REGAL: A Successful Model of Collaboration for Innovation between University and Aluminium Industry

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Abstract

Innovation is the key driver to meet business objectives in today's highly competitive industry and the aluminium industry in not exempt from this rule. In turn, the backbone of innovation is "*people*" since no innovation is expected from a machine. Education is of primary importance to assure the succession of highly qualified "*people*" and training "*minds*" for tomorrow. Although the educational institutes are the primary responsible to train "*people*", the training is a shared responsibility and the collaboration of the industry is necessary to make this process more efficient and targeted. In this paper, we will present Aluminium Research Center (REGAL) as an example of successful collaboration between aluminium industry and educational institutes. The objectives of the Center and its mode of operation will be discussed, followed by a few examples and outcomes.

Keywords: University-Industry collaboration, REGAL, Innovation, Training.

1. Introduction

Innovation is the leading component of competitiveness of a company, especially when the characteristics of the market is rapidly changing. According to McKinsey & Company [1], 84% of the executives interviewed agree on the importance of innovation on the success and growth of their business. More drastically, many of them support the theme "*Innovate or Die*". While there is a consensus that innovation gives competitive advantage to the companies, this advantage is volatile or difficult to maintain in a rapidly changing market environment [2]. Thus, to keep the competitive advantage, the company needs to innovate, constantly and sustainably.

Innovation, according to Merriam Webster, can refer to something new or to a change made to an existing product, idea, or field. In more specific terms, innovation could be defined as "*developing new technologies and bringing them to the market*" or "*developing the new means of operation to adapt a process to the new market realities*". The literature is rich of ideas, surveys and reviews, all attempting to provide successful models for innovation.

Innovation is indeed crucial in rapidly changing industries; i.e. video-game or software industries, with products of extremely short life span. In a more traditional industry, such as aluminium industry, one may think that the need for innovation is not that urgent since the industry uses a century-old technology, Hall-Héroult process. Furthermore, all competitors use the same technology, with some minor differences which give them competitive advantage to some extent. The point is that the need for innovation is not necessarily limited to the core business or technology. In fact, the competitiveness does not rely on the core process only, but also on the related technologies. For instance, integration of sophisticated measuring and monitoring tools, artificial intelligence, and data processing algorithms into the main process have substantially changed aluminium process during the past decades. New solutions, namely digitalization and automation have emerged in this industry, leading it to the fourth industrial revolution: Industry 4.0 [3]. This makes the industry more multidisciplinary than ever. No one producer can hope to keep its competitiveness without aggressive innovation plans to integrate and take advantage of these emerging technologies in its core process.

Beside the competition with traditional competitors, that are the other aluminium producers, a number of other parameters also force the industry to innovate. The main one is the competition of aluminium with other materials. Development of high-performance steel alloys or light-weight composites threatens the market share of aluminium, forcing the industry to be more and more cost effective and to permanently innovate to develop new alloys meeting expressed or unexpressed end user needs. Another parameter is the shortage of raw materials or their degrading characteristics. The tremendous growth of aluminium production rate during past few decades results in the shortage of high-quality raw materials, thus forcing the industry to continuously adapt itself to the new, rather low-quality, raw materials. Finally, new and increasingly tight regulations force the industry to decrease its environmental footprint and improve its social image. Addressing all these challenges is not possible but by sustainable innovation.

Considering the multidisciplinary characteristic of the aluminium industry and the need for innovation in multiple fronts, it is hard to conceive that a firm can afford it alone. The good news is that part of innovation process can be outsourced. The concept of outsourcing innovation was very well described by Henry Chesbrough [4]. It is so important that Chesbrough's book was cited more than 19 000 times since its publication in 2003. The concept, as summarized below, is quite simple: it challenges the "*closed innovation paradigm*" and proposes "*open innovation*" instead.

Closed innovation, having been practiced for longtime in the past century by many successful companies, is based on full control of the innovation by the firm. That is the company generates the new ideas, develops them and markets them. The famous innovation funnel (Figure 1) is well describing the closed innovation process, where the ideas are generated inside the company, pass through R&D and development steps followed by the *Gate Reviews* and finally few of them survive up to the commercialization step. The boundaries of the funnel are impermeable and do not let any idea go out. The full control on whole innovation process gives the company a competitive advantage. New products are generated and the revenue increases. The firm re-invests a fraction of the revenue in R&D and innovation, resulting in generation and commercialization of other new ideas. Although the concept worked very well for a while, it suffered from difficulty to keep the sensitive information confidential, namely by moving employees. In addition, supporting the whole innovation chain required substantial R&D infrastructure and only large firms were able to afford it. Small and medium-sized businesses can still use this concept for simple processes, not requiring multidisciplinary R&D infrastructure.

Open Innovation concept was proposed to address issues encountered with *closed innovation*. The logic behind it is: It is more and more difficult to do everything internally and keep it confidential, so, why doing internally if it is possible to make it externally? As stated by J. B. Quinn [5]: "*with billions of minds becoming innovation sources for our marketplace, no one company acting alone can hope to out-innovate every competitor, potential competitor, supplier or external knowledge source around the world*". Thus, the *open innovation paradigm* suggests to outsource the innovation and take advantage of it, no matter who generates it or where it is generated. As schematized in Figure 2, any part of the innovation process chain can be outsourced, as long as it is in line with the business model of the firm. The boundaries of the firm are not hermetic anymore, allowing the integration of the ideas or well-developed technologies inside the firm. Once integrated inside, the external innovation can be further developed by the firm or can be combined with those generated inside the firm to create new value-added innovation. In addition, if for any reason, the firm cannot commercialize a new idea generated inside the firm, it can outsource the commercialization part of the technology. A very good example of this is the Elysis technology, which has been developed by Alcoa internally, but Alcoa joined with Rio Tinto (a traditional competitor) to create a new joined business for commercialization and deployment of the technology. Table 1 shows the principles of *open* and *closed innovation* paradigms as summarized by Chesbrough.

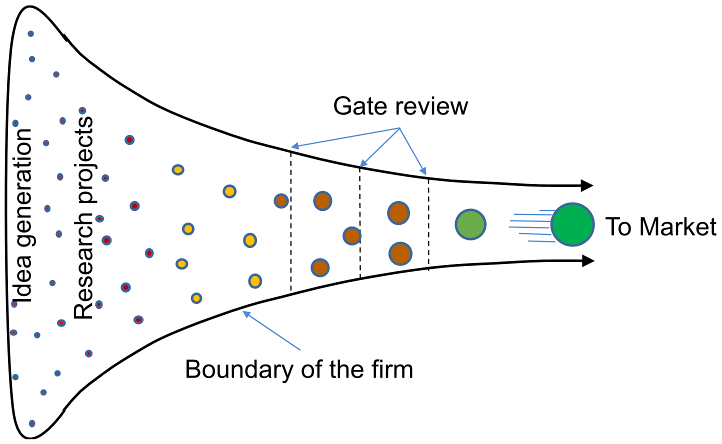

Figure 1. The closed paradigm for managing industrial R&D. (Adopted from [4]).

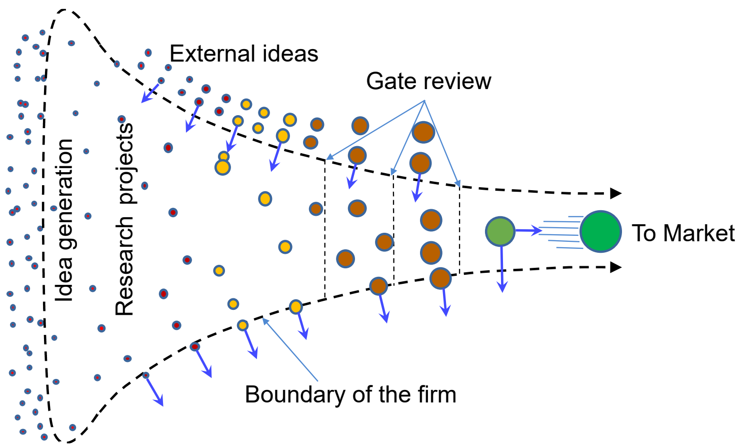

Figure 2. The open paradigm for managing industrial R&D. (Adopted from [4]).

The external innovation can be acquired by different means. For instance, open literature and public knowledge could be used as a source of innovation. However, in many cases, the available knowledge in open literature cannot be used *as is* since it is not fully adapted to the firm's technology or business model, thus requiring further development before being used. The external innovation can also come from the suppliers or partners. This type of interaction is routinely practiced by the aluminium industry where there is a mutual benefit for the partners. Universities are playing a key role in generation of knowledge, and if well-directed, they could be the principal source of external innovation. In this paper, we will further explore the role of university as an external source of innovation for aluminium industry. We will emphasize on the advantages that university/industry (UI) relationship may offer to the aluminium industry to innovate and to keep its competitive advantage vis-à-vis competitors or other materials while respecting tight environmental regulations.

Table 1. Contrasting principles in open and closed innovation [4].

Closed innovation principles	Open innovation principles
The smart people in our field work for us	We need to work with smart people inside and outside our company
To profit from R&D, we must discover it, develop it, and ship it ourselves	External R&D can create significant value; Internal R&D is needed to claim some portion of that value.
If we discover it ourselves, we will get it to market first	We don't have to originate the research to profit from it.
The company that gets an innovation to market first will win.	Building a better business model is better than getting to market first.
If we create the most and the best ideas in the industry, we will win.	If we make the best use of internal and external ideas, we will win.
We should control our IP, so that our competitors don't profit from our ideas.	We should profit from others' use of our IP, and we should buy others' IP when-ever it advances our own business model.

2. University/Industry collaboration for innovation

The role of the University in the modern societies is to educate people and generate public knowledge. This knowledge could, in principal, be used by anybody. However, the policy makers often encourage the universities to transfer this knowledge to the industry, preferably the national ones, in order that the society takes benefit of it. After all, this is the public money which generates the knowledge and it is normal that the same public takes advantage of it. This is possibly the main reason why funding organizations actively promote knowledge transfer from university to industry. Universities, on the other hand, raise their revenue either by increasing the funding levels or by valorizing the generated knowledge.

There are several channels for knowledge flow between university and industry. Schartinger et al. [6] made a comprehensive research on different types of knowledge interactions (16 different types) between universities and sectors of economic activities in Australia. These types of interactions could be classified in four main categories; joint research, contract research, people mobility and training of industrial people [7]. Commercialization of academic knowledge, usually via patenting and licensing or entrepreneurship, could also be considered as channels for knowledge flow [8]. Schartinger et al. [6] concluded that, among different knowledge transfer channels, direct research collaboration is one of the most effective ones, but the effect of other parameters should not be underestimated in their role in innovation process. Manotungvorapun and Gerdsri [9] stipulated, however, that such a collaboration could fail due to different reasons such as divergence in strategic goals, cultural mismatch or lack of commitment. Therefore, the interaction channels must be chosen carefully for successful partnership between university and industry.

3. Parameters influencing the success of UI collaborations

Many researchers attempted to identify the parameters influencing the success of UI collaborations. Usually, identification of these parameters is not difficult, since most of them are intuitive. However, quantification of their impact on the success of the UI collaboration is not trivial. The difficulty arises from the fact that the definition of the degree of success may differ from one firm to another. Some outputs of the collaboration may have direct and measurable impact on the firm's business; i.e. increasing productivity or cost-effectiveness. Patenting, licensing and commercialization are the examples of research outputs to measure the degree of success since their impacts are measurable. On the other hand, some outcomes may have indirect and non-measurable impacts; i.e. improvement of social image of the firm. This is why the methodology used to choose different parameters and to assess the degree of success should be carefully considered before getting into the conclusion. Following are some key parameters that we noticed, influencing the success of UI collaboration.

- ***Understanding collaboration goals***

The authors believe that for a successful and effective UI collaboration, university and industry must mutually understand and respect each other's goal. The goal of industry, in most cases, is to take commercial advantage of the research results while the goal of a university researcher, in most cases, is to take academic advantage. At the first glance it seems difficult to respect these goals in a collaborative research project since commercial advantage means to keep the information confidential, at least for a period of time, while the academic advantage implies publishing the results as soon as possible. In other words, industry believes on "*innovate or die*" and academic researcher believes on "*publish or perish*". At this point, the notion of *open innovation* is of extreme importance, that is a significant part of the research work, usually related to the exploratory or fundamental aspects, is done by university, then the knowledge is transferred to industry who makes the integration of the knowledge into its own process. The fundamental aspects of the work can be published, satisfying the university goal, and the specific use of the knowledge in the firm's process can be kept confidential or be further developed internally, out of the collaboration framework.

- ***Complementarity of expertise and resources***

Complementarity of expertise and resources is possibly one of the most important parameters enhancing UI collaboration. Some authors observed that the success of UI collaboration depends on complementarity of resources [10]. Perkmann et al. [8] noted that the best academic researchers only work with industry if there is also some academic benefit to be derived. Industry aims at outsourcing innovation and looks for resources and ideas that are not available internally. These resources could be research infrastructure, specific expertise or labor. On the other hand, the university researcher wants to have access to industrial data and facilities or to the real problems encountered with the current technology in order to better define research projects through which students will be trained. There is no doubt that the firms have deep knowledge and many real data related to their own technology, which are the great assets for training of students. In many cases, generation of reliable data is expensive and time consuming. So that the industrial data could be used either as is or as a solid base to generate targeted new data in a research project. The industrial facilities can also be used for field trials and proof of concept, otherwise impossible in a university laboratory. Complementarity therefore represents a substantial benefit for a project and enhances mutual learning, thus increasing the level of satisfaction of both partners and the chance of success of the collaborative research.

- ***Characteristics of university or research center***

Among the characteristics of university or research center which could influence the success of the UI collaboration are: academic research quality, individual characteristics of the researcher, geographical location, and faculty/department culture. Research at prestigious universities tends to acquire or maintain international reputation. This type of research is usually very fundamental and avant-gardist, not necessarily addressing the challenges of traditional industry. Mansfield and Lee [11] note that the probability that a firm collaborates with a university is directly related to the quality of the university to some point. Beyond this point, they mention: "*some types of R&D can be performed as well by a good scientist as by a Nobel laureate*". Barra et al. [12] also concluded that international academic reputation does not automatically imply the generation of local knowledge spillover. The proximity of a university is another important parameter in UI collaboration. Maietta [13] found that a firm within a radius of 150 km from a university has a higher likelihood of product innovation than those at higher distance. In a more recent study, Barra et al. [12] studied the effect of academic excellence, measured by indicators of publications and citation, on the innovation of local firms in Europe. They found that top-10 publications of local universities are always associated with more firm innovation than top-25 publications. This clearly shows that the innovation capacity of the local firms has a direct relationship with the quality research performed in a local university. Interestingly, this study revealed that the quality of the research is more important than the ranking of the university on the innovation capacity of the local firms. They showed that second- and third-tier universities generate more knowledge spillovers than the first-tier universities. Finally, the research culture of the university or research center may have local peer effect on the individual academic. That is, if the colleagues of the same rank prioritize applied research or collaboration with industry, the individual researcher will, more likely do the same [8]. Este et al. [14] revealed that interdisciplinary scientists are more inclined to collaborate with industry and have greater probability to generate applied knowledge. From these viewpoints, research centers and clusters may play an important role in UI collaboration success by creating an environment where the UI collaboration is valorized and that the researchers with complementary expertise can work together on multidisciplinary projects.

- ***Level of engagement***

Perkmann et al. [8] published a very good review paper on academic engagement and its effect on knowledge commercialization. They defined engagement as knowledge-related collaboration by academic researchers with non-academic organizations. Engagement may take different forms, i.e. collaborative research, consulting, etc. which is distinguished from well-established channels for knowledge flow such as patenting and licensing. They revealed that the volume of engagement activities in the universities is higher than patenting and licensing, thus firms must be well-equipped to effectively participate in collaboration activities with universities. Beside a number of parameters affecting the engagement level of firms in a UI collaboration, as discussed in this review, we would like to emphasize on the level of involvement of the firms and its extremely positive effect on the success of UI interaction. It is important to consider that university researchers are not looking only for financial support from the partner, rather they also pursue academic benefits. These benefits could be in the form of data exchange, field trials, scientific discussions or participation of the firm scientists in student training process. In a best-practice scenario, the industrial partner should mandate one (or more) of its scientists to interact with university researchers in a regular basis, rather than waiting for a progress or final report. The interaction must be in all steps of a project; from defining the objectives and determining the methodologies to analyzing and publication of the results. This type of involvement has a number of benefits. First, the firm participates in detailed definition of the project objectives, thus being able to orient the research towards its specific needs. Second, the regular interactions result in natural flow of knowledge from university to firm. Third, the firm scientists participate in student training by challenging them and giving practical insights which are crucial to develop the technology applicable in the firm's process. Finally, in case a research project does not give the expected outcome for any technical reasons, both university and firm scientists collaborate together to re-orient the objectives of the project and to eliminate any misinterpretation of the new research orientation. Such an interaction may also positively influence on the mutual trust and willingness of the people from both sides to define further collaborations in the future.

4. Advantages of university-industry collaboration

The university-industry collaboration, if well-defined and executed, could offer numerous advantages and may significantly contribute to the innovation capability of the firm. One may classify these contributions in two main categories; direct and indirect contributions. The former is often quantifiable, although not always trivial, and its impact is felt in short and medium timeframe. The latter, however, is difficult to be quantified and its impact could be felt in long-term. Among numerous quantifiable and non-quantifiable advantages, the followings are highlighted, based on the authors experience and observations.

- ***Quantifiable or direct advantages***

Patenting and licensing: Commercialization is the most evident way for a university-based knowledge to contribute in innovation capability of a firm. Patenting and licensing are the most practiced channels to achieve this goal. When a technology is developed and patented by university, it becomes marketable and any firm (local or international) could purchase it. However, when the technology is developed within the framework of a collaborative research, in most cases the partner has right of first refusal, giving the partner a commercial advantage. Furthermore, a well-engaged partner is also well-placed to evaluate the technology, its value and its potential of implementation within its business, saving due diligence costs and implementation risks. Finally, if the firm's scientists are involved in the project, the probability that they participate in the invention process is much higher, thus resulting in a co-invention between university and industry. The co-invention is more likely to happen when the invention process requires industrial participation. An invention often begins with an original idea which must be improved and tested for its utility and robustness and to determine its boundary conditions before going through the patent filing process. The original idea could be substantially modified or improved according to the subsequent testing results: that is what we call the "invention process". The secondary improvements in the invention process are as important as the original idea. In a heavy industry, such as aluminium production process, an invention process may require field trials and long-term monitoring of the performance indicators to determine the invention boundaries and its robustness. No one university or research center is equipped for such testing. So that, the know-how of industrial engineers and scientists in this process is an absolute necessity, giving the chance to generation of new insights to improve the original idea. In such case, the industrial scientists become naturally co-inventor and the firm becomes co-owner of the new technology, taking advantage of its commercial value.

Financial impact on research cost: Due to the massive public investment, research cost in a university is substantially lower than that in private sector. In many universities, including all Canadian universities, the salary of the professors and some research staff is not considered in the direct research cost. Research-based universities are also well-equipped with research instruments and tools. Except for few very large firms, no one firm can afford to have such a diversified and cutting-edge infrastructure. Although there may exist an internal service cost for using the major instruments and tools, it is usually a small fraction of the real cost, basically because the capital cost is not considered and, in many cases, the operators salary is also assumed by the university. Thus, the internal service cost is limited to the operation and maintenance of the instruments. A substantial fraction of the direct cost of a collaborative research is also supported by public funding. For instance, depending on the size of the industry and the nature of the research, between 50 % and 90 % of the research direct cost can be supported by Canadian public funding. It is more or less the same in Europe and the USA. To all these financial advantages, is added the tax credit that is also offered to the firms when they are engaged in collaborative R&D activities. Figure 3 summarizes an example of the financial structure of an R&D program and the contribution of different funding sources, according to the collaborative research program in Canada. The grant structure has been slightly modified recently and the details can be found in [15].

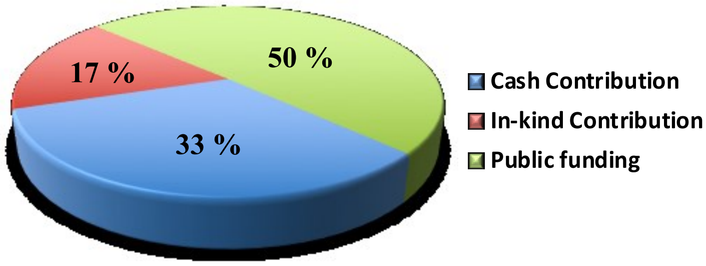

Figure 3. Example of the financial structure of a UI collaboration project, according to the collaborative research program in Canada (R&D tax credit can also be claimed by the firm).

Complementarity of infrastructure: High-quality research requires sophisticated research infrastructure such as laboratory and characterization facilities. Experienced operators make difference regarding the performance of the research facilities and getting the best of them. Universities are the ideal places where the operators are well trained due to the diversity of the projects. These facilities usually complement the R&D infrastructure of the firm, as well. A UI collaboration offers therefore the opportunity to the collaborative research projects to take advantage of the cutting-edge infrastructure and well-trained operators. When the firm has the similar laboratory infrastructure, the interaction between the operators results in increasing the knowledge of both sides. In such cases, they can share the expertise of each other for developing specific protocols for analysis, interpretation or cross-checking of their results.

- ***Non-quantifiable or indirect advantages***

The prime objective of university is to train highly qualified people (HQP). The HQP should not be considered as a simple product of the university, rather as the future leaders of the society. As stated by Coldstream et al. [2] "*The economy of the future will be how educated people, they not we, decide it to be*". So, it is our responsibility today to train them and to prepare them to craft the society of tomorrow. The whole society benefits from the HQP, including the aluminium industry. If the industry needs people in line with its objectives of tomorrow, it is wise to participate in their education today, or at least specify the profile of HQP it needs.

When we talk about university industry collaboration for innovation, we implicitly target the graduate students, i.e. master, PhD and postdoctoral fellows, although under graduate students may also contribute to R&D activities. Their training path usually follows a traditional way for the basic knowledge, i.e. mathematics, physics, … Once at graduate levels, the training method heavily switches to the project-based learning. That is the learning process is derived by student and facilitated by the supervisor [16]. The research project is considered as a vehicle for training through which the student learns how to address a scientific problem in an independent and scientifically rigorous way. This is in this period that they are educated to grow, to innovate, to change and to adapt themselves to the realities of the future. So, in principle, any kind of project can be used for training. At the end, the HQP will be specialist of his/her specific field while being independent scientist, capable of addressing new challenges of the related fields.

Involvement of industry in UI collaborations provides vehicles for training, giving the opportunity to train HQP in the specific field on which the industry is interested. This results in more specialized people available on the marketplace for the industry. Furthermore, each vehicle represents a real problematic of the industry and the outcome of the research could provide a potential solution for this problematic. Thus, through collaborative research, the industry not only gets the benefit of the research outcome, but also it ensures the availability of the HQP on the marketplace.

Another important, yet not measurable, advantage of UI collaboration is the great opportunity that the industrial partners have regarding the choice of right HQP for their business. Hiring HQP is a challenging task for industry, usually beginning by a pre-selection process based on the curriculum of potential candidates, followed by a series of tests and interviews. The interview may take as short as one hour or may take a whole day. Some firms may decide to make more than one interview. This process is possibly the most critical step where the pre-qualified people are challenged and evaluated to make sure that they will fit in the profile targeted by the employer. It is quite impossible to assess all aspects of a human being within a short period of interview. A UI project, when the partner is involved, gives the opportunity to challenge and question the students over a long period of time (typically from 2 to 4 years for master and PhD students, respectively). The students are continuously evaluated while facing different, sometimes tough, situations. This evaluation is not only about the knowledge and the personality of the students, but also about a number of other qualities such as how fast they learn and adapt themselves, how they are willing for team work, etc. In short, the UI collaboration is an ideal vitrine for the students to show what they are capable of and to the industrial partners to assess their qualities over a long period of time. When such candidates are hired by the UI collaborator, they will be productive from the first day since they usually get adequate training about the partner's process during their graduate projects, thus eliminating or significantly shortening the incubation time usually required for a new employee.

The same advantage applies also to the university research staff, including professors, research assistants and technicians. When starting a new industrial project, the staff needs an incubation time to learn all the subtleties of the process before being fully productive. In a research team, especially in a research center specialized on a given field, i.e. aluminium industry, all staff have already a solid background for an effective communication with the partner, better understanding the problematic and efficient supervision and training of graduate students. A long-term collaboration with industry through different UI projects allows therefore building a priceless know-how within the research center which facilitates the liaison between university and industry. It also helps nucleation of new ideas and increases the chance of success in public grant applications.

Finally, policy makers regularly consult with universities and research centers to establish new research policies. At these points, university researchers could have significant influence on the establishment of new policies related to industrial research and funding attribution rules. The same remark is also valid for establishing new norms and regulations. Research outcome, typically in the form of publications, are also important to give confidence to the policy makers to implement new norms. As an example, if a new idea is emerged for using aluminium in a new application where other materials are traditionally used, the existing norms are certainly not adapted for aluminium. UI collaboration and the research outcome may play an important role to convince the authorities to establish new and Al-adapted norms, opening a window for marketing the new idea.

5. REGAL: an example of successful model for UI collaboration

In this section, we present Aluminium Research Center (REGAL) as a successful model to enhance UI collaboration. The structure of the Center as well as its missions are briefly discussed. Then, we try to reveal the indicators of performance and the role of the Center in enhancing university-industry collaboration for Innovation.

REGAL was founded in 2004 and financially supported ever since by the government of Quebec province, Canada [17]. The Center regroups 38 regular members (professors) from six universities and one college (Laval University, McGill, UQAC, École Polytechnique de Montréal, ÉTS, Uiversity of Sherbrooke and CEGEP de Trois-Rivières). Furthermore, more than 60 researchers from other universities and industry are collaborating with the regular members on the aluminium-related projects. The mission of the Center can be resumed as:

- Train highly-qualified personnel and support knowledge transfer towards industry
- Create synergies among universities, public institutions and industry
- Align R&D with the industry's needs by favoring specific actions with small and medium-sized businesses (SMEs) while continuing to work on fundamental aspects
- Promote networking with other large aluminium research centers around the world

The R&D activities of the Center are divided in two major axes: Axis I: Production of primary aluminium, covering the fields such as alumina refining, aluminum smelting, carbon anodes, and waste management, Axis II: Fabrication and applications of aluminium, covering the downstream of the aluminium value chain; i.e. alloying, concept and design, new applications and recycling. With strong synergy between the members and solid relationship with industry and governmental agencies the Center becomes an important player in R&D and training in the field of aluminium in Canada. Thanks to the contribution of FRQNT (*Fond de Recherche Nature et Technologies du Quebec* [18]), the Center creates a synergy between researchers from university and industry, resulting in a wide range of research projects with substantial research budget of 10 MCAD/a.

The policy of REGAL is based on creation of a synergy to enhance collaboration between university researchers and industrial partners from the aluminium sector. This is achieved by reducing or eliminating the administrative barriers between university researchers and encouraging them to collaborate by sharing the major research infrastructure, by enhancing the interactions between students, by supporting the early-stage innovative ideas, and by facilitating the international interactions of its members.

One of the indications for success of the Center, which is regularly monitored, is the rate of collaboration between the members. The collaboration is essentially defined by co-direction of the graduate students, where the principal supervisor is a regular member of REGAL and the co-supervisor is another professor or an industrial researcher. The projects with two or more co-supervisors are prioritized for financial support. The main objective of this parameter is to enhance the multidisciplinary research since the expertise of the co-supervisor often complements that of the supervisor. The co-supervision of an industrial member significantly increases the level of involvement of the industry in the collaborative research.

REGAL also initiated a platform for sharing all major research instruments and tools. Each university, being more specialized in a specific field, is equipped with certain type of major research tools, which are not necessarily available in other universities. Being a member of the Center gives the right to the member to have access to the tools of all other universities with the same internal service cost. As the public grants to purchase major research tools are quite competitive, the members can be unified to apply for one major grant, thus better justifying the need for the tool and increasing the chance of success. Furthermore, having access to these instruments prevents the redundancy and gives the opportunity to the members to purchase different types of tools, thus significantly increasing the diversity of the research infrastructure. Such a diversified research infrastructure enhances the complementarity with the industrial partner's facilities, allows high-quality research, and increases the chance of success for a UI research project.

REGAL members believe on collective learning and the positive effect of learning environment on motivating the young scientists. In this regard, all REGAL students are gathered, once a year, in an event entitled "REGAL Student Day-JER" (JER stands for *Journée des Étudiants du REGAL*). In this event, students from 6 universities present a poster, resuming their research project. One student from each university is selected for an oral presentation. Typically, 70 posters and 6 presentations are delivered during this event. Students, researchers and industrial delegates spend a whole day together and create their own scientific network. The personal contacts enhance further future interactions. Almost all Al-related industries of the province participate in this event, attend the student conferences and poster sessions, and challenge them. The JER is an ideal place for the industrial delegates to evaluate the potential candidates for their imminent positions. The posters and presentations are gathered in a document, edited and published in the form of "*Encyclopedia of Research on Aluminium in Quebec* [19]". This document gives a quite good perspective of research activities in the province of Quebec and reveals the typical challenges and the tendency of the industry. An additional "intensive training day" is also organized together with JER where specialized and complementary courses are delivered to all REGAL students and industrial engineers. A great majority of the instructors are chosen among REGAL members (academia and industrial). Such complementary training activities are possible thanks to the critical mass of the Center and its multidisciplinary and multi-institutional character.

The Center collaborates with AluQuébec [20], an Industrial Cluster on Aluminium created and supported by the Québec Government, and its center of expertise (CeAl [21]) to enhance the synergy between universities and the companies active in the Quebec aluminium industry. CeAl's mission is to collect, produce and disseminate the available knowledge of aluminum processing. Its mandate is to encourage and facilitate the use of aluminum. A special attention is payed for offering information and technical support to the small and medium-sized businesses with limited R&D capabilities. REGAL would play in important role in supporting CeAl in terms of creating specialized courses for industry, technical Webinars, scientific forums, and establishing a database of different expertise and research capabilities available for the industry.

REGAL is also active in collaborating with internationally recognized researchers and institutes in the field of aluminium. This collaboration usually takes place in the form of exchange of graduate students or researchers. In 2018, REGAL joined with Norwegian University of Science and Technology (NTNU) and SINTEF to create a platform of collaboration and student exchange. The imitative is fully supported by the Norwegian government in the framework of *Norwegian-Canadian Partnership in Research and Education in Primary Production of Aluminium*. Students and researchers from both sides can spend part of their research time (up to 6 months) in the partner's facilities to conduct a new research or complement their ongoing work. Apart from the technical benefits, this exchange platform allows interaction of different research cultures thus enhancing collective and mutual learning.

Since its creation, REGAL significantly contributed to the HQP training and knowledge transfer to aluminium industry. 270 graduate students and postdoctoral fellows are currently working on different Al-related projects. The average annual rate of graduation is about 55 HQP, who enter into the marketplace. Due to the multidisciplinary character of the Center and the multiple interactions between students and industrial partners, the graduated HQP have a broad knowledge on the aluminium industry while being specialized in their own specific field. The principal knowledge dissemination path for REGAL members is publishing their work in scientific journals and conferences. In average, 275 manuscripts are published by the REGAL members annually. About half of the publications are co-authored by at least two REGAL members and, in 86 % of them a student is the principal co-author. Although most of the research results are published, the industrial partners take also advantage of the unpublished research outcome, generated in the course of the collaborative projects, and integrate them in their process. REGAL also contributes in technology transfer via patenting and licensing when a technology has reached a mature state. The average mature technology transfer is about 5 per year.

As successful partnerships on the primary production of aluminium, the long-term collaborations of REGAL researchers with large firms such as Alcoa, Rio Tinto, and Aluminerie Alouette can be cited. Here we present, as an example, some more details about Alcoa partnership with REGAL researchers.

Alcoa is collaborating with a team of REGAL researchers for more than 11 years. The university team is composed of several professors and research staff with diversified expertise, i.e. materials science, advanced numerical modeling, multivariate analysis, heat and energy management and fluid mechanics. The overall objective of the program is to increase the energy efficiency and to reduce the environmental footprint of the process. Both experimental and numerical approaches are used to better understand the material/process relationships, to provide robust numerical tools for further optimization of the process, and to develop advanced tools for online quality control of the process. In the course of this program, 40 HQP were trained and graduated and 15 others are currently pursuing their education. Three scientists from Alcoa are intimately involved in the whole training process, from definition of the objectives and methodology to data analysis and results dissemination. Interestingly, a few of these Alcoa scientists are the HQP having been graduated from the same UI collaboration program (a non-measured advantage of the collaboration). The knowledge is naturally transferred to the partner by their involvement in all steps of the projects and the monthly progress meetings. Two bi-annual meetings are held each year while a number of other scientists and engineers from Alcoa participate in a one-day event. All students present their work, either in the form of poster or an oral presentation, and are challenged by the Alcoa people. The key for the success of the collaborative program is the high level of involvement of Alcoa people in the research projects where they can define the targets of each project and follow its progress. Such a high-level involvement helps mutual understanding of the capabilities and the limitations of both parties and adjusting the expectations, accordingly.

6. Conclusion

As the managers of university-industry collaboration projects, the authors can make the following conclusions, based on their observations and the indicators of performance. These conclusions support most of the observations already noticed in the literature.

- A UI collaboration would be more efficient and sustainable when both university and industrial researchers understand their goals and respect them. The goals should not be unilateral, rather they must satisfy the expectations of both parties. That is, the prime goal of the university is to train highly-qualified people through a project-based learning and that of the industry is to take advantage of the innovation capability of the university and to integrate it into their process.

- The objectives of a UI project must be set in a way to cover both fundamental and practical aspects of the technology. The former being publishable immediately and the latter being kept confidential for a while and used by the firm.

- UI collaboration is more efficient when the firm has an *Open Innovation* policy with a high-level of involvement in all steps of a research project and when the university team is recognized as a worldwide expert cluster in the collaboration field.

- The university team or the research center is more productive when it is multidisciplinary, capable of addressing all aspects of the technology simultaneously.

- The critical mass of the university team or the research center is an important factor enhancing the interaction of students, promoting collaborative learning process, and organizing complementary training sessions.

- The long-term collaborations with a firm result in the development of the specific know-how by the university staff related to the firm's requirements, making the training process more attractive and the communication and knowledge transfer more efficient.

- The benefits of the UI collaboration project should not be limited only to the measurable parameters, but the non-measured parameters should also be taken into the account.

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