Public-Private Research Collaborations in Canadian Forestry Genomics: Knowledge Management and Innovation

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1 Introduction

Genomics research promises and has begun to deliver social and economic benefits in health, agriculture, environment, forestry and fisheries. Evidence of these benefits includes providing high nutrient level crops through improved consistency in plant breeding, identifying and selecting for the best quality fish in aquaculture, and enabling early detection of cancerous tumors. In order to fully reap the benefits of genomics research it is essential that the knowledge generated is properly managed and disseminated. This means creating pathways and tracking methods for research to move from the discovery phase in the laboratory through to socially embedded innovations. Canadians recognize the importance of genomics research. It is now necessary to develop strategies to translate and transfer genomics research in order to maximize social and economic benefit.

Forests are both economically and socially important to Canadians: they are part of our economic wellbeing, and they are tied to Canadians’ deep-rooted conceptions of Canada as a land envied by others for its pristine wilderness. Tree genomics research will help to both maintain and improve this resource. Genomics research can be used to increase growth rates, health and performance; it can also improve pest control methods and adaptation levels to unfavorable conditions (Genome Canada, 2008a; Natural Resources Canada (NRCan), 2004b). In order to use the knowledge being generated by this field it is essential that

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good research, development and delivery (RD&D) management practices are employed. This study investigates the current RD&D management practices in tree genomics research through interviews with two experts in the field.

2 Forestry Genomics in the Canadian Context

Forests are a valuable Canadian bioresource. Canada is the world leader in export of forest products, accounting for nearly 16 percent of the world trade. The forest industry was worth $78.3 billion in 2007 and contributed $23.4 billion to Canada’s trade balance that year (Natural Resources Canada (NRCan), 2008). The forest industry contributes approximately three percent to Canada’s gross domestic product. It employs 822 400 people, with direct jobs in the industry making up nearly two percent of Canada’s total employment (Natural Resources Canada (NRCan), 2008). Over 300 rural and remote communities, particularly in British Columbia, Quebec and Ontario, depend on the forest industry for at least half of their income. Western Canada produces mainly wood products, while the eastern provinces produce more pulp and paper (Natural Resources Canada (NRCan), 2008). In addition to their economic value, forests are also socially and environmentally important. Many Canadian Aboriginal communities are established in forested (Natural Resources Canada (NRCan), 2004a) areas. Forests also maintain Canadian biodiversity as well as play a central role in sustaining the ecosystem.

There is a rising demand from the international community for high-quality wood for building and for the production of high-quality paper. The challenge of meeting increasing demand is complicated by the coincidental threats of climate change and outbreaks of pests. Climate change is expected to cause a drastic reduction in the amount of usable soils for growing commercial forests. Areas typically well suited for species-specific tree growth may be rendered useless due to changes in the environment. Insects also pose a significant threat to Canadian forests. The spruce budworm is considered one of the most detrimental forest insect pests in all of Canada (Canadian Forestry Service (CFS), 2007a). The weevil is another extremely common and highly detrimental Canadian conifer pest (Canadian Forestry Service (CFS), 2007b). Outbreaks of these pests greatly impact commercial forests and pose a serious risk to the Canadian tree industry.

Genomics research is critical to sustainably managing and benefitting from Canada’s forests. In order for Canada’s tree species to survive predicted changes in climate it is crucial that tree breeders understand and select for genes associated with cold acclimation, drought tolerance and growth phenology. In order to protect Canadian forests from serious pest damage it is necessary to identify environmentally sustainable pest resistance mechanisms.

Canada is emerging as an international leader in forestry genomics as a result of significant public investment. Between 1999 and 2004 the Government of Canada invested $11 million in the field (Natural Resources Canada (NRCan), 2004b). Also at the start of this time frame, the not-for-profit organization Genome Canada was established to lead the national strategy on genomics.
Over the past eight years, Genome Canada has held three national competitions for funding large-scale genomics and proteomics research projects. Genome Canada has funded six forestry genomics projects since 2000 (Genome Canada, 2008a). To date, Genome Canada has invested nearly $30 million to projects specific to forestry genomics (Genome Canada, 2008a). Canada’s reputation as an international leader in tree genomics is a direct result of this investment (Natural Resources Canada (NRCan), 2007).

Canadian forestry genomics is particularly strong in the areas of tree genomics, fungal genomics, insect and viral genomics, and molecular diagnostics. The first forestry genomics project in Canada investigated the mechanisms of wood formation and pest resistance in forest trees. Poplar was chosen for this study because of its rapid growth and generation times as well as its desirable wood quality traits. Researchers in this project worked with international collaborators to develop the first draft genome sequence and annotation of the poplar genome. This project provided Canadians with an improved understanding of the benefits and compromises of desired breeding characteristics, such as increased growth rate and wood quality (Genome Canada, 2008b).

From this first project onward, Canadian tree genomics researchers have been the frontrunners in what is a new and important genomics field. One of Canada’s current tree genomics research projects is in response to the increasing threat on conifer forests by outbreaks of insect pests and impacts of climate change. This project seeks to identify and use the natural genetic variation of forest trees in order to support breeding for resistance and adaptation in conifers to improve forest health overall (Treenomix, 2008).

Canadian genomics researchers are also studying high-performance spruce trees for better quality wood. Spruce is the most common species in forest plantations. Canada’s spruce population composes 32% of Canada’s boreal forests and is of major economic importance. Spruce is a multi-purpose species with important commercial value as saw logs and for pulpwood. With a worldwide increase in the production of cheap wood and fiber, cost effective and niche products are needed in order to ensure Canadian success. Studies of tree growth and yield, as well as wood properties, are essential to help enhance the economic performance of the Canadian forest product industry. In an effort to mitigate the effects of climate change and to maintain Canada’s reputation for producing high quality trees, Canadian spruce genomics research is geared towards developing tools and protocols that select for specific growth, stress-adapted and wood quality genes (Arborea, 2008).

In order to derive social benefit from Canadian tree genomics research, the knowledge generated by this research must be properly managed and disseminated. The Science and Technology Strategy put forward by the Conservative government in May 2007 recognizes the need for greater university-private sector collaborations and seeks to improve commercialization pathways from universities to the private sector. The strategy explains:

Efforts to support the transfer of technology from Canadian universities to the private sector are resulting in spin-off companies,
technology licensing agreements, and patent filings. More can be done to encourage technology transfer at both ends of that process. A review will be launched to uncover factors that might be inhibiting S&T collaboration between industry and the higher-education sector (universities and colleges). This review will include an assessment of whether a new approach to intellectual property management of university research is warranted. In the meantime, the government will pilot new approaches to university and government laboratory technology transfer; greater involvement by the private sector in the design of these new approaches is needed (Industry Canada, 2007).

Canadian tree genomics is not currently a patent-intensive R&D environment. A mere four patents were listed in the Canadian Intellectual Property Office patent database under ‘tree molecular breeding’ contrasted against over nearly 2800 listing ‘crop.’ With the multiple novel tree breeding selection and protection technologies being reported in tree genomics in Canada alone, it seems unlikely that the limited number of patents in the field is an accurate indication of innovation. Instead, perhaps this is a case where intellectual property protection through patenting is not prioritized.

This paper examines the contribution of knowledge management strategies in tree genomic biotechnology research with respect to the promotion of efficient and effective knowledge creation, translation and use. The hypothesis being tested is that the contribution of knowledge management to biotechnology innovation is undervalued, and that successful strategies can be identified. The next section: 1) introduces the case forestry genomics study, 2) describes the organizational context for forestry genomics in Canada, 3) discuss what knowledge is being produced, 4) discusses the knowledge tracking methods used, 5) explores the knowledge transfer mechanisms by which the knowledge generated is disseminated and the role of intellectual property in this dissemination, and 6) explores the impact of the funding agency’s accountability practices and policies upon research and dissemination activities.

The results of the analyses of this case study will be used in a project to generate best practice guidelines that promote and sustain innovative behavior. It is part of the larger project in which knowledge management is being studied from the standpoint of innovation in support of food security. This research project, Knowledge Management and Global Food Security, is a Genome Canada funded research project based at the University of Ottawa (Castle, 2010). The results of this project will be of interest to public policy makers, researchers and industry partners engaged in collaborative research, and the knowledge management research community.

3 Research Method

This case analysis is based on open-ended interviews with two expert researchers in tree genomics. The researchers interviewed for this study are leading innovative research projects on opposite sides of the country, and both projects have
potential for significant national socio-economic benefits. The interviewees have considerable experience with tree genomics and, in particular, projects funded through Genome Canada. Both researchers have held leadership positions for multiple Genome Canada projects. Combined, their experience spans from the commencement of forestry genomics research in Canada to current, cutting edge, work in the field.

The interviews were approximately one hour in length and consisted of 15 questions encompassing five major categories in the research study design: organizational context, producing, tracking, transferring knowledge, and accountability for knowledge management. The complete case study interview guide is attached in Appendix A. The fifteen question interview was transcribed from the digital recording and analyzed. The answers were examined to assess whether current policies and practices enable or limit knowledge management and transfer, and what anticipated effects of current knowledge management practices on forestry genomic and biotechnology innovation in Canada.

3.1 Organizational Context

Answers to the first three questions posed to the interviewees provide a basic understanding of: 1) the work being done in the interviewee’s respective labs, 2) their role in their given research group, and 3) where their research stands on the continuum between pure and applied science.

Both researchers identified themselves as co-leaders for their given projects; however the interviewees have very different roles in their respective groups. The first researcher saw his co-leadership role as being one of a few research heads working in collaboration with other researchers and their teams toward a shared goal. Researcher One expressed this by saying:

There’s a lot of work and discussion that goes on around managing the project cohesively where activities are very integrated, and so there’s a lot of integration across groups and projects. In addition to that my lab provides data that feeds into other activities in the project so a lot of what we’re communicating is about sharing data and integrating data, and using data from one part of the project to feed into the other parts of the project.

The other researcher’s team decided to separate the responsibilities between leaders. The interviewee had limited awareness of the responsibilities that fell outside of his own activities within the project. According to Researcher Two, in his research group, there is a relatively distinct partition of the structural and functional sections of the project: “it's pretty well divided, especially at the technician level.”

The interviewees were then asked to describe their laboratories in terms of the nature of their research. When asked to place their research along the continuum between pure science and commercialization of technology both researchers categorized their work as being predominantly pure science. According to the
first researcher interviewed, his work is “basic science but all of the experiments are structured to be able to provide tools that can be transferred to application.” He expanded on this, saying:

We’re in forestry so we’re a field of application rather than a field of basic science. However, within forestry what we do is quite basic research, we’re looking at genes and DNA rather than out in the field measuring trees so we are more at the discovery end of things with the forestry. However, within the current project we have people who are participating in specific experiments where we’re trying to take basic discoveries and validate their potential utility in a tree breeding operation.

The second researcher also describes his work as a mixture of both pure and applied science, with a focus on pure science. According to him, there are a variety of research projects going on within his lab; some activities fall closer to pure science work and others are much more applied.

Following this question, the interviewees were asked to explain the goal or mission of their given projects and then to identify the motivation for themselves and their team members to produce particular kinds of research results. According to Researcher One, his multi-disciplinary project aims, “to develop solutions to support sustainable forestry... selecting trees that will be best suited for reforestation; we also envision applications in conservation of genetic diversity.” According to Researcher One, the motivation for doing this work is derived from more general factors:

I think the main motivation here is that people have been touting the potential for biotechnology in genetics and molecular biology for a long time, and a lot of us really see that now we really do have a chance to make a difference. Whereas in the past it’s been hard to really materialize or deliver on what was promised or what was envisioned... a lot of people are quite motivated with that opportunity as well as the sheer, level or scope of the work that we can do. Rather than get one gene at a time or a few genes at a time now it’s really bigger scale and everyone sees that will impact them.

Researcher Two pointed out that the research has the potential to have an impact on both a national and international level:

By developing tools for one (tree species) perhaps we can transfer that knowledge to other breeding programs with other (tree species)... you don’t necessarily have to develop knowledge and tools for trees in Canada... you can develop stuff which then you sell to different countries.

Forestry industry-specific goals motivate both researchers, and both explicitly and by reference each researcher is driven by basic curiosity regarding what biotechnology can do.
3.2 Producing Knowledge

Once the setting and motivation for producing knowledge was explained, the interviewees discussed the actual knowledge being generated by their work and identified the main beneficiaries of this knowledge. They then pointed to current and potential problems that impede production in tree genomics research. Both interviewees identify the scientific community as the most immediate beneficiaries of their research because of the foundational nature of their work. The current gene identification stage enables further research, which is more likely to have an application orientation. Peer-reviewed publications are therefore an important outlet.

Knowing what knowledge to generate or produce can be extremely difficult. According to Researcher Two, the unpredictability of the market makes knowing what research to pursue a struggle:

> inherent in forestry [is that] you can’t predict the markets 20 or 30 years in advance[...] what do you breed for you know? Both the two basic areas are pulp characteristics versus structural wood. . . . Pulp paper versus timber [...] the market for those two types of things may be vastly different [by the time research is done] maybe we’ll live in a paperless society.

When asked about R&D difficulties, Researcher One explained that production can be threatened by two main things:

The biggest one in my opinion is mismanagement or miscommunication. Within a large project each PI has to commit to and work towards specific deliverables and some people have a hard time with that. And that generates a lot of insecurity around that group’s activities because you’re not quite sure what it is they’re going to deliver, and whether that those things that they will deliver will meet the expectations of another group. And so I think that’s most often the problem is that you just have this profound miscommunication between PIs or between groups, that’s one possibility. The other, the other possibility is, is this level of insecurity or instability because of a group or individuals not being well supported by their institution [not enough] money, not able to recruit enough people rapidly enough.

Due to the high level of integration of his project, Researcher One also explains that production could be seriously impeded if one group does not follow through:

... in other projects that I’ve been part of there have been very clear examples of people not [producing] for all sorts of reasons and so that’s always frustrating. The more integrated the activities are the bigger the impact will be. And so in our case there is a pretty
Based on the interviewees’ responses there are still uncertainties regarding identification of research questions whose results will be most useful, and there is both uncertainty and insecurity regarding operation of collaborative research groups in the particular context of these groups’ institutional settings. Both factors pose threats to tree genomics knowledge production. The interviewees explained that after the current foundational research is complete tree genomics research will likely see a shift in the main beneficiaries of this research are, moving from the scientific community to the general public.

3.3 Tracking Knowledge

Tracking of knowledge is currently not a priority for either of the interviewees and their research teams. Researcher One stated: “we don’t do any detailed tracking.” He did, however, point to his scientific advisory board and stakeholder committees as some means by which his team does informal knowledge tracking. Researcher Two did not mention formal tracking at all. Knowledge tracking for multi-researcher, multi-institution research projects of the kind engaged in by the researchers is not generally a priority to universities. Likewise, research institutions have provided few incentives to the interviewed researchers with respect to pursuing intellectual property protection. As will be discussed in the section reviewing knowledge transfer, there are few research-industry partnerships in the discussed projects, therefore, neither researcher has incentives to pay attention to this aspect of knowledge management. Overall knowledge tracking is an area of extremely low priority for tree genomics researchers and until institutions or partners provide incentives for systematic knowledge management, tree genomics researchers will not invest the time into improving it.

3.4 Transferring Knowledge

While both researchers seek to disseminate their work beyond academe, they have experienced difficulties in creating effective industry partnerships. While Researcher One is working toward more productive relationships in the future, Researcher Two has resigned himself to working with the provincial ministries only, and is skeptical of any further industry partnerships.

The interviewees both stated that firms are largely uninterested in investing in research. According to Researcher One, “the forest products industry has just not invested in reforestation, they do the bare minimum.” When included as project partners, firms were unreliable funders, prone to secrecy, and the researcher-firm relationships suffered from a lack of reciprocity. Based on Researcher Two’s experiences with both private and public partnerships, “the best way to ensure application is to develop partnerships with people such as government agencies or not-for-profit organizations.” He recalls his project working with industry as “a one-way collaboration where they were benefiting from us
and not vice versa. [...] We found that they’re very protective [...] (also) they’re afraid of being associated with genetically modified trees.”

Researcher Two elaborated on his preference for government partnerships over working with industry: “working with government promotes stability because companies are always being bought out... and also they often won’t share their material.” As an example, he made reference to a company which previously worked with university scientists but then completely stopped working on pedigree programs that would be relevant to the researchers’ work. Unlike his colleague, Researcher One is making significant efforts to improve his relationships with potential industry partners and change their perspective of their role. He and his team are:

> working at educating industry and trying to build small pilot projects or niche projects to get them to get involved and invest on a smaller scale. [...] I think we are slowly changing industry’s view, which until recently has been just, cut trees and run.

As an example of the potential to change industry’s view, he noted companies in Western Canada who are investing in small scale genomics projects to improve specific tree species and make them more efficient.

Researcher One also uses stakeholder and advisory committee meetings to disseminate information and stimulate new ideas:

> we bring [funders and stakeholders, including industry] together about once a year and have a pretty targeted discussion with them. We talk about technology transfer and what’s the best way to promote that, we also talk about outreach activities.

According to him, these informal meetings:

> generate more awareness of what the potentials are, what the issues might be, and to stimulate discussions [...] [They are a way] to start being more proactive... It’s creating an opportunity to get people talking and get more partnerships perhaps to evolve, and also help guide us with our approaches to tech transfer.

As an outcome of these meetings, Researcher One’s team is conducting a series of interviews with Canadian tree breeders to better understand, “exactly what they want and what they need.”

University-industry knowledge transfer is commonly expected to require intellectual property protection, especially in the form of patents. In forestry however, intellectual property protection through patenting is usually a low priority. Unlike the patent-centered pharmaceutical industry, forestry firms usually protect their proprietary data with trade secrets. When Researcher One was asked about intellectual property protection he said:
We’ve looked at protecting intellectual property and done a little bit of it, but within our field we give it quite a low priority because the potential for commercialization per se is low. And so given that our institutions are telling us patenting isn’t really something they want to invest in, at the same time we see that, within our field the best way to ensure application is to develop partnerships with the people who will be using the technology and these people are in government agencies mostly, or in not for profit organizations, and oftentimes they can’t afford to go out and pay for expenses, services, or technology so we have to work with them. Therefore publication is not such a big concern, it doesn’t inhibit our ability to work with them, it doesn’t inhibit their ability to take up the technology and so that’s the context that we see ourselves in.

According to Researcher One intellectual property may be important in future research, because “the landscape could change, forcing companies to get more involved.” He further explains this prediction stating:

At this point the most important results are more basic or fundamental, and I believe it’s the scientific community that’s benefiting. Because we’re working with un-characterized systems, forestries, we have to do a lot of technology development and basic data gathering cells, and that all goes into the public domain and gets published. Two years from now we should have decent markers that could be used in tree breeding conservation, but that’ll be a different story.

Changes that may prompt more industry involvement include the development of a forest certification, in which markers could be identified to address specific issues like gene pollution with exotic species, or conservation issues. In the current climate, the researchers are only concerned with intellectual property as it relates to protecting academic integrity; common instruments are data protection policies and data confidentiality and non-disclosure policies.

3.5 Accountability for Knowledge Management

Genome Canada requires that its research projects account for their spending, progress toward goals, and results, all in return for investment of public funds in the projects. The interviewees were asked to describe the impact of these accountability practices on the conduct of research and dissemination of results. Both researchers considered the accountability requirements reasonable given the comparatively large size of the grants.

According to Researcher One:

the reporting issue is one that we’ve dealt with quite efficiently. We structured the project in the beginning so that deliverables are clearly defined, and that kind of simplifies the reporting question. Now then you of course have to follow up to make sure that people
are meeting the deliverables. So far it’s going quite well it’s not been a big challenge and we have people, project managers to help us with the reporting.

Researcher One and his team use the reporting practices as an organizational tool to keep the group focused without limiting their ability to explore new directions:

we’re quite independent in our thinking process, we follow the guidelines to the degree they need to be followed but we also adapt the thinking...we develop our own vision and our own plan, and then see how Genome Canada guidelines can help us get there.

In order to stay accountable within the group, Researcher One explains that they also have a lot of “detailed discussions, regular meetings and accountability to the scientific advisory board.”

According to Researcher Two, the reporting is an obstacle to productivity. Quarterly reporting is not conducive to research that naturally follows an annual cycle:

Our workflow is quite seasonal. We collect the material in the spring or early summer for experiments, and then process it throughout the whole year so it flows in more or less a yearly cycle [also... ] project managers are not around enough to really know what’s being done in terms of science.

4 Conclusion

This case study focuses on the mechanisms by which tree knowledge in genomics research in Canada is being managed by the research teams, and the ways in which the funding agency’s accountability practices and policies help or hinder knowledge translation and knowledge transfer. The goal of the study is to contribute to a better understanding of knowledge management in the Canadian innovation system by investigating two Canadian forestry projects from a knowledge management perspective.

Interviews with two highly reputed researchers in the area of tree genomics provided important perspectives on the policies and practices which are currently in place, guiding knowledge management in the field. Interestingly, the researchers hold very different insights on their roles, their research projects and the tree genomics research relationship with industry.

The researchers have opposite perspectives on the possibility of improved and increased industry partnerships. One researcher is entirely uninterested in working with industry as a result of negative past experiences. He deems industry partners secretive and unreliable. He views research-industry relationships as unidirectional and without benefit for the research team. The other
researcher is making targeted efforts to forge positive relationships with industry. This researcher and his team are working to educate industry on their activities. They are also keeping open lines of communication with potential industry partners in order to better understand what industry is looking for in the hopes of generating research that will attract industry to them.

Although the two researchers maintain different opinions on the effectiveness of knowledge management practices within the Canadian tree genomics industry, it is agreed that knowledge tracking and intellectual property receive little to no attention in the current tree genomics research environment. Patents are not a priority because they are expensive to produce and because commercialization of research is limited. The institutions within which tree genomics research is being done provide little or no incentives for researchers to patent. Furthermore, research in tree genomics is normally used by government or not-for-profit organizations who cannot afford to pay for the costs incurred from obtaining and defending patents.

The interviewees diverged on their opinions of accountability practices by their current funding body. Researcher Two found that the practices did not flow with the organisation of their research. Researcher Two found the practices restrictive and is disappointed with the lack of useful feedback from Genome Canada. On the other hand, Researcher One views the accountability practices as guidelines to keep them on track. Researcher One does not find these practices restrictive and sees them as a bare minimum for the level of accountability they should uphold. Research One claims team do a far more critical and detailed analysis of their own work than what they are held to by their funders. Researcher One is enthusiastic about the potential of further work with Genome Canada; while Researcher Two will likely not submit an application for the upcoming Genome Canada competition.

Canada’s forests are an important bioresource that Canadian scientists work to sustain. Genomics research provides a better understanding of pest resistance mechanisms, organism interactions and wood formation. It has the potential to significantly improve high-yield plantations and sustainable, intensive forestry. This case study provides insight into how tree genomics knowledge is managed and disseminated in Canada today. As efforts to commercialize tree genomics R&D improve, knowledge management strategies will need to be adapted; and areas that are currently given low priority such as tracking and intellectual property protection will perhaps be afforded more attention. In order to ensure that Canadians continue to benefit from the biodiversity and economic success of Canadian forests, it is essential that Canada invests in management strategies to best disseminate the knowledge generated through tree genomics research.

A Case Study Interview Guide

1. Would you please describe your role in your organization and in this project [insert ILRI, BeCA, TNC as appropriate]? 
   Follow on: In that role, what kind of information or knowledge do you
generate, give to others, and get from them? [If there is no mention of finance, policies, communication methods such as email, prompt with respect to each of these categories.]

2. What is your organization's place on the continuum between pure scientific research and commercialization of technology?
   Follow on: If the answer involves research, then ask: what is the balance between pure and applied scientific research?

3. What are the mission and goals of your organization?
   Follow on: What motivations are there within your organization to pursue its mission and goals?

4. How does your organization guide research, by policies or incentives or profit-sharing or similar mechanisms?
   Follow on: Same question for development.
   Follow on: Same question for knowledge translation and transfer.
   Follow on: How are these activities related? Or are they separate?

5. How effective are the policies bearing on your organization's research? Knowledge translation and transfer?

6. Who are your funders, and at what stage are they involved in research, development and knowledge translation/transfer?

7. How do you track knowledge coming into your organization, and how do you track knowledge going out?

8. How effective are your organization's operations with respect to tracking (internal) and translating/transferring (external) knowledge?

9. When does your organization track (internal) and translate/transfer (external) knowledge - what are the stages and triggers?

10. Who benefits from your R&D activities?

11. What are the most important results of your R&D activities?
   Follow on: Why do you feel this is the most important result?
   Follow on: How important are publications to your organization? Patents or other forms of intellectual property? Development of commercial products, processes or services?
   Follow on: What incentives are there for your organization to produce publications? Patents or other forms of intellectual property? Commercial products, processes or services?

12. What counts, to your organization, as an unsuccessful R&D collaboration?
   Follow-on: If underlying science or technology not mentioned, query; if sufficiency of funding not mentioned, query; if all reported institutionally with no reference to personal role, ask: 'How do you feel personally when you are involved in an unsuccessful R&D collaboration?'
   Follow on: In retrospect, can you identify whether the cause of unsuccessful R&D collaboration is mostly caused by policies, persons, technological failures, or other causes or some blend of these causes?

13. Within your major projects, to whom are you accountable and in what ways (for example: regulatory approvals, transfer of lab techniques or markers,
or feedback regarding the effectiveness of knowledge, processes, or techniques you have been given)?

14. How onerous are these accountability requirements as part of your workload?
   Follow on: Do the accountability requirements of this project have a good ‘fit’ with your normal workflow?
   Follow on: Do particular stages of the collaborative R&D process involve especially difficult reporting or accountability tasks?

15. Overall, have the policies guiding this project’s path from pure research to commercial product or process tended to make that process quicker, and more efficient, or slower and less efficient?
   Follow on: Have the policies guiding this project left your organization better prepared for efficient collaborative R&D in the future?
   Follow on: Would you recommend to your organization that you embark on a similar project again?

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