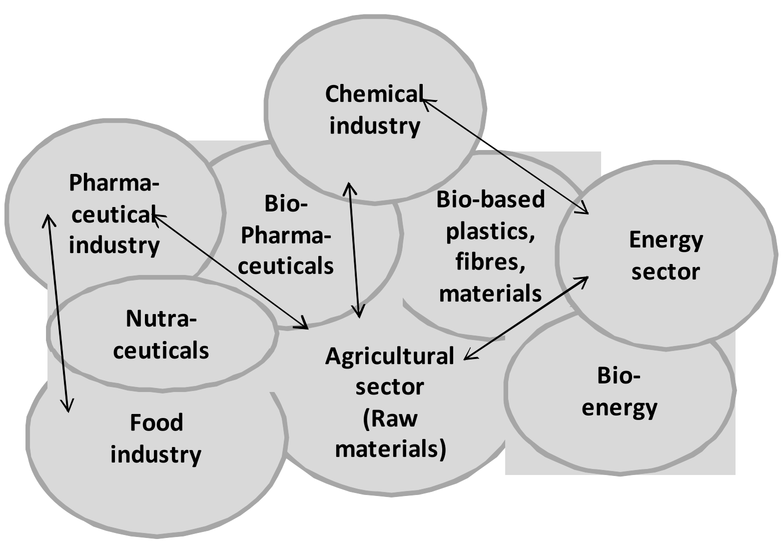

Figure 5. Fields of industry convergence in the bio-economy
Source: Adapted from Bröring (2005)

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While these new industry segments present a plethora of opportunities for new fields of business and economic growth, they are often also quite challenging as firms have to employ knowledge and technologies not within their traditional framework of expertise or core businesses -- they frequently lack the knowledge and experiences necessary to cope with the risks and uncertainties of the new field. Naturally, in most cases of convergence, sourcing the essential knowledge and experiences from beyond their own factory gate is necessary and key to successful innovation management.

At this point one may anticipate a competition for the resources and capabilities to benefit from the bio-economy. But which of the detailed industries will be most successful to build a competitive advantage in these emerging fields? As the patent analyses given in Figure 1 shows, there are many ongoing activities in the area of establishing new bioprocesses, e.g. bioconversion and bio-production including fermentation – but it is not yet clear which industry player (agro, vs. chemicals, vs. energy) will be most successful in the newly emerging industry sector.

To conclude, the issue of industry convergence poses many research questions:

1) How will the development of the bio-economy and renewable products incent the development/reconfiguration of supply chains in the agricultural, industrial and pharmaceutical industries?
2) What types of renewable innovations have the most potential to disrupt the agricultural, industrial and pharmaceutical industries and result in industry convergence?
3) How will risk motivations incent collaboration and joint ventures between firms in the agricultural, industrial and pharmaceutical industries to commercialize renewable innovations?
4) What is the role of open innovation in the process of convergence in the emerging bio-economy?
5) To what extent and by what measures (e.g. patent analysis) can companies anticipate trends of either technology or market convergence in the bio-economy?
6) What is the role of path dependencies for the development of successful innovation strategies and industry convergence in the bio-economy?
7) What are the challenges for cross-industry collaborations since different industry players are following different approaches as regards innovation and R&D?

Final Comment

The agricultural sector is increasingly becoming a source of raw materials for industries or sectors beyond the traditional fiber and nutrition industries. The different applications of agricultural resources leverages the importance of this sector becoming an input supplier for at least four different industries: (1) food and nutrition products, (2) energy, (3) industrial chemical products (including synthetic fibers, plastics, wall coverings, and other products that have historically been derived from the petrochemical industry), and (4) health and pharmaceutical products. The development of the bio-economy and the disruptive innovation that supports it creates three interconnected dilemmas: (1) the competing goals dilemma, (2) the incumbent vs. new entrant competition dilemma, and (3) the industry boundaries dilemma. These three dilemmas frame a number of important research questions, which can only be resolved in a close

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interdisciplinary collaboration of technology and innovation management scholars, economists and biological/natural scientists in order to provide the necessary insight into new technology developments in the bio-economy. This paper discusses these dilemmas and identifies a number of research questions related to each of the three dilemmas that will provide a more complete understanding of the innovation and adoption challenges and opportunities in the bio-economy sector.

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