Moving Promising Technologies off the Shelf

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Editor's Preface

Launched in 2009, GPS: *Where Genomics, Public Policy and Society Meet* is a series hosted by Genome Canada to facilitate a dialogue between federal policymakers and researchers exploring issues at the interface of genomics and its ethical, environmental, economic, legal and social aspects (or GE^{3}LS).

Overarching themes for the series and specific topics are selected on the basis of their importance and timeliness, as well as the "ripeness" of the underlying scholarship. Accordingly, the first series focused on "Genetic Information," whereas in year two, attention shifted to "Translational Genomics." Our third series, "The Innovation Continuum" broadens the discussion by casting the process of innovation in a broader societal context.

At the core of these exchanges is the development of policy briefs that explore options to balance the promotion of science and technology while respecting the many other considerations that affect the cultural, social or economic well-being of our society.

Co-authors of the briefs are leaders in their field and are commissioned by Genome Canada to synthesize and translate current academic scholarship and policy documentation into a range of policy options. The briefs also benefit from valuable input provided by invited commentators and other experts who participate in GPS events. Briefs are not intended to reflect the authors' personal views, nor those of Genome Canada. Rather than advocating a unique recommendation, briefs attempt to establish a broader evidence base that can inform various policymaking needs at a time when emerging genomic technologies across the life sciences stand to have a profound impact on Canada.

Karine Morin
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Executive Summary

This Policy Brief explores how potential economic and social benefits of applied research can be more fully realized. Structural hurdles that prevent innovations from making the leap 'from lab to living room' are considered. Two projects funded by Genome Canada are used to illustrate the challenges of innovation, emphasizing the need to build economic and social considerations into technical developments. We discuss key technological, commercial, organizational and social hurdles that must be overcome, and how corresponding levers can be exploited for more efficient diffusion. Specific recommendations are offered with implications to both science policy and universities: 1) Improve scientists' awareness of organizational, commercial and social aspects at an early stage in the innovation process; 2) Improve technology transfer offices' abilities to partner with more passive knowledge-seeking industries; 3) Provide longer-term projects to allow the exploration and initial development of the benefits of a science or a technology. We conclude with policy issues for further research.

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I. Context

The importance of publically-funded research for innovation, commercialization and economic development has been widely acknowledged (Cohen, Nelson, & Walsh, 2002; Mansfield, 1998; Pavitt, 1998; Rosenberg & Nelson, 1994; Reamer, Icerman & Youtie, 2003; Salter & Martin, 2001). Increasingly, Canadian government policy has focused on research as a stimulus for economic and social benefits (Langford, Hall, Josty, Matos, & Jacobson, 2006), shifting from discovery research to the "translation of discoveries" into targeted industry sectors through early end-user engagement and commercialization efforts (Halliwell & Smith, 2011; Joly & Dove, 2012). Such policies are consistent with the academic discourse promoting interactive approaches to innovation, rather than linear "technology push" approaches that have left promising technologies from scientific endeavors sitting on the shelf.

One such example of a publically-funded research agency undergoing this shift is Genome Canada, the not-for-profit funding organization developing and implementing the Canadian strategy for large-scale genomics and proteomics research. The mandate of this agency is to establish Canada as a player in the global 'bioeconomy' (Meulien, 2012), which encompasses medical, manufacturing, chemicals, bioremediation, biomonitoring tools, novel bioproducts and biofuels applications (Sheppard, Gillespie, Hirsch, & Begley, 2011). Table 1 summarizes Genome Canada's transition towards translational research for the bioeconomy.

Table 1. Evolution of Genomics Research in Canada

	Discovery Research	Integrated Research	Translational Research
Characteristics	• Large scale scientific projects (e.g. gene sequencing) • Stand-alone GE^{3}LS studies on biotech controversies (e.g., social, legal, ethical aspects), public consultation	• Applications-oriented (discovery, but with stated purpose) • GE^{3}LS embedded within research team • Expectation to collaborate with different experts (science & social sciences)	• Research targeting bio-products, eco-monitoring tools, medical tools, bioinformatics • Emphasis on benefits for Canada • GE^{3}LS contributes directly to team effort • Increased expectation to collaborate with different experts, plus need to manage transaction costs typically beyond expectations of discovery research
Output measures	• Publications, patents, citations, awards	• Publications, patents, citations, awards	• Publications, patents, citations, awards • Patent licensing • Genomics tools • New venture spin-offs

While more collaborative commercialization models in the bioeconomy have been proposed as more efficient (Sheppard, Gillespie, Hirsch, & Begley, 2011; see also OECD, 2009, Chapter 6)[1], they often take for granted non-technical factors, such as university-industry benefit-sharing agreements that build non-scientific capabilities and establish relationships with various stakeholders. Science-based innovation is a complex process where different types of knowledge and individuals enter and exit throughout the development cycle, from discovery (basic science), to development and commercialization (Langford, Hall, Josty, Matos, & Jacobson, 2006; Hall & Martin, 2005), and migrates across institutional boundaries through (1) cooperative research and development; (2) licensing or sale of intellectual property and spin-offs; (3) technical assistance; (4) information exchanges; and (5) hiring skilled people. However, these commercialization processes are dependent on context, including individual capabilities, organizational capacities (Reamer, Icerman & Youtie, 2003) and the industry setting. Furthermore, indicators for university research performance continue to be based on scientific publications, citations, patents and awards, which may blur or even hinder translational research (Langford, Hall, Josty, Matos & Jacobson, 2006). Thus, while the benefits of translational research appear promising, they also come along with these additional challenges that need to be addressed.

An increased emphasis on different industry sectors also results in differences in commercial viability, stakeholder concerns and decision-making criteria. Industry heterogeneity impacts innovation from two related perspectives. First, industrial settings often play a key role in whether a technology developed through public funds will be sought out and commercialized by firms. While some industries, such as pharmaceuticals, actively monitor and engage with university researchers, most industries are more passive. We propose that technology transfer offices, scientists and early developers of technology are not adequately prepared to manage relationships with passive industry players, but rather apply a standardized approach implicitly based on active industries. As a result, promising technologies with longer-term societal benefits suitable for passive industries may end up sitting on the shelf.

Second, decision-making and incentives differ among key technology developers, users and other stakeholders. Bringing technological and commercial knowledge together, as well as knowledge about potential social reaction to the technology, at the earliest phases of development is an effective means to better shape technology for adoption and utilization (Clark & Wheelright, 1993; Hall & Martin, 2005; Hall, Matos, Silvestre & Martin, 2011; Teece, 1986; Matos & Hall, 2007). However, bringing knowledge from such diverse stakeholders adds complexity and ambiguity; reconciling their concerns may be difficult, as many stakeholders may have different incentives, interests and decision-making criteria from the scientists developing the technology. In some cases, the stakeholders and their concerns may even be difficult to identify (Matos & Hall, 2007).

[1] In Chapter 6 the authors identify "two business models that could emerge in the future: collaborative models for sharing knowledge and reducing research costs, and integrator models to create and maintain markets. Collaborative models are relevant to all application areas."

To illustrate these challenges, we analyze two cases of bioeconomy technology using the TCOS Framework of Innovative Uncertainties. The first case is an assessment of a proposed forest pathogen bio-monitoring kit, while the second is an examination of the development of lignin-based bioproducts that can be used for a replacement of petroleum feedstock in vanillin, resins and carbon fibers.

II. Background and Theoretical Underpinnings

The "TCOS" Framework of Innovative Uncertainties is an analytical tool that allows developers to identify key technical, commercial, organizational and social issues at an early phase of the technology's development, thus shaping the innovation path of the technology for improved commercialization opportunities.

Technological uncertainty involves overcoming scientific, technical and engineering hurdles – i.e. the role of scientists and engineers. ***Commercial uncertainty*** is whether the new technology can compete successfully in the marketplace, how to introduce the technology and whether alternatives might be less expensive or more effective – i.e. the role of marketing and new product development. ***Organizational uncertainty*** involves determining whether an organization can profit from the technology – i.e. the role of senior strategists and patent lawyers. Even if a new product or process is technologically and commercially viable, the developers may not appropriate the benefits of the innovation if they lack the means to protect the intellectual property and the capabilities and complementary assets such as manufacturing capabilities, complementary technologies, distribution and services (Teece, 1986) necessary to bring it to market. ***Social uncertainty*** is concerned with the societal impact of the technology, and how diverse secondary stakeholders may affect or be affected by its development. It differs from technological, commercial and organizational uncertainties, as it involves interactions among many stakeholders outside the value chain. As a result, some potentially influential social stakeholders may be difficult to identify or have concerns that are difficult to reconcile, making social uncertainties more ambiguous (Hall & Martin, 2005; Matos & Hall, 2007). Scientific evidence may align poorly with such stakeholder concerns or fail to adequately address ethical, religious, cultural and/or social concerns of those affected by the technology (Shapiro, 2000), creating managerial decision-making difficulties for science-based organizations. We have found that social uncertainties are often managed in an *ad hoc* manner by many organizations, and indeed some are ill-equipped to manage such uncertainties.

The TCOS Framework recognizes that primary stakeholders within the value chain, such as suppliers, customers and complementary innovators, and secondary stakeholders such as environmental and social advocates, have different decision-making criteria. Technical (e.g. scientists and engineers) and commercial (e.g. marketing staff) stakeholders typically follow scientific methodologies for evaluation (Popper, 1959). However, such methods do not necessarily capture social uncertainty (Hall & Martin, 2005). For example, Monsanto's development of transgenic seeds was opposed by a wide range of stakeholders, often on non-scientific grounds, such as the intellectual property rights of farmers and the impact on subsistence communities (Matos & Hall, 2007). Understanding these different perspectives and decision-making criteria is likely to be equally challenging in translational research for the bioeconomy.

III. The Issues

Current policies associated with the new translational model are based on the assumption that benefits will eventually be captured by Canadian industry, resulting in benefits to Canada. However, modifying policy objectives is only the first step: infrastructure and a greater understanding of the opportunities and challenges associated with the integration of research, development and commercialization that reflects industry and stakeholder idiosyncrasies needs to be better understood.

The Timing Issue: Evaluating science by outcome measures focused on translation within a given period is likely to be inaccurate or misleading, as the time horizon to move from science to market is typically much longer than current research funding models. For example, fax machines were deemed technically feasible decades before introduction (Schnaars & Wymbs, 2004). It may even lead scientists to focus on developing short-term options at the expense of longer-term, but much larger opportunities.

The Incentives to Collaborate Issue: Translational research requires scientists to work in close coordination with social scientists and business, something historically discouraged by academics (Turnhout, Stuiver, Klostermann, Harms & Leeuwis, 2013). The added objectives and expectations call for additional skills and knowledge, and can detract scientists from their core areas of expertise. Furthermore, there remains uncertainty about how scientists can be assessed and thus rewarded for 'lab to market' activities, the results of which may not come to fruition in currently-used assessment periods.

The Heterogeneity Issue: As discussed above, the translational model calls for collaborations among a wider range of stakeholders and in different industrial settings. Such heterogeneity in terms of decision-making criteria, objectives and motivations, along with industry differences, means that a 'one size fits all' approach to technology development will likely result in many promising technologies sitting on the shelf.

IV. TCOS Analysis: Cases from the new Bioeconomy

The following two cases illustrate the challenges of these issues in new technology development. They are for illustrative purposes only and not intended to be a comprehensive analysis of these technologies, but rather to illustrate how the TCOS framework can help assess emerging bioeconomy technologies in a number of industrial settings.

4.1 Forest Pathogen Detection

A novel biomonitoring tool for pathogen detection is being developed by University of British Columbia Forestry Professor and Natural Resources Canada researcher Dr. Richard Hamelin. The 'Tree Aggressors Identification using Genomics Approaches' (TAIGA) team is developing a biochip that is expected to improve Canada's capacity in forest disease diagnostics and pathogen detection, and thus potentially improve forest management and import-export certification practices and policies in Canada and beyond.

Anticipated first adopters are regulatory agencies mandated to detect known pathogens and identify unknown pathogens, which includes the Canadian Food Inspection Agency (CFIA), one of the key collaborators for the TAIGA project, and the United Nations Food and Agriculture Organization, the administrator for the International Plant Protection Convention (IPPC), comprised of 177 signatories globally. The Convention on Biodiversity (CBD) is potentially an important policy driver for more specialized pathogen detection tools, as this international agreement places the responsibility for proof of pest-free materials on the exporting country. The test being developed will be used to monitor for known and novel pathogens for rusts, cankers, leaf spots and root diseases.

Technological levers include the use of open arrays that are more reliable, faster and able to process more samples than incumbent techniques, which can lead to prevention through earlier detection and more efficient surveillance of forest disease. Regulatory agencies currently rely on visual inspection. However, pathogens can be present but show no visible symptoms, whereas a genomics-based diagnostic test has the ability to tell if a tree is carrying a pathogen even if it looks healthy. A successful example of a similar test is the use of a DNA-based kit for Sudden Oak Death provided to the CFIA. However, the pathogen detection tool will need to be validated and incorporated into the agency's risk assessment tool box.

A technological hurdle identified by multiple stakeholders is the potential inability of the tests to detect whether a pathogen is dead or alive, and concerns over false positive or negative results. For false positives, this may lead to plants or products erroneously being placed into quarantine for extended periods, destroyed or banned from export. In the case of false negatives, the introduction of an invasive species into Canadian nurseries or forests can be catastrophic. According to some stakeholders, the test will simplify pest risk assessments and reduce inaccurate results, partly by screening for pathogenic genes rather than species. For example, one policy actor stated: "Let's just look for a particular group of pathogenic genes, and if we pick those up, we've got a problem… it simplifies things enormously". These findings were communicated to the scientists, along with general advice regarding the importance of emphasizing to potential end-users that monitoring and assessment procedures are simpler and more accurate than previous approaches and will thus likely enhance reliability.

Significant ***commercial levers*** include easier use by border workers, simplifying the process for the CFIA and reducing confinement periods for wood products at borders due to more reliable and faster processing. There are also opportunities to commercialize the methodologies and assay tools internationally, and even greater opportunities may arise in next-generation technologies targeting agriculture. Some forestry industry players are expected to utilize the technology in voluntary phytosanitary certification programs. For example, interview subjects suggested that there may be significant savings in export costs by using a specialized pathogen detection tool. To develop these types of applications, it is necessary for the technology developers to emphasize through marketing that the technology has more utility than just as a regulatory tool.

Some national policy makers identified added costs as a potential ***commercial hurdle***, a persistent issue in this highly price-sensitive forestry industry. Another possible hurdle relates to how the technology impacts individual entities within the supply chain. While the overall system will benefit from the technology, individual firms may be adversely affected to varying degrees, especially due to the complexities of international trade. Such difficult-to-determine uncertainties may result in some players resisting the technology. A potential solution to this problem is, for example, to encourage the insurance industry to develop compensation schemes for participants that are adversely affected.

Although university researchers typically lack the complementary assets for successful technology diffusion in a passive industry such as forestry, an ***organizational lever*** of this technology is the early involvement and support of the primary user, the CFIA. Such a relationship can not only compensate for a lack of complementary assets, but also provide early knowledge about how the technology may be shaped for greater utility, and help establish credibility and legitimacy for other users such as international regulators and private firms.

Table 2. TCOS Analysis – Pathogen Detection

Tech.	Levers	• More reliable, faster and able to process more samples than incumbent techniques • Potential to enhance certainty in risk assessments
	Hurdles	• Detecting if pathogen are dead or alive • False positives and negatives
Comm.	Levers	• May reduce confinement periods for wood products at borders • Voluntary phytosanitary certification programs may benefit private sector
	Hurdles	• Industry price sensitive • Impacts on value-chain members vary • Purpose of end users differ; needs to be defined • International trade complexities • May be perceived only as a regulatory tool
Org.	Levers	• Collaboration with CFIA provides complementary assets, credibility and early feedback to improve technology
	Hurdles	• Technology transfer offices often lack resources to engage with passive industries • Lack of guidelines, best practices, training
Social	Levers	• Will add value in risk assessment procedures and help to protect Canada against pathogens • Increasing support for forest protection from governments, affected stakeholders (e.g. First Nations) • Will help address increased risks due to climate change
	Hurdles	• Potential trade implications due to 'stakeholder ambiguity' • Need clear post-detection actions

We found that a key ***organizational hurdle*** is that companies in forestry often lack the capacity to identify and integrate scientific breakthroughs. University technology transfer offices usually lack the necessary resources to engage with such passive industries, but rather focus on potential partners that are more active, such as pharmaceuticals. Building capacity through, for example, training and developing application guidelines to improve users' forest management best practices is thus necessary. Note that some firms within the sector are more proactive and may use technology to stay ahead of regulation, and can thus be targeted as lead users. For example, forestry companies that harvest trees from their own land are more willing to adopt such technology than those using Crown or government-owned land, as are municipalities and nurseries that want to improve their practices through voluntary certification. Indeed, several organizations indicated they would be interested in portable pathogen detection technologies, which may be available in the future. The scientists are focusing on translational efforts through organizing stakeholder training workshops, investigating other end-user communication methods, and partnering with the university technology transfer office to develop solutions for the passive industry problem.

Our findings suggest that ***social levers*** can act as a key driver of the technology. For example, there are many high-profile cases of pathogen outbreaks due to increased international trade, and the possibility of such outbreaks is expected to become greater with climate change. Most stakeholders, including industry representatives, policy actors, non-governmental organizations (NGOs) and First Nations, have indicated strong support for the development of technologies that help to manage and maintain forest ecosystems. The scientists have indicated they may investigate these forest management applications in future research efforts.

Social hurdles, particularly regarding international trade, are more ambiguous: for example, the technology may be seen as a mechanism that could be used to restrict trade rather than for forest protection purposes. 'Stakeholder ambiguity' (i.e. differences in the interpretation of the detection results) may be used to support trade protectionism in the guise of forest protection. The technology developers need to emphasize that the purpose of the tool is to provide more accurate data (i.e. reduce ambiguity), and needs to be framed within a broader trade policy context.

4.2 Lignin-Based Bioproducts

Various lignocellulose degradation techniques developed by University of British Columbia Professors Lindsay Eltis and Bill Mohn offer opportunities to replace petroleum-based feedstock with biomass, providing new production platforms with potentially improved environmental impacts and economic opportunities for producers of vanillin, resins, carbon fibers and biofuels. Environmental management tools such as Life Cycle Assessment (LCA) are being used to provide supporting evidence on the potential environmental and social benefits of these new developments. The resultant bioproducts have important sustainable qualities; however, large-scale production will only be realized if production can be scaled up to become economically feasible.

We discuss applications for two different industrial settings. The first is the development of a bioprocess to produce vanillin from lignin using soil bacteria as biocatalyst. The resulting vanillin can be used as a replacement for natural vanillin and petroleum-based vanillin products in the food additives, cosmetics, perfumes and pharmaceuticals industries. The second application is a bioprocess using soil bacteria to modify lignin that can be used as partial replacement of phenol in the production of phenol-formaldehyde resin. The resulting new product is lignin phenol-formaldehyde resin (LPF resin) for the construction industry. Both processes have been proven at laboratory scale, a ***technological lever***, although further research is needed to determine if industrial production levels are feasible (a ***technological hurdle***). Hurdles for LPF resin include demonstrating product performance when applied under extreme environmental conditions and compliance with building code requirements. The challenge for RHA1 vanillin is to demonstrate richness of flavor, fragrance profile for perfumes, particle size distribution and solubility of crystals.

Commercial levers for both applications include the utilization of abundant, renewable and stable supplies that are independent of fluctuating oil prices. They can also be positioned as 'eco-products.' These applications differ, however, in terms of potential market size, with PF resins much larger at $1.5B versus synthetic vanillin at $400M, and with regards to whether the industry utilizes commodity or differentiation pricing. For example, there is a huge difference in market prices between synthetic or non-natural vanillin (~$17/kg) and natural vanillin (~$700/kg). This difference is considered a lever, as it demonstrates that the industry is not set solely by price. However, to qualify as 'natural', all production steps, from raw material processing to purification, must meet the natural product definition set by regulatory agencies (Wong, 2012), a considerable ***commercial hurdle*** that has yet to be resolved. Indeed, an attempt to meet all of these requirements would create additional technical hurdles. In contrast, the resin market is a highly price-sensitive one where "pennies matter", according to one industry official. This is in part due to the slow-down in the housing market since 2008, which requires reliable suppliers of raw materials and inexpensive transportation of large volumes of lignin to deal with price fluctuations in such a commodity-based industry.

As for ***organizational levers***, patenting for both technologies are feasible, and there are opportunities to out-license to firms that possess complementary assets, such as specialty resin suppliers and food additive companies. However, similar to the pathogens case, ***organizational hurdles*** include university technology transfer offices that are currently unequipped to diffuse technology into relatively small, low-volume industries such as vanillin, particularly when the few important industry players are not located in Canada. Not only are the offices inadequately equipped to engage with passive, low-margin industries such as resins, but a 'push model' is unlikely to result in technology commercialization because universities lack adequate capabilities and complementary assets to bring this product platform close to market, while client industries lack the search capabilities to find it. The technology developers must therefore proactively seek out and engage with potential adopters.

Social levers are potentially important drivers of these technologies, mostly through improved environmental characteristics. We found strong support from all stakeholders for investment in renewable alternatives to petroleum. For example, legislation to reduce formaldehyde emissions from composite wood products in California is motivating the development of environmentally friendly resins, thus increasing the potential market for LPF resin (which is made from renewable sources, has no formaldehyde emissions and is favorable to Leadership in Energy and Environmental Design (LEED) certification). Vanillin potentially offers environmental advantages over incumbent processes, having renewable feedstock, lower carbon footprint and less energy required in the production process.

Preliminary LCA studies conducted by the scientists provide evidence that ecological attributes of both LPF resin and vanillin are better than the incumbent options. Such levers may provide a value proposition to compensate for the technological, commercial and organizational hurdles. However, this is dependent on whether they can overcome ***social hurdles*** such as meeting regulatory approval (particularly expensive for food additives) and ensuring that environmental practices are met throughout all life cycle stages (such as forest operations, transportation of inputs and, specifically for vanillin, post-production purification). For example, the 'eco-value' propositions for both technologies may be disputed if they use lignin harvested from unsustainable forestry practices.

Table 3. TCOS Analysis: Lignin-based Vanillin and Resin

		RHA1 Vanillin	LPF Resin
Tech.	Levers	• Demonstrated proof of principle	• Demonstrated proof of principle
	Hurdles	• Production scalability • Particle size, distribution, solubility, viscosity of solutions • Adopt process steps that meet 'natural' qualifications	• Production scalability • Meet extreme temperature and moisture standards • Comply with national and international building codes
Comm.	Levers	• Large price variances • Abundant, renewable, stable supply • Potential 'natural' eco–product niche	• Eco-products increasing market niche • Renewable; independent of fluctuating oil prices • Potential reduction in input cost
	Hurdles	• Cost effective production unproven • Compliance with the natural product definition of regulatory agencies	• Thin margins in industry • Need reliable supply, low transport costs • Fluctuations in construction industry
Org.	Levers	• Patentable • Can be out-licensed to incumbent vanillin producers with complementary assets and capabilities	• Patentable • Can be out-licensed to specialty resin suppliers that possess complementary assets and capabilities
	Hurdles	• Tech-transfer offices not equipped to deal with low volume, smaller and non-local industries	• Tech-transfer offices not equipped to deal with passive, low margin industries
Social	Levers	• Renewable, lower environmental impacts • Potential 'natural' eco-product, leverage commercial viability	• Renewable; no formaldehyde concerns, lower environmental impacts • Favorable to LEED certification
	Hurdles	• Need to ensure environmentally sound practices throughout life cycle • Need regulatory approval	• Need to ensure environmentaly sound practices throughout life cycle stages • Need regulatory approval

4.3 Summary of Uncertainty Analysis

We used the TCOS Framework to illustrate how technological, commercial, organizational and social levers and hurdles can be identified and analyzed, allowing the technology developers to better understand the challenges and opportunities involved in translating their efforts into useful applications for the bioeconomy.

Although these technologies have been proven in the lab, there remain significant hurdles that must be overcome. We suggest that focusing on value propositions that emphasize improved environmental protection and performance characteristics of end products can enhance commercial opportunities. In the pathogen detection case, social levers such as enhanced biosecurity and ecosystem management strategies can act as strong legitimizing forces. The diagnostic procedure can also provide value to a range of end users such as nurseries, through next-generation hand-held technologies. For biocatalyst lignin production, a key value proposition relates to its potentially more sustainable characteristics when compared to incumbent technologies based on petroleum feed stocks. Thus, while there may still be technological and commercial uncertainties, the 'eco-value proposition' of more sustainable processes provides a legitimate incentive for investment, which could eventually provide the resources required to overcome these uncertainties.

V. Policy Options

Option 1: Improve scientists' awareness of organizational, commercial and social aspects at an early stage in the innovation process

The key to more effective technological innovation is early scanning of industry features, market dynamics, firm capabilities, benefit appropriation and potential social and environmental impacts. Such an approach is consistent with the 'gatekeeper' concept (Allen, 1977), defined as someone who interfaces between the internal and external environment. This includes *technological gatekeepers* with high levels of technical competence who continually monitor the scientific literature, as well as *stakeholder gatekeepers* (Hall, Matos, Martin, & Bachor, 2012)[2], individuals with political and social awareness who identify external stakeholders that may fear and/or perceive negative impacts of an innovation, ameliorate their concerns and identify socially beneficial contexts to enhance the technology's legitimacy. Project leaders need to be aware that the translational model increasingly calls for these gatekeeping functions, as is the case with the above Genome Canada projects and their policy of expecting GE^{3}LS researchers to contribute directly to the team's effort. To achieve this awareness, we suggest that innovation specialists can help scientists better understand the hurdles and levers of key commercial, organizational and social uncertainties by conducting anticipatory assessments such as the TCOS Framework.

Option 2: Improve technology transfer offices' abilities to partner with more passive knowledge-seeking industries

University technology transfer offices are the gatekeepers linking universities to industry. Many of these offices logically focus on the transfer of medical research—a lucrative industry in which firms play an active role in seeking out opportunities from research. However, the bioeconomy involves a wider range of industries, some of which are more passive. Technology transfer offices thus need to transition toward a more active role in identifying applications in more passive industrial contexts. Further research is needed to understand what resources and capabilities are required to make this transition, particularly with respect to opportunity recognition, raising awareness of research, suitable modes of interaction and measurement and reward systems for the technology transfer office. Transitioning trained personnel from universities into the private sector is one such mechanism (Langford, Hall, Josty, Matos & Jacobson, 2006; Reamer, Icerman & Youtie, 2003).

Option 3: Provide longer-term projects to allow the exploration and development of the benefits of a science/technology

While early interaction between scientists and social scientists can help mitigate organizational and social risks, it can also help identify additional opportunities that may not have been known at the start of the project. For example, lignin degradation may offer ways to produce a variety of other products in small quantities using inexpensive and readily available organic waste. While the material properties may differ slightly from existing chemicals, these differences may provide advantages for new or existing applications (Linton & Walsh, 2003; Linton & Walsh, 2008). Furthermore, as biocatalyst lignin production is a platform technology, there are perhaps hundreds of different products that could be developed. Assessing platform rather than an individual technology calls for assessing a wide range of products over a long period of time, and may not be conducive to traditional venture capital approaches that focus on return from a single product venture. For example, pressure to generate a quick return may result in a heavy focus on vanillin at the expense of the larger resin market or the even larger carbon fiber market.

By understanding and responding to user interests at an early stage, it may also be possible to enroll unanticipated users, particularly for future applications. For example, engaging international stakeholders may identify other applications for pathogen detection. The TCOS analysis can thus be used as a *'gate-opener'*, identifying opportunities that may otherwise be beyond the scope of the initial project. However, most research activities (including the two discussed here) are established as individual projects with a schedule that aligns with the research funding period. Wider societal benefits often emerge long after the project is completed, resulting in promising technologies being left on the shelf for an extended time or even indefinitely. A translational model thus requires long-term funding commitments to exploit such opportunities.

[2] Please note that 'stakeholder gatekeeper' was coined by our colleague Prof. Michael Martin and first published in Hall, Matos, Martin, & Bachor, 2012.

VI. Practical Applications and Considerations

Prior to being able to develop effective policy, we must understand the potential pathways to markets in terms of steps, critical events and hurdles. Once these different pathways and challenges are understood, we can then attempt to accelerate the process by determining the 'critical path' to be followed.

A fundamental change in the mission and training for research to be more translational requires making it easier for a researcher to be an entrepreneur. However, the development of entrepreneurial capabilities requires new skills, resources and time. Translational research also creates increased transaction costs for activities seeking out industry partners and potential customers, for intellectual property management, legal and administrative expenses, for consultations with a wider range of stakeholders and for funding agencies' increasingly demanding accountability and research ethics policies. All of these activities provide utility and valuable insights that facilitate commercialization and gain societal benefits. However, these time-consuming activities require skills and decision-making heuristics that are often peripheral to lead researchers, thus raising the question "are we expecting too much from our scientists?" It is crucial to recognize that while the benefits of the translational model are promising, there are also additional associated costs.

VII. Future Research

Although much progress has been made in understanding translational research, further research is needed to understand pathways to commercialization. While many hurdles are broadly recognized, we need to understand the different ways in which these hurdles can be overcome, and the knowledge requirements needed to move research from development to commercial application. Further development and application of the TCOS framework is one possible aid that can help move promising technologies off the shelf.

Techniques for opportunity recognition are needed to fully evaluate the options that science and derivative technology may offer in terms of creating economic and societal benefits. However, the still-dominant traditional 'neoclassical' economics perspective provides only limited explanation of the benefits offered by science and technology, particularly because assumptions such as perfect information, no transaction costs and a general 'all things being equal' perspective ignore the key challenges identified in this paper. Options, Game, Evolutionary Economics, Stakeholder and Transaction Cost theories are only a few alternatives for better understanding the requirements, challenges, uncertainties and hurdles associated with commercialization pathways.

Our preliminary research found that IP is often treated relatively homogeneously in a 'one size fits all' approach—but as noted above, the bioeconomy involves a wide range of potential industries that may not be captured under such an approach. Further research is thus needed to understand both how various industries seek out university knowledge and how technology transfer offices can modify their IP policies and develop more effective search mechanisms to identify potential users that traditionally have not been on their radar.

As discussed above, the translational model requires greater commercialization efforts on the part of scientists. Within the entrepreneurship literature, there is a distinction between Schumpeterian entrepreneurship (exploiting new knowledge for commercial gain) versus Kirznerian entrepreneurship (exploiting existing knowledge). (For a recent discussion of this distinction see Hall, Matos, Sheehan & Silvestre, 2012.) The translational model implicitly expects that in addition to creating new knowledge, scientists will take on a larger share of the risks and administrative functions; but it is not clear if the scientists are receiving increased rewards or whether the rewards continue to be captured by traditional Kirznerian entrepreneurs such as venture capitalists. Further research is needed to explore whether venture capitalists are aware of the shift towards a translational model, whether they are willing to engage with the scientists at early phases and whether they continue to expect a large share of the profits.

References

Allen, T. J. (1977). *Managing the Flow of Technology: Technology Transfer and the Dissemination of Technological Information Within the Research and Development Organization*. Cambridge, Massachusetts: MIT Press.

Cohen, W.M., Nelson, R.R., & Walsh, J.P. (2002). Links and impacts: the influence of public research on industrial R&D. *Management Science*, 48, 1-23.

Clark, K. B., & Wheelwright, S. C. (1993). *Managing New Product and Process Development: Text and Cases*. New York: Free Press.

Hall, J., & Martin, M. (2005). Disruptive Technologies, Stakeholders and the Innovation Value Chain: A Framework for Evaluating Radical Technology Development. *R&D Management*, 35 (3), 273-284.

Hall, J., Matos, S., Martin, M., & Bachor, V. (2012). *Overcoming Technological, Commercial, Organizational and Social Uncertainties of Innovation: The Case of Forest Biomass as a Replacement of Petroleum-Based Feed Stocks*. Proceedings from PICMET 2012 Conference: Technology Management for Emerging Technologies, Vancouver.

Hall, J., Matos, S., Sheehan, L., & Silvestre, B. (2012). Entrepreneurship and Innovation at the Base of the Pyramid: A Recipe for Inclusive Growth or Social Exclusion. *Journal of Management Studies*, 49, 785–812.

Hall, J., Matos, S., Silvestre, B., & Martin, M. (2011). Managing the Technological, Commercial, Organizational and Social Uncertainties of Industrial Evolution: The Case of Brazilian Energy and Agriculture. *Technological Forecasting and Social Change*, 78 (7), 1147-1157.

Halliwell, J., & Smith, W. (2011). Paradox and potential: trends in science policy and practice in Canada and New Zealand. *Prometheus: Critical Studies in Innovation*, 29 (4), 373-391.

Joly, Y., & Dove, E. (2012). *Moving Beyond Commercialization: Strategies to Maximize the Social and Economic Impact of Genomics Research*. Genome Canada Policy Brief No. 5. Retrieved from: http://www.genomecanada.ca/medias/pdf/en/valorisationRecherche-policy-directions-brief.pdf

Langford, C.H., Hall, J., Josty, P., Matos, S., & Jacobson, A. (2006). Indicators and outcomes of Canadian university research: proxies becoming goals? *Research Policy*, 35 (10), 1586–1598.

Linton, J.D., & Walsh, S.T. (2003). From Bench to Business. *Nature Materials*, 2 (5), 287-289.

Linton, J.D. & Walsh, S. (2008). A Theory of Innovation for Process Based Innovations such as Nanotechnology. *Technological Forecasting and Social Change*, 75, 583-594.

Mansfield, E. (1998). Academic research and industrial innovation: an update of empirical findings. *Research Policy*, 26, 773–776.

Matos, S., & Hall, J. (2007). Integrating Sustainable Development in the Extended Value Chain: The Case of Life Cycle Assessment in the Oil & Gas and Agricultural Biotechnology Industries. *Journal of Operations Management*, 25 (6), 1083-1102.

Meulien, P. (2012). Building a new bridge to the future. *Innovations and Partnerships: From the Barcode of Life to Bioindustrial Commercialization*, Media Planet, independent supplement to the National Post, Feb. http://www.bcn.ualberta.ca/~/media/biorefining/Home/Documents/MediaplanetInnovationsPartnerships.pdf

Organization for Economic Cooperation and Development (2009). *The Bioeconomy to 2030: designing a policy agenda*. Retrieved from: http://www.oecd.org/futures/bioeconomy/2030

Pavitt, K. (1998). Technologies, products and organization in the innovating firm: what Adam Smith tells us and Joseph Schumpeter doesn't. *Industrial and Corporate Change*, 7 (3), 433–452.

Popper, K. (1959). *Conjectures and Refutations*, 5th ed., New York: Harper and Row.

Reamer, A., Icerman, L., & Youtie, J. (2003). Technology Transfer and Commercialization: Their Role in Economic Development. Economic Development Administration, U.S. Department of Commerce, Washington D.C.

Rosenberg, N., & Nelson, R.R. (1994). American universities and technical advance in industry. *Research Policy*, 23, 323–348.

Salter, A. J., & Martin, B.R. (2001). The economic benefits of publicly funded basic research: a critical review. *Research Policy*, 30 (3), 509–532.

Schnaars S., & Wymbs, C. (2004). On the persistence of lackluster demand—the history of the video telephone. *Technological Forecasting and Social Change*, 71 (3), 197–216.

Shapiro, R. (2000). The Welcome Tension of Technology: The Need for Dialogue about Agricultural Biotechnology. *CEO Series, Business Leaders: Thought and Action*, issue 37. St. Louis, MO: Center for the Study of American Business, Washington University.

Sheppard, A. W., Gillespie, I., Hirsch, M., & Begley, C. (2011). Biosecurity and sustainability within the growing global bioeconomy. *Current Opinion in Environmental Sustainability*, 3 (1-2), 4-10.

Teece, D. (1986). Profiting from technological innovation. *Research Policy*, 15, 285–305.

Turnhout, E., Stuiver, M. Klostermann, J., Harms, B., & Leeuwis, C. (2013). New roles of science in society: Different repertoires of knowledge brokering, *Science and Public Policy*, 40, 354–365.

Wong, J. T. (2012). *Technological, commercial, organizational, and social uncertainties of a novel process for vanillin production from lignin*. (Unpublished MBA thesis). Simon Fraser University, Vancouver.

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