Could open science stimulate industry partnerships in Chemical Engineering university research?

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Abstract
Open science means sharing all information in the research process as early as possible and making the output available without restriction on use. In the most expansive definition of open science, this includes sharing early-stage inventions that could be the subject of patent applications. We illustrate how this expansive open science definition has attracted pharmaceutical companies to partner with universities to tackle big problems in biomedicine. We propose that by applying this framework to engineering, it will also encourage industry to work collaboratively with researchers in academia to tackle some of our big problems: climate change, energy sustainability, food security, and water quality and quantity. However, there are misgivings or misconceptions about adopting open science in engineering. This article explores some of the barriers to open science in academia in general, and specifically as applied to university-based research in Chemical Engineering.

KEYWORDS
circular economy, intellectual property, open science, research impact, sustainability

1 | PROBLEM STATEMENT

The hardest technical problems that engineers tackle, such as climate change, energy sustainability, food security, and water quality and quantity, cannot be solved without partnerships among universities, governments, and industry. These solutions must also be global because low and middle income countries are particularly affected. In this article, we ask the question of whether the current and accepted framework for engineering research at Canadian universities is adequately structured to meet these challenges, and whether we should explore alternatives. We focus particularly on industry partnerships, knowledge translation, and commercialization, because these areas are central to creating societal impact from our work.

2 | BACKGROUND

Partnerships with industry are essential to tackle real-world problems. Industry brings expertise and funding, and provides critical knowledge relating to logistics, scale-up, and technical barriers to implementation of new inventions. Industry partnerships are also encouraged by universities and governments. Indeed, one of the Ontario government’s 10 new metrics of success for the province’s universities is the level of industry funding.

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Yet, the increased emphasis on industry partnerships and private-sector funding in the university system raises questions about alignment with the academic mission. In the University of Toronto’s Statement of Institutional Purposes,[1] the university expresses that its primary commitment is to the principles of equal opportunity, equity, and justice, and collaborations with industry are mentioned only once—as a means to contribute to the university’s research aims. These possibly conflicting aims raise interesting questions for academic engineers. How do we best ensure that our partnerships with industry conform to our stated academic purpose?

To have real-world impact, it is also important to translate our knowledge into practice, and this often involves the private sector. While the greatest translational and economic impact of universities comes indirectly from our graduates entering the workforce, in recent decades there has been increased emphasis on creating more direct economic impact, including through spin-off companies. This emphasis has been supported both by government innovation policies emphasizing the value of intellectual property (IP), as well as by the new attention on university rankings, which use patents as a proxy metric for innovation. The prevailing narratives are that industry would not collaborate with universities without being able to secure some IP rights based on academic research and that university patents are needed to attract investment into our spin-off companies. As will be explained in more detail in this article, these contentions are not supported by strong evidence.

Government policies promote patenting in part to ensure a return on their investment in university research. Setting aside whether generating commercial returns should be our aim, although patenting university-based research may stimulate some domestic economic activity through the creation of spin-off companies, patenting also risks preventing the broader commercial application of the invention and its derivatives, and perhaps even greater economic growth. Indeed, in focusing on the few successful spin-offs that might have been enabled by a patent, we are perhaps ignoring the bigger picture.[2] Nearly all universities lose money protecting their IP, and the pathway to a patent, which requires secrecy and necessitates withholding data, ideas, and knowledge from peers, is counter to the academic mission. Indeed, by encouraging patents and IP, universities risk losing emphasis on nurturing students/their curiosity and on local community engagement. On balance, how do we ensure that our innovation policies at universities are truly serving the common good?

These issues are particularly relevant for chemical engineers, whose expertise is central to solving many of society’s big problems. Here, we argue that adopting an expansive open science view would not limit innovation, but would in fact accelerate research, attract more industry funding and perhaps even create more opportunities to spin-off companies while also better aligning with the public good mission of the university.

3 WHAT IS OPEN SCIENCE?

Open science encompasses many related terms, from open dissemination of data and publications, to openly sharing all research data and material in real time (Figure 1). Generically, open science is sharing all information in the research process, as early as possible, and making the output available without restriction on use. At the cutting edge, open science also involves diminishing or even eliminating the use of restrictive IP, such as patents.[3]

As reflected in the base of the pyramid in Figure 1, the most widely discussed component of open science relates to publishing in Open Access journals and removing paywalls to reading such articles. Open source is widely implemented in the context of computer software. Open data includes the use of pre-print servers such as arXiv, bioRxiv, and engRxiv and publicly accessible data repositories of all kinds (e.g., National Center for Biotechnology Information (NCBI), GitHub.com for software, Zenodo.org for research data, University of Toronto’s T-space, and many others).

Open innovation is a term that is applied to two or more organizations that collaborate to meet an objective, but are still free to file patents jointly and do not have to share the output broadly. Open collaboration, open lab notebooks and not filing for patents are the most extreme embodiments of the Open Movement.

3.1 Open science’s current focus is on academic output

The discussion of open science in academia is currently dominated by the publication system, and how and when publications and data should be made available to the public. In the academic environment, there is now broad
support for the idea that academic publications should be made available to the public early, even before publication (in pre-print archives) or, at minimum, immediately after publication.\cite{4} However, full implementation will require a re-think of the current publication system which is dominated by for-profit publishers and non-profit learned societies, both of whose income derives mostly from publication fees. In essence the debate is not whether academic publications should be made available immediately, but simply who pays for the real costs associated with publishing. The debate is further complicated by the fact that many of the for-profit publishers, whose business model is currently inconsistent with immediate open access, control some of the journals held in high esteem by academics, who in turn resist efforts by funders to mandate their publishing in Open Access journals. A new business model will undoubtedly emerge in the next few years, and in the meantime, making late versions of papers freely available on pre-print servers offers a temporary solution.

The other dominating issue relates to data availability and reusability. The concept of FAIR (findable, accessible, interoperable, and reusable) has emerged as a driving principle in this area.\cite{5} While there is now general support for the idea, there are few labs and universities that have the infrastructure and resources to make their data conform to these principles. Furthermore, no broad agreement exists as to which data are valuable enough to share. Providing training in data organization and management should be and is becoming a major focus of university libraries.

### 3.2 Our academic reward system is slowing progress toward open data and publications

One of the most significant obstacles to the aims of open science is the current incentive system for researchers. The academic system greatly rewards discovery, defined as the first to publish. Much less attention is given to those that do the detailed, foundational work that creates the building-blocks for big discoveries, to those that reproduce discoveries or correct incorrect discoveries, and to those that contribute knowledge outside the traditional academic venues. In fact, most traditional journals refuse to publish confirmatory studies. The fear of being scooped (having your research idea stolen) and the personal and professional rewards in being first cause many to be reticent to share their data, even after publication. This culture is exacerbated by the emphasis on bibliometrics and other publication metrics in promotion, hiring, and funding. Few of these structures truly recognize the value of open science or reward sharing.\cite{6} The aggregate result of these incentive systems is that research becomes about achieving higher metrics, such as publishing in journals with high impact factors, and not about widely disseminating scientific discoveries. This is most evident in early career researchers, who aim to publish in well-known journals to boost their reputation and advance their careers.\cite{6}

The concerns surrounding traditional metrics have become well known, and high-profile efforts have tried to address them, such as the San Francisco Declaration on Research Assessment (DORA). DORA signatories promise to assess research on its own merits and to end the use of Journal Impact Factors (JIF) in funding, hiring, and promotion decisions. DORA currently has 2105 organisational and 16 728 individual signatories.\cite{7}

The Canadian science and engineering communities have not been significant players in open science. The Canadian Tri-councils only signed DORA in 2019, and many Canadian universities have yet to sign.\cite{8} The United States and European governments have made significant commitments to data sharing over the years with databases such as NCBI (https://www.ncbi.nlm.nih.gov/) and EBI (European Bioinformatics Institute, https://www.ebi.ac.uk/) and the European Commission (EC) is pushing Plan S, a policy that will mandate that any publication funded by the EC must be open at time of publication.\cite{9} In contrast, the Canadian Tri-Council funding agencies mandated open access only in 2015,\cite{10} and they required only that any peer reviewed journal publications arising from full or partial agency support be freely accessible within 12 months, which is among the longest period of any country with an open science policy. Canada is now making more of a push toward open science, and the federal government released a Federal Roadmap for Open Science. However, this relates only to federal department research, and it is not clear how or if the government will ensure compliance or provide the resources for implementation.\cite{11}

### 4 Open Science, Industry, and Commercialization

Most of the important global problems must be tackled in partnership with end-users, often industry. These collaborations introduce complexity in balancing the interests of industry with academic freedom, and on how to share knowledge, future intellectual property rights, and any commercial benefit. These complexities are based on the premises that industry requires IP rights and that patents are important for the university’s mission. We argue that neither premise is strongly supported by the evidence. Indeed, the U.S. National Academies published a detailed
report highlighting the role of open science in broadening the impact of research, including changes in the business environment,[12] and Allen and Mehler articulate many benefits of open science to researchers, including early career researchers.[13]

Although this perspective is focused on university patenting, there is mounting evidence that patents in any context do not spur innovation,[14–16] and a strong case can be made that patents and trade secrets developed through public funding should not be allowed for any institution. Certainly, universities with mandates to promote social good should not accept private sector funding from companies whose aims are clearly antithetical to this mission, such as those that profit from activities known to negatively impact environmental and human health.

Here, we propose that adopting a more expansive view of open science, in which we partner with industry only on projects that eschew patents, will allow academic engineers to create greater social and economic impact.[17]

But first, we will outline common misconceptions of the importance of university patents to industry partnerships and innovation.

4.1 | Industry and other end-users require IP to collaborate

Conducting research in partnership with industry or other end-users is clearly beneficial, particularly in engineering. Funding mechanisms to leverage such partnerships are common. However, there is a misconception that a primary reason that industry seeks these collaborations is to obtain and protect IP. In fact, multiple surveys of research managers in industry rank IP rights as lower priority than either access to new ideas, know-how, and technologies, or tacit knowledge though direct interactions with researchers. In a survey of 355 firms participating in Engineering Research Centres (ERCs) in the US, only 15% reported that the ability to license inventions and/or software was the motivating factor in their decision to participate.[18] For many, access to talent was a key benefit in such partnerships.

Of course, if the university wishes to protect its IP in an industry partnership, then industry will insist on equal rights. Currently, all university and industry template partnerships agreements have clauses that deal with patenting and how IP will be shared. Given that this is the norm, it is natural for academics to assume that IP is the most important component of securing industry partnerships. But the inference that industry would not partner with a university without the right to secure IP rights developed at or with the university is an assumption that is not borne out by the evidence. Our own experience spanning dozens of research projects with many Canadian and multinational industry partners over the past 25 years agrees with the findings from US ERCs,[18], industry executives value our partnerships not for the potential IP, but for other reasons. The Montreal Neurological Institute declared itself an open science institute in 2016, eschewing patents, and almost immediately observed a marked increase in industry funding.[19]

4.2 | Governments require researchers to protect IP and to file patents

The Bayh-Dole act, which ceded IP rights from US federal funders to universities and is the international model for technology transfer, created the original impetus for universities to pursue ever-increasing numbers of patent filings. However, while Bayh-Dole places some obligations on universities to patent when inventions made with US federal funding are disclosed by their researchers, in practice university professors have broad discretion to determine whether an invention disclosure is warranted or whether their work is more suitable for the public domain. Similarly, in Canada, although federal or provincial laws do not require university researchers to patent, government innovation policies and university rankings emphasize patenting as a metric of innovation—this creates an incentive for universities to file for patents.[20] Accordingly, many universities have employment contracts that require employees to disclose to the university any potentially patentable invention. Documents produced by university technology transfer and commercialization offices (TTOs) emphasize the need to report and file invention disclosures for every new discovery.[20] Many academics believe that their universities enforce these policies or that they will be in breach of contact if they do not comply. Patenting has become ingrained in researchers’ way of thinking.[20] The reality is that TTOs at universities are highly supportive of open science, and the requirement to disclose inventions has never been enforced against professors for electing to publish instead of pursuing IP. Publishing papers and reports, presenting seminars and workshops at conferences, and teaching remain the primary means of dissemination of university research.

4.3 | University patents are required to start a company from university research

Universities create the most local economic impact passively through their graduates. In recent years, government have been promoting the concept of universities as
more active participants in the innovation process, consequently focusing on technology start-ups as a visible consequence. The start-up innovation narrative classically involves a patented university invention, venture capital investment, and a new spin-off company. While this story can be true, and should be celebrated, it is far from the norm. While it is also true that start-ups with a patent have better growth potential, start-ups do not require a university-based patent. In fact, in a study of almost 2000 professors in the US who had started a business, two thirds launched the company without a patent. In Canada at the Montreal Neurological Institute (MNI), of 15 spin-off companies, only seven were formed around a foundational patent, and of these only one reported that the patent was a key part of their ongoing business (see section 5 for more on the MNI).

It is critically important at this point to distinguish patenting strategies for research done at a university (whether in collaboration with a company or not) from research done entirely within a company. Universities, especially public universities, patent as one way to promote technology transfer, and licensing income is merely a potential consequence, not the driver. Patents are not essential to the university’s mission despite the common view that they work as a currency in the marketplace of universities. In industry, patents can be used to justify large financial investments to advance early inventions to market. But more often, they serve as bargaining tools in negotiations or as a proxy measure of corporate innovation to investors or shareholders, akin to how the number of patents is used as a metric in ranking universities in innovation. Patenting also correlates with company growth; small and medium sized enterprises (SMEs) that obtain patents are more likely to grow into larger companies; SMEs with patents are also four times more likely to export their product.

4.4 Patents are easy to file

Academics who have been through the patent process almost universally agree that it was more time-consuming than imagined, especially if the invention resulted from a collaboration. In some cases, decisions about inventorship can also be disputed and cause distress. Furthermore, patents need to be filed in multiple jurisdictions and filing, maintenance, and litigation fees can quickly add up. Initial patent applications can cost from $5000–15 000 in Canada, in addition to similar costs incurred to file in the US and Europe, and this does not include maintenance fees and patent litigation. The latter is a tremendous time and money sink not factored into decisions to patent.

And what about the returns? Ninety-seven percent of patents do not recoup the cost of filing them, and in terms of university patenting, nearly all technology transfer offices lose money for the university. To be fair, this analysis does not account for the economic impact of the start-up companies that were based on university patents, but it also does not factor in the hidden costs associated with the intention to patent, for instance the requirement for ancillary legal contracts such as material transfer agreements (MTAs).

MTAs are contracts that provide legal provenance over materials transferred between legally distinct institutions. Canadian universities and hospitals execute over 5000 MTAs each year. On average, they can take months to complete. The economic cost to the research system in time and lost opportunity is not inconsequential. Five weeks for each of 5000 MTAs inserts the equivalent of ~25 000 weeks (480 years!) of delay to research and translation annually.

4.5 Open science will not benefit Canadians

Government investments in university research are correlated with growth in the knowledge industries, and there is an idea that by not protecting the university’s IP, the benefits would flow to other countries. Setting aside arguments of social responsibility as one of the wealthiest nations on earth, we instead focus on economic arguments to demonstrate the strengths of following open science principles. It is difficult to quantify the local economic benefits resulting from licensing activity, as compared to the impact from general flow of people and knowledge from the university to the local environment. Though one may argue that by creating an open science cluster with industry, there will be more local economic spin-offs. However, what is certain is that patenting and licensing a technology to a local start-up does not in any way guarantee that the technology will develop and stay in Canada, or ensure the creation of high-quality jobs and tax revenue in Canada, since many successful Canadian IP-based start-ups are bought by foreign companies.

5 Real World Evidence: Open Science Can Attract Industry Partners

We imagine Canadian academia working collaboratively with industry partners to tackle important problems, and to structure these collaborations according to open science principles in which all the output will be placed into
the public domain, without restriction on use and patent-free. And while this might seem quixotic, there are many Canadian projects that are already implementing this strategy. Specific examples familiar to the authors are illustrated below; we are certain that others exist, and we would love to hear from groups espousing and practising open science.

The Structural Genomics Consortium (SGC), the MNI, and Meds 4 Kids (M4K Pharma), all with strong ties to the pharmaceutical sector, have explicitly embraced open science with a mission to accelerate medical discovery or to price medicines more affordably, and with a commitment not to patent any of their research. SGC and the MNI primarily focus on the discovery process of medical research, while M4K aims to complete the entire research and development process, from early drug discovery to a final commercial product. These initiatives, which practice open science in the pharmaceutical sector, arguably the sector that is most concerned with IP, are a model for other disciplines. Their efforts include other open science innovations, including open lab notebooks and bespoken collaboration agreements that facilitate data sharing.

In engineering, there are also long-standing academic-industry research partnerships that have followed open science principles without explicitly stating so in their vision or mission. The Pulp and Paper Centre (PPC) at the University of Toronto is a prime example. The PPC has not filed for a patent in 20 years, but over this period has been funded continuously by over 20 companies in that sector.

Why do the companies continue to support the PPC? The PPC attracts industry because together they work on important problems that encompass fundamental principles and are common to all companies. The PPC engages the industry partners at every step, working side-by-side, providing transparency and thus ensuring that the research is accurate and trustworthy. Each year 30–50 students are closely engaged with their partners in industry, including frequent mill visits, culminating in an annual 3-day November meeting which has consistently attracted over 20 companies for decades, irrespective of economic downturns. There are four primary reasons these companies continue returning to the PPC: (a) to get basic and fundamental understanding of operational and technical problems they are facing; (b) to distribute the cost of addressing problems together, through a consortium; (c) to share industrial experiences and to learn from one another; and (d) to meet students. Notably, IP ownership through patents is not a priority.

BioZone, which is a Bioscience and Bioengineering Research Centre within the Chemical Engineering Department at the University of Toronto, again illustrates how several academic-industry partnerships have been consistent with open science principles. BioZone comprises about nine professors and over 100 students and research staff with a wide range of expertise. They work in an open, pooled space, sharing all equipment, encouraging wide-ranging and interdisciplinary discussions. Officially inaugurated in 2011, the driving force behind BioZone was to find a way to effectively capitalize on the tremendous advances in genomic science to develop biotechnologies with reduced energy and carbon footprints, consistent with a circular economy and environmental sustainability.

Like many engineering groups, BioZone works closely with industry. Over the past decade, more than 30 industry partners have contributed $2.5 million in funding to support collaborative projects. The vast majority of the research has been simply published and disseminated through presentations at project meetings and relatively few patent applications have been pursued—none with industry. But we’d like to do better. We have now embarked on a program to explore the various levels of open science principles within BioZone. Our vision is to create an environment conducive to working with industry on global problems and our idea is that by committing to open science principles we might more easily collaborate with leading industry scientists and also more effectively translate research into practice. The first step in this process is funded through a new Natural Science and Engineering Research Council (NSERC) CREATE training grant. Using this funding, we will develop data fluency, entrepreneurship, communication, and leadership skills through the lens of open science. Together with our students and colleagues in law, we will attempt to define metrics for evaluating true impact in engineering. We held our first workshop on Open Access and Publishing in January 2020 and plan a second workshop on Open Science and Innovation that was temporarily postponed due to the COVID-19 pandemic.

As we embark on our open science project, we wished to get insight into the views of our constituents. Accordingly, over the summer of 2020, three law students
worked together with students from Chemical Engineering to explore perceptions of open science within BioZone. They conducted a survey to evaluate and try to understand perceptions of open science among our members. The survey obtained 67 responses from 10 principal investigators, 27 staff members, and 30 students. Open science was perceived very positively among all who took the survey.

Research Efficiency and Increased Transparency were the most frequently selected reasons for adopting open science principles (Figure 2). In this case, both received over 80% of all survey responders’ votes, with Broader Adoption of Inventions coming in as a close third.

Our BioZone survey also confirmed that some researchers are afraid of being scooped, particularly if they practice open science. This fear is generally pervasive among academic researchers, and is in large part a consequence of the same misplaced incentive structures rewarding first report of a discovery in a high impact factor journal and devaluing high quality and confirmatory results. But consider for a moment if research were truly open—we would then know what others are doing and thus be less likely to be in a position to get scooped and more likely to collaborate effectively. Open science may actually reduce rather than exacerbate this concern.

To this end, we at BioZone are looking to try to do things a little differently by adopting open science principles, particularly with respect to publications, data deposition, and not filing for patents. The sudden and urgent need to share research brought to light with the COVID-19 pandemic might be the push that we need to realize that open science is actually the best approach to solve major urgent challenges we are facing, including climate change and sustainability. An open science consortium is being considered around a community of practice in anaerobic digestion (AD), bringing industrial, municipal, government, and academic partners together to bridge fundamental knowledge of the AD microbiome with process performance, and to expand the applications of the technology for Canada. Other consortia are also being considered focused on CO2 fixation and the circular economy. Internationally, examples of open science efforts are emerging too. Aarhus University in Denmark has open projects in engineering on smart polymer materials (spoman-os.org) and in the life sciences (Open Discovery Innovation Network; ODIN[30]) that are being carried out with industry without a framework of patents, the latter inspired in part by the SGC. Eindhoven University of Technology in the Netherlands is another example of an open community sharing code and data (https://osceindhoven.github.io/). We would love to hear from other groups who are interested in signing up to open science as well, so that perhaps together we can develop and share best practices for effectively translating academic research to solve big problems.

6 | FINAL COMMENTS

Given that the scientific enterprise is built around exchanging ideas and concepts, in no field of human endeavour does placing any barriers to the flow of
knowledge and exchange of ideas accelerate innovation. Simply, for maximum impact, science and engineering should not be encumbered. A process systems engineering analogy is that an addition of a constraint in an optimization problem can never improve the objective function. Similarly, the introduction of delays in publishing information or creation of knowledge silos can only slow down the process of innovation. Hence, we argue that open science should be embraced and traditional perspectives that reward restrictive patenting should place more value on open science.

The open movement began with a mandate for access to journal articles where pre-prints were available instantly. The 2018 report from the National Academies of Sciences, Engineering, and Medicine is a cogent summary of the barriers to open science and evidence for the need for change. This report states: “The reader is invited to imagine a world of complete open publication, where all steps of the research process are findable, accessible, interoperable, and reusable (FAIR).”[12]

Open science in the broadest sense means data sharing before and during the research process and eliminating the use of restrictive protection of IP, such as patents. In this perspective, we have tried to objectively document the most common misconceptions about IP and university-based research. Looking at the larger picture, Canada, compared to peer nations, is struggling with respect to innovation. For decades, our nation’s private sector in aggregate spends less in research and development (R&D) as a fraction of GDP than those of most Organisation for Economic Co-operation and Development (OECD) nations.[31] By contrast, in comparison to peer nations, Canada’s investment in higher education research as a fraction of GDP is quite high. This disconnect has spurred new partnership initiatives by provincial and federal governments such as the superclusters program.[32] Perhaps there is a unique opportunity, against this backdrop, to rethink engineering innovation and more fully engage Canadian companies by embracing open science.

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