Additive Manufacturing Consultation Report

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1. Background

Additive manufacturing (AM) is now transforming innovation in various industrial fields. This ground-breaking manufacturing class of processes allows to rethink the conventional way things are made from the early design steps and prototyping to the final fabrication of finished parts. AM is being adopted at increasing rates in several fields such as aerospace, automotive, and oil and gas part manufacturing. Each of these fields take advantage of new design opportunities, shortened prototyping time and easier supply chain management of complex and custom parts. With an actual market value of $5B, AM is predicted to grow up to $20B in 2020 (25% CAGR over five years). With large players across diverse industries such as GE, Michelin, Boeing, United Technologies and Zimmer Biomet investing massively in these technologies, the competitive landscape is being irreversibly transformed.

Additive manufacturing is currently seeing is greatest successes in prototyping and tool-making for plastic 3D printing, while metal AM is excelling at mould making, customer-specific custom part manufacturing and low-volume production of serial components. Due to the wide array of possible uses for this new class of technology, and the rapid changing nature of digital-to-physical workflows, Creadditive has been called upon to produce a work plan and tour Alberta with Innotech Alberta (IA) to review the state of technology adoption, as well as the short- and long-term opportunities for further adoption of these technologies.

As such, Tonya Wolfe has prepared a schedule for visits across Alberta which spanned the week of Nov. 26, 2018 in the following cities:

- Nov. 26: Calgary
- Nov. 27: Red Deer
- Nov. 28: Edmonton
- Nov. 29: Fort McMurray
- Nov. 30: Grande Prairie

1.1. Mandate

The mandate undertaken by Creadditive for this AM Evaluation tour of Alberta included:

- Evaluation of the potential of digital manufacturing and AM for the companies selected by IA in the context of the AM Evaluation visits;
- To build and present high-level business cases for AM, and more specifically the four broad classes of metal AM technologies (Selective Laser Melting, Directed Energy Deposition, Cold Spray AM and Sintering technologies)
- To assess the possibilities for the adoption of mature plastic AM processes to increase the efficiency and cost-effectiveness of prototyping, tooling and replacement part production workflows using Fused Deposition Modeling, Stereolithography and Selective Laser Sintering for polymers.
- To evaluate the possibility of using in-situ repair AM techniques such as Cold Spray and Directed Energy Deposition to repair, repurpose or refurbish worn and damaged components to reduce equipment downtime and cut the time required for unproductive or maintenance operations.
- To appraise the suitability of using 3D scanning and digitization techniques for the reverse engineering of complex components and hard-to-obtain spare parts (such as discontinued or long-lead-time parts).

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- To produce a report outlining the discussions had with the companies and entities met during the tour, covering all aspects of the proposed mandate, and offering an overview of the current situation and proposed ideas for the efficient and cost-effective adoption of the technologies discussed.

1.2. General Objectives

The goal of the AM evaluation visits performed by Creadditive with Innotech Alberta (IA) is to review the state of additive manufacturing technology adoption, as well as the short- and long-term opportunities for further adoption or integration of these technologies in current workflows. The focus of the evaluation visits are the opportunities which are specific to each type of AM technology, for example: visual prototypes, jigs, fixtures and tooling for plastic AM, moulds and short-run production for metal AM, etc.

In addition to these areas of focus, the new possibilities presented by these technologies for the in-situ repair or refurbishment of components will be explored, as well as the required expertise in 3D scanning and digitization for the reverse engineering of repairable or hard-to-obtain parts.

1.3. Specific Outcomes

The specific outcomes that are desired at the end of this exercise can be described as follows:

- For companies who are unfamiliar with AM or who do not currently have a plan to integrate these technologies in their workflow, an introduction to AM and its possibilities to reduce costs and lead times or to increase the functional value of parts through redesign will be presented;
- For companies who are currently planning to integrate AM in their workflows, or companies who already use AM solutions for certain workflows, a methodology for preparing a solid business case for the implementation of an AM solution or for sub-contracting AM solutions will be presented, with a focus on the specific challenges faced by the companies or their industry;
- For companies who are veterans in the use or commissioning of AM solutions in their workflows, the possibilities offered by advanced AM applications will be presented, as well as methods to further leverage the solutions or investments which are currently in place for these companies;
- For IA representatives in each community visited, the integration of AM-specific resources and expertise into their core service offering to their clients by educating them on the challenges and success stories of AM, and the presentation of the various types of resources available to them in Canada.

1.4. Industry 4.0 Context

The expression "Industry 4.0" has been first developed in Germany, to designate a new era in manufacturing which is focused on the integration of cyber information systems and physical production systems. Including such areas as the "Internet-of-Things" (connected objects and manufacturing tools), advanced automation, cloud-based Big Data processing, artificial intelligence and digital manufacturing, Industry 4.0 is thought-of as being the next step in the evolution of manufacturing processes to include the interactions between objects and manufacturing tools using digital systems that can analyse and relay information in real time, faster than human intervention would allow.

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Examples of Industry 4.0 applications include the control and planning of maintenance operation by computers from large data sets obtained from instrumenting the manufacturing tools. By measuring operating pressure, temperature, vibrations, etc. a computer is able to predict when equipment is likely to fail, and to adapt the maintenance schedule to minimize the impact of these operations. Another example is the digital supply chain, where items are produced using advanced manufacturing techniques like 3D printing in a "pull" type supply chain, where human interaction is minimal. Web user interfaces allow customer to submit product requests (purchases) which are automatically assigned to a production equipment, where a computer uses digital files to program the manufacturing operation according to the nature and number of parts being manufactured. Parts are then made and possibly even packed and shipped automatically, with only minimal human interaction or supervision.

Additive manufacturing is considered an integral part of Industry 4.0, as it is well suited to the digital-physical synergy which is characteristic of this new manufacturing paradigm. Indeed, the digital files required for AM can be computer-processed for direct production readiness, and once the AM equipment is calibrated and properly set-up, manual intervention is not usually necessary during processing. Post-processing operations, such as part unloading and finishing, can also be automated as is evident in many of the new commercial AM solutions which are "production cell" based: a cell would comprise several stations which perform specific, sequential and automated functions. Such cells usually transcend AM alone, and include connected robotic equipment, which can also take advantage of Big Data analytics, Artificial Intelligence, or internet-connected functions to form an advanced manufacturing operation.

1.5. Advanced Manufacturing in Canada

Advanced manufacturing has not yet found widespread acceptance in Canada. Although we belong in one of the most industrialized countries in the world, and Canada is a significant player in the global manufacturing market, Canada is lagging in its adoption of digital manufacturing and automation technologies. There are many reasons for this lag:

- Lower capital availability than in the USA and industrialized Europe;
- Until recently, the manufacturing sector seemed to be a low priority for the various levels of Government in Canada, which is reflected in the financial incentives and measures that affect this sector;
- The strength of labour movements which are resistant to automation due to concerns about job losses;
- The apprehensions regarding the adoption of emergent technologies in general vs. the use of "tried-and-true" solutions.

There are many factors which should be considered as advantages for Canada to adopt the new technologies or systems that comprise Industry 4.0:

- These technologies are better suited to distributed manufacturing models, where the production of goods is not centralized in a specific location, but where smaller, local factories can run cost-efficiently;
- Distributed manufacturing and re-aligned supply chains can allow for less transportation of materials, as material is ordered on an as-needed basis, requiring fewer intermediate steps (and as such less total distance traveled for finished assemblies);

- The presence of a highly skilled domestic labour force across the country, and of attractive living conditions for skilled talent from immigration;
- Well established research capabilities in Universities and Colleges, as well as government-run or subsidized research laboratories containing state-of-the-art equipment and expertise;
- The proximity of the largest national economy south of the border, where Canada has a comparatively weaker currency and the existence of several free trade agreements with other highly industrialized countries (CETA, USMCA, CPTPP, etc.);
- Industry Canada (ISED) lists less than 100 Canadian companies currently engaged in offering 3D printing solutions on its website.

1.6. Advanced Manufacturing Elsewhere in North America and Europe

Adoption of Industry 4.0 is most prevalent in Germany and Europe, where it was first developed. For the past decade, European nations have consolidated their productivity gains by leveraging technology to ensure that they remain strong contenders in the manufacturing world, even as China and the USA are gaining on the productivity front due to increased adoption of automation and digital manufacturing technologies. Although AM equipment and materials are a small part of the world GDP (accounting for approximately 10B$ in 2018, worldwide) it has shown year-on-year growth of 25% (Compounded Annual Growth Rate, CAGR) for the past 5 years. Although there are no ways of estimating the current market value of AM produced components (in part due to reporting deficiencies, e.g. there are no NAICS code for AM-produced goods), it is expected to at least mirror the growth in equipment.

A few statistics concerning the monetary value of the manufacturing sector in the world's economic superpowers vs Canada show a striking portrait of the situation:

- 200B$ GDP in Canada from Manufacturing (10% of GDP and shrinking)
- 800B$ GDP in Germany from Manufacturing (22% of GDP and growing)
- 2,125B$ GDP in USA from Manufacturing (12% of GDP and stable)
- 3,660B$ GDP in China from Manufacturing (30% of GDP and growing)

This value creation by other countries' investments in manufacturing is expected to play a significant role in creating high quality, well paid employment opportunities and is believed to be a significant contributor to the high standard of living in Europe, and to the rise of China's standard of living for its middle class over the past 50 years.

In the same way, investment in AM platforms, and more specifically investment in the development of AM platforms such as those that are seen in Europe (EOS - Germany, Renishaw – UK, Additive Industries – Netherlands), in the USA (GE Additive, Markforged, Desktop Metal) and in China (copycat brands of industrial equipment) will most likely translate into a further advantage when it comes to local adoption of the technology and further growth of the manufacturing sector from AM, which could quickly become difficult to catch up to for a country like Canada.

2. Consultation Methodology

2.1. Approach

Sessions were planned by IA representatives, and were attended by both Creadditive and IA. The format for each city was decided by the local IA representative who best understood the needs of the clientele in their region.

Individual sessions with selected companies were performed on-site at the company's main manufacturing location, to explore the individual need of companies that are more familiar with AM and are in the process of implementing an AM strategy or application. These visits allowed a better understanding of the general state of manufacturing in the target company, including the possibility to evaluate other technology adoption, such as automation, data collection and processing. This format was preferred in Calgary, Red Deer, Edmonton and Fort McMurray.

Group education and discussion sessions with selected companies were also planned at IA's local office in Grande Prairie. The goal of these education and discussion sessions was to introduce companies to the various applications where AM has found success previously, and to see what the local needs for AM are when reflecting upon these areas of successful implementation.

In total, 23 companies were interviewed using the processes described previously, with 13 in-person visits on-site, 2 conference calls and 8 companies participating in the roundtable education and discussion session.

2.2. Data Collection and Treatment

The information collected in this report has been obtained by the consultant through the process described in Section 2.1 and has been discussed with the Client's representative throughout the report writing process. The report represents the consultant's informed opinion of the situation based on these meetings and discussions and should be considered as such. The consultant offers no warranty or guarantee as to the accurateness or completeness of the responses or opinions provided by the consulted 3rd parties, which are relayed and commented herein.

This report does not provide any information on specific companies' forays into AM, as the discussions had with the companies could contain privileged or confidential information. As such, only summaries of discussions based on the perceived typical response are reported, to preserve this confidentiality.

Finally, since only a limited number of interviews could be conducted during the AM visits, it is best to assume that this sample cannot perfectly represent Alberta's manufacturing sector as a whole but should give the reader an indication as to the state of awareness and adoption of the technology class discussed.

3. General Visit Observations and Discussion

3.1. Alberta's Technological Readiness

From the visits and discussions that were had during the AM tour, it was possible to sample Alberta's technological readiness, or its capacity to accept change stemming from the adoption of new technologies to increase performance and productivity. It is the consultant's view that in this respect, Alberta resembles Quebec and Ontario in its ability and willingness to adopt Industry 4.0 technologies, with AM in particular. Although the actual adoption rate seems to be lagging, this is believed to be mainly due to a lag in adoption of AM for the oil-and-gas industry, which is Alberta's main vertical market, compared to Quebec and Ontario who have a stronger showing in industries which were early adopters of this technology: medical device manufacturers and aeronautic suppliers.

Indeed, when it comes to the adoption of plastic component AM, Alberta's portrait in the industrial manufacturing sphere resembles that of other provinces, as the technology was found to be mainly used for basic applications such as prototyping and to produce jigs, fixtures and tools. Many small run and/or low dollar value applications were discussed as being implemented at companies familiar with AM, especially to replace expensive plastic injection moulded prototypes by cheaper and faster to produce plastic 3D printed alternatives. This allows Albertan manufacturers to iterate through the design cycle faster and at a lower cost and ensures the competitiveness of Alberta's design and build operations. In many cases, the equipment used are hobby or light commercial grade equipment (e.g.: Formlabs, Makerbot, etc.) which are relatively inexpensive and are easy to use. In other cases, the solution is curently sub-contracted to out-of-province service providers, which own the equipment and possess the expertise to operate higher-end industrial equipment, with no future plans to bring production in-house.

No current applications of 3D printed engineered plastics or composites were found with the companies visited (examples of engineered solutions using application-specific plastic grades would include the production of temporary tooling for molds and dies, as well as mass-customization of products to individual customers or for specific requirements). These types of applications are important value drivers of AM, as they provide the most value as well as the best Return-On-Investment (ROI) to the product and can best leverage AM expertise for the design of new or alternative product lines.

With respect to metal AM, adoption has not yet begun in Alberta, with the exception of discrete technology experimentations by the largest companies visited, who are currently investigating different AM processes with out-of-province service providers. This is partly due to the lack of awareness of the different types of metal AM processes and their different advantages and limitations, and partly due to fear of potential regulatory barriers by various standardization bodies such as the American Petroleum Institute (API) or the Alberta Boilers Safety Association (ABSA).

In terms of broader digital or advanced manufacturing spheres of activity, Alberta is showing good adoption of CNC technology and is beginning to embrace automation of certain repetitive and low-human-value tasks such as loading and unloading materials from equipment or in storage. The adoption is not as widespread as it is elsewhere in the world, where Europe in general is excelling, but it is not for a lack of potential. Current capital shortage and the recent difficult economic situation in Alberta seem to have slowed the adoption of such technologies. There were no indications of technology adoption for some of the branches of Industry 4.0, namely the use of artificial intelligence, big data, distributed cloud computing solutions or IOT from the visits that were conducted.

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Digital literacy, or the capacity to use digital files for information transfer, design and analysis was found during the visits to be a challenge for smaller manufacturing operations but in general, but a higher level of literacy is encountered vs. the consultant's experience with similar size Quebec and Ontario manufacturing companies. This has most likely been spurred forward by the massive adoption in CNC equipment, which is prevalent in the medium and larger sized companies that were visited. This digital literacy is a necessary first step to the adoption of advanced manufacturing technologies, as automated equipment needs digital information to process its tasks, and human interaction in the form of programming, converting and verifying this data is ubiquitous.

Finally, Alberta's education and research institutions are well placed to help companies adopt and derive value from digital technologies, from their ability to provide education about the technologies to the possibility of using government subsidized equipment to create proof-of-concept prototypes which de-risk the elaboration of a business cases for industry. Furthermore, the Universities' and Colleges' role of training tomorrow's work force in advanced manufacturing is enabled by the equipment access that is granted to students, and the various technology focused programs that are currently in place. Although the equipment availability is currently sufficient, it would be important for Government to continue to invest in AM technology application development, and to support the acquisition of key pieces of equipment to continue growth and reduce the technology gap that still exists between the average company and international leaders in their fields.

3.2. Province-wide Interest and Participation

Across the various locations visited, a bird's-eye-view awareness of AM technologies was found to be present. Most organisations were aware of AM, and of its disruptive nature with respect to traditional manufacturing practices but were not versed in the technology's specific benefits or limitations, other than its capability to provide economic value for short run manufacturing and prototyping of plastic parts. Some organisations had investigated metal additive manufacturing, but in most cases the consensus seems to be that this technology is too expensive and ill suited to the size of components that need to be manufactured.

In companies that were more knowledgeable of the technology, it was found that the AM awareness was focused usually in a single individual or a small technical group, and that management was not aware of the specifics of the technology's potential for new product or new workflow development. In companies that were less knowledgeable regarding AM, members of management or owners usually stated that they follow the trends and announcements regarding the technology in the news superficially. This seems to be due to a belief that the technology has not yet found maturity, and that this technology would only be of significance to their business in several (5-10) years. In most cases, these same executives expressed an interest in participating in AM-centric events, to keep informed on the technology's development and to see how the competitive landscape is evolving through time.

This interest towards AM from executives is primordial to the successful implementation of the technology, as demonstrated by the leaders in the field. In most cases where AM was successfully applied in traditional industries, the best successes have been found in companies which have embraced the holistic process of Additive Manufacturing, which entailed significant investments in terms of time, manpower and financial resources. For these investments to be brought to fruition, and for a company's culture to change from traditional manufacturing to AM, it is imperative that the change is supported (or even pushed forward) by senior executives, who have the power and means to focus company resources

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for the successful and unmitigated adoption of the technology. A striking example of this is GE's adoption of the technology for its Aviation and Medical business units, and the subsequent development of GE Additive, an entire division devoted to the development of AM equipment and processes, born from the interests and opportunities perceived by the leaders of the other GE business units. Without the concerted vision of upper management, GE would not be in the position of dominance (in AM, at least) that it is in today.

The awareness of the competitive landscape in advanced manufacturing and Industry 4.0 in general is a point of great importance, as the technology is moving forward quickly, and the rest of the industrialized world is focusing on these types of new technologies to obtain the gains in productivity that will increase their competitive advantage. A low or absent level of awareness of what is occurring in USA or Europe has been found through the discussions with Albertan companies. A general sense of being late-comers to advanced manufacturing applications seems to be prevalent but with the exception of high-profile cases, there seems to be little knowledge of where the expertise is currently held, which companies are currently leading the AM scene and the state of technology adoption in the rest of the world.

An interesting point to note, however, is the willingness of the consulted companies to discuss AM with an external consultant and the openness to being challenged on their beliefs regarding the technology. The companies that were met during the visits were open to the possibility of obtaining a prognostic of the suitability of AM processes for their businesses, even if they were skeptical that the investigations would lead to the discovery of good business cases in the short term. Companies seemed ready and willing to invest a certain amount of time with experts to explore potential avenues for increased productivity. Most companies were also interested in joining a group which would focus on AM technologies to keep abreast of technological developments and to connect with like-minded parties which share an interest in this class of technologies. The interviewed companies suggested many roles or actions for this group to undertake, with the only recurring theme being that the group should serve to keep members up-to-date with the state of the technology and with the various applications/opportunities that could be of interest to the oil and gas component manufacturing industry.

It is the consultant's opinion that despite the lack of consensus on what actions the group should have (from the consulted companies), the group should focus on actions which will most strongly reduce the barriers to adoption for all involved. Although more information on this opinion can be found in section 3.4, but it is worth noting beforehand that companies seem to be reluctant to be the innovators in their field with a technology that has not yet found widespread success and endorsement in conservative industries. This reducing the reluctance to change and the apprehension towards the technology should be the focus of an AM-centered group, which can be accomplished in several ways, including through technology access agreements and by facilitating application development partnerships between SMEs and larger companies.

3.3. Alberta-specific Opportunities in AM

Vision of Opportunity

Alberta's manufacturing sector presents significant opportunity for the widespread adoption of AM solutions, with a focus on metallic AM due to the nature of the pre-existing expertise and capacity in metal forming and transformation. Furthermore, since metal AM is less mature than its plastic AM counterpart, it is also a better arena in which to compete for a first-mover's advantage from technology adoption. As in many other industries, conventionally manufactured components such as complex fluid manifolds, compact heat exchangers, single-piece flow controllers and hard-to-machine assemblies are ideal candidates for investigations where the redesign of the part aims for both production cost reduction and increase in functional capacity. AM is especially well suited for the latter, by enabling higher heat transfer rates per unit volume or lower pressure losses in fluid channels due to complex, un-machinable addition of features to the base design, for example. In other applications, the possibility of reducing part count and assembly labour by directly 3D printing an assembly as a single component can extend the life and reduce the weight of said assemblies, and thus present better value for a similar or even lower total (manufacturing plus assembly) cost than the original components.

Many of the discussions that were had around AM investigations in Alberta revolved around concerns to reduce manufacturing costs on current products. With a few notable exceptions in the manufactured products' end-users category, the visit did not reveal much appetite for higher value manufacturing from most companies interviewed. This is an important observation, as there seems to be a discrepancy in the points-of-view of the manufacturers and of the end-users, which indicates that typical part buyers (at the end-user companies) might not be well educated on or be particularly receptive to the value proposition of more expensive components. This entails that perhaps business development efforts for higher value components need to follow a different marketing channel than typical off-the-shelf components (i.e. through the maintenance engineering or plant operation teams instead of the corporate buyers or purchasing department). Although this is a very interesting topic on its own, it is not the focus of the report to analyze the marketing strategy of AM-based solutions. It is imperative to keep in mind, however, that the value of an opportunity in manufacturing a higher value component tied intrinsically with a company's ability to subsequently sell this product to cover this opportunity's development cost.

With respect to the opportunities presented by AM technologies, there is unfortunately no single formula or overarching principle which dictates where opportunities can be found using AM. The value of an AM solution (and its cost effectiveness) is usually derived from thorough investigation and product re-design phases, as components that were designed for manufacturing operations (DFM, which has been the dominant design philosophy since the 1980's) usually are poor candidates for direct transfer to a different manufacturing process due to the nature of the design process which was used to generate the geometries, tolerances, surface finishes and other requirements from the application constraints.

Furthermore, the design freedom, versatility of AM solutions (advantages) and its slow material processing rates (disadvantage) align well with low volume, high mix applications, which was discussed to be the main manufacturing mode in Alberta. This alignment between process characteristics and manufacturing paradigm creates an opportunity for the rapid adoption of the technology. More specifically, the versatility in terms of types of component morphologies (organic, lattice, varying wall/member thicknesses, etc.) that can be produced using AM solutions ensures that many types of parts for various applications or clients could be manufactured using a single equipment. The only caveat to this is the manufacturing envelope size limitation of the chosen equipment: appropriate technologies must be selected to reflect the fact that a large portion of the interest in AM in Alberta would be for larger parts that typically exceed Powder Bed Fusion (PBF) build chambers, for example. In this sense, continuing the example for metal AM, Directed Energy Deposition (DED) or Cold Spray (CS) AM processes would be much better suited to Alberta's manufacturing reality than PBF would be, even though PBF is the technology of choice in the medical field and although PBF is a more widely accessible technology.

The commercial success of AM in industries such as the aerospace and medical sector have also favored the development of AM solutions where high-value and traditionally difficult to form alloys (Ti-6Al-4V, IN718/625, Al-12Si-Mg, 17-4 PH SS) are easier and cheaper to obtain than other grades of materials which are more often encountered in traditional manufacturing operations. All these factors contribute to a situation where the best use-cases for AM are the complete re-design of components or assemblies using altogether different materials and following design for additive manufacturing best practices directly from the application's requirements, and not by modifying an existing design. In the case of the oil and gas component manufacturing industry, similar conclusions can be drawn, where the highest value of an AM enabled solution would be derived in applications requiring exotic, expensive or difficult to form materials using designs that are optimized for AM processes. Of course, this process requires more expertise, time and resources to be deployed for the successful integration of AM, but this can be thought of as an opportunity instead of a challenge: the more resources need to be devoted to the development of an endeavour, the more time it takes for a fast follower to duplicate these efforts and develop a competing product.

Although the apprehensions concerning regulatory issues in Alberta's core industries are founded and these barriers present challenges, they can also be seen as opportunities to deliver unique value to clients with products that meet the regulatory standards and offer superior performance to conventionally manufactured products. In this sense, once a product has been developed and approved, the regulations become a deterrent to fast followers and allow the company who first developed the product to obtain a significant head start with the product before a competitor can develop an equivalent solution. In the same vein, the existence of regulations by API and ABSA that proscribe the use of heat-adding metal deposition technologies for manufacturing and repair create opportunities for the use of cold-fusion based technologies such as Cold Spray, which is currently underrepresented in the industrial world due to the massive attention that is being devoted to powder bed AM technologies in the discussions of metal AM technologies. If Alberta has a particular set of regulatory challenges which prescribe the use of alternative AM methods instead of heat-fusion based technologies, this creates an opportunity to use these lesser known alternative methods and quickly become a reference in the industrial world for these technologies.

Prospective Paths for AM Implementation

More concretely, there are several areas in which AM could open new possibilities for Alberta's businesses. Many people believe that the best opportunities lie in aerospace and medical applications, which could very well be true but for which competition is already established and for which the regulatory barriers are difficult for companies without prior expertise in these sectors to tackle, in addition to the technical challenge presented by the adoption of a new technology class such as AM. As such, the author cautions against the urge to try to follow existing AM markets, and instead recommends that Alberta puts to profit the existing strengths of its manufacturing sector and explores new ways of diversifying its economy without having to contend with excessive competition.

The first step in the AM journey seems to be the simplest iteration possible: to implement an in-province service provider for additive manufacturing expertise and printing services. Several smaller service bureaus exist in Alberta, who could benefit from investment (government, private, or mixed) and access to expert resources to bring their service offering to the next level. This would translate to an ability of these firms to obtain more business from Albertan companies who are already using out-of-province expertise and services from Quebec, Ontario and Saskatchewan. Indeed, in the visits performed, not many businesses were found who could be able to justify the cost of high-end industrial equipment for their internal use alone, but a need for this capacity does exist and the absence of a service provider who can meet this need represents a lost opportunity both in term of revenue and in term of the AM talent pool growth in Alberta.

A second area of opportunity would be for design firms to become well versed in design for AM, or for the creation of dedicated AM design service providers. In addition to helping spur other companies to adopt the technology through the service offering, design firms would benefit from the advantage of being able to sell their products (the intellectual property resulting from the design process) internationally and with little physical or geographic barriers. This could also start a transition for the manufacturing sector to move from the production of physical goods towards the production of digital or intellectual property-based goods. This move is interesting in the measure where the equipment investment can be minimal, as demonstrators and proof-of-concepts could be produced on the various equipment available in Alberta's colleges, universities and research institutions, while building the talent pool and creating stronger ties between academia and industry. Government can also participate to reduce the barriers to this type of collaboration, by developing programs to offset a percentage of the cost of an AM solution development. A good example of a program which helps SMEs adopt AM would be CME/Canada Makes' Metal Additive Demonstration Program (http://canadamakes.ca/funding/program-for-metal-additive-technology-demonstration-projects/), which offers up to 5,000$ for SMEs to try out metal AM technologies with a service provider. A similar program which could offer a company funding to offset a part or the totality of the cost of small projects for AM implementation if performed on an academic institution's equipment could ensure that the AM equipment in Universities and Colleges would be available for industry to develop today's application, while the institutions focus on more fundamental research for tomorrow.

In terms of industries where AM shows promise in Alberta specifically, the province's main industry focusing on oil and gas related component fabrication could profit from the redesign of components for AM technologies to increase the service life of the components submitted to severe operating conditions. This includes the development of directed energy deposition or cold spray additive manufacturing solutions to build hard faced features on shafts, for example. In addition to these applications, complex fluid manifolds, heat exchangers, valves and critical assemblies could be good candidates for redesign using powder bed technology. Larger equipment and hard-to-obtain/discontinued spare parts could also be manufactured using electric arc based additive manufacturing processes.

AM technologies could also pave the way for a diversification in manufacturing operations to different sectors of the economy: railway, mining and electric farming equipment all present new opportunities for the technology to leverage value, and in some cases present challenges which are quite similar to those described previously: rail applications are subject to regulations which proscribe the use of heat-addition-based technologies for the repair of rolling stock, mining applications could benefit from the development of higher service life components and for the direct nearby manufacturing of replacement parts, while electric farming vehicles would benefit from lighter rolling apparatus with lower rotational inertia to increase their service time per battery charge. Finally, the maintenance/repair/overhaul (MRO) business presents several opportunities in agriculture, automotive and aerospace applications who are currently being investigated elsewhere than Canada, but that might not focus on parts and failure mechanisms which are typical of harsh Canadian winters.

3.4. Paving the Way Forward

As mentioned previously, Canada has a good opportunity to become a leader in the field of additive manufacturing, and there is room for Alberta's industries to find their niche in this endeavour. Realizing this vision will require focused and immediate action, however, as the technology gap is widening, and other economies have access to massive funds to fuel this development.

The first step, as with any other important issue, is to acknowledge the importance of AM adoption by manufacturers as a driver of value and of the existing gap in AM adoption between Alberta's current state and leading technology adopters. Once this gap has been identified and areas of focus are determined an affirmation of the will to act to reduce this gap must be made by the various stakeholders, including government and industry players. Once political and industrial will is aligned on the importance of action, it is then possible to act on these wills in a collaborative and focused manner.

In a second stage, it would be important to assess the capabilities that Alberta currently has to lead AM projects with in-province expertise and equipment, namely that of the various universities, colleges and Innotech Alberta. A brief exploration of industrial interest has been performed in the context of this project, but it would be important to do a more thorough analysis of selected companies for their potential and willingness to identify and develop or co-develop AM solutions. For example, Innotech Alberta has expertise in AM to prepare, lead and document development projects that would stem from industrial diagnostic visits, which could be funded by IRAP or Alberta Innovates to increase competitiveness of industry using this technology. The essential part of this step is to ensure that easy wins and early successes can be found rapidly, to fuel the adoption and allow the expert parties to present documented cases of net gains. These early successes will then encourage skeptics to look at the technology to create their own easy wins or to attend education session to learn more about the technology's potential, while veterans of these projects will develop an appetite for more ambitious actions or to internalize parts of the developed processes.

Another key intervention would be the to raise awareness of the technology's advantages and limitations through training sessions geared towards purchasing and management groups, as well as more focused Design for Additive Manufacturing sessions for more technically inclined audiences. This will allow the various groups to better understand how the technology operates and how these principles can be leveraged to create new and better designs that are adapted to AM. This can be done simultaneously as the second stage of assessment, or even before assessment interventions begin to ensure that the expectations are set to the right level, and to ensure that the manufacturers can assist the assessor in zeroing-in on high potential components. Finally, offering workshops to IRAP's ITAs, Alberta Innovates' TDAs and the Government of Canada's local representatives from certain departments such as ISED, DND, etc. regarding the state of AM and its potential for manufacturing could be quite helpful in securing political will and funding towards this class of technology.

Alberta would also benefit from a provincial-level association/group to identify important and shared issues for manufacturers and machine shops. This association could perform many roles, including:

- Interfacing with government bodies to help them understand the challenges faced by Alberta's manufacturing sector with respect to advanced manufacturing and the need to fund innovation to increase competitiveness;

- Keep up to date with relevant associations both at the national level (e.g.: Canada Makes, Advanced Manufacturing Supercluster) and in other provinces (e.g.: Réseau QC3D);
- Send a representative to represent group interests at trade shows, economic missions, etc. to ensure Alberta is included in AM business opportunities in Canada and abroad;
- Organise training sessions to increase awareness of 3D printing opportunities, offer continuous learning workshops to train potential users and management;
- Perform in-house AM evaluation visits, to determine the potential of a company to adopt AM technologies and point towards potentially successful business cases based on the company's expertise, products and workflows;
- Manage an Innovation and Technology Centre, Technology Access Centre (TAC) or similar type of institution including staffing, machine operation, operator qualification and running the day-to-day activities of the centre.

The creation of an Innovation and Technology Centre (either institution-run, such as a TAC or industry-led, such as the Centres for Excellence) could benefit the province by creating a frame where companies can work towards building a business case with lower financial risks. Consortium-based lab access seems to be interesting for many regions, but the fear is that resources will be centralized and difficult to access by communities farther from the larger centres in Edmonton and Calgary. As such, the technology access center could adopt a decentralized model that works on bringing together industry, academia and government to work collaboratively in reducing the barriers to technology adoption with the following roles and priorities:

- Government can leverage private investment using fund matching programs that are already in place (Mitacs, NSERC), research and development funds (IRAP, ISED), regional economic development funds (city-level and Alberta Innovates);
- Government should also facilitate relations between the different agents and between the different funding and lending bodies (federal, provincial and municipal, as well as BDC and provincial lenders) to present a coherent and unified funding application and proposal from industry, as well as a coherent and unified offer package from funders and lenders;
- Government can purchase equipment time from centre for academia access and for R&D projects which can offset equipment purchase risk without resorting as much on traditional funding and lending mechanisms;
- Academia can provide expertise and trainee labour by providing access to student and faculty time to the consortium, in exchange for equipment access time. Education institutions can also chair roundtable discussions regarding the training and education aspect, to modify curriculums and introduce new courses according to shortcomings or gaps identified by the centre's members;
- Industry can provide guidance, management and oversight of Technology Centre, as well as the initial seed funding for the center, which demonstrates willingness and viability of the initiative.

4. Conclusion

The visits conducted in Alberta in the context of this project focused on the evaluation of Additive Manufacturing awareness and readiness, as well as to identify key areas of opportunity for the implementation of AM solutions in various sectors, industries or manufacturing operation type.

It was found that Alberta shows a similar technological readiness level as other Canadian provinces, although this level is lower than elsewhere in the world, such as Europe, the USA or China. Alberta has a similar interest towards AM as can be found in other Canadian provinces, where cautious optimism seems to be prevalent. Low-level plastic AM solutions (e.g.: prototyping and tooling) can be found in many companies, but no evidence of higher-level applications (e.g.: engineered solutions to replace metal components) was found, while discrete experimentations with metal AM were discussed with the larger companies involved. This seems to be due to a belief that the technology has not yet reached the level of maturity required to warrant interest for their businesses, which is typical of Canadian businesses with the notable exception of high-tech industries such as aerospace. Alberta's education and research institutions seem ready and well-placed to assist industry in developing AM applications and expertise. Despite the limited types of AM equipment available for industrial use, they can also be the starting point in de-risking applications by providing a test bench or prototyping centre for these AM designs. The lack of accessible industrial equipment and of alternative AM processes, however, limits the current reach of academic institutions into AM explorations with Alberta's SMEs.

The companies visited over the course of this project showed interest towards the technology class and would be open to having a group or association that would promote AM technologies and that could provide education and training for AM. Companies seem to have a low awareness of the competitive landscape and geography in advanced manufacturing. A general sense of late adoption is felt, but the consequences of this delay do not seem obvious to the participants. Furthermore, AM understanding is usually focused in a few individuals in a company, and while management is usually aware they are generally not cognisant of the opportunities enabled by this technology class and of how to draw the best value from it, which is a limiting factor for AM success due to the significant resources that must be devoted to the project (financial, engineering, training, etc.) which are typically controlled by upper management.

Alberta's opportunities in AM are tangible, mainly due to the current manufacturing mode being low volume, high mix production scenarios, which align well with the versatility and the advantages of AM solutions, while being less affected by its disadvantages, such as low processing speeds. There is significant opportunity in AM across Alberta in the oil and gas vertical, especially for metal additive manufacturing focused on the extension of component service life and for the manufacturing of complex geometry components, but the best opportunities in AM will come from the redesign of components and assemblies to provide better value rather than for the reduction of manufacturing cost directly. There seems to be immediate space in Alberta's industrial weave for service providers for both design services and plastic 3D printing as well as an opportunity for economic diversification based on AM integration in the current manufacturing context that exists in rail, mining, electric farming vehicle manufacturing and maintenance, repair, overhaul operations in various sectors.

It is the consultant's belief that immediate and focused actions are required to ensure Alberta gets the most out of AM, and that a first-mover's advantage can be developed in its key sectors. The first action is the realization and affirmation that there is a gap in advanced manufacturing technology adoption between Alberta, Canada and the rest of the world. The assessment of the AM capacities of research centres and service providers, as well as of the companies willing to invest in the development of AM solutions with high potential business cases is key to obtaining early wins and building momentum for technology adoption. Education of the technologies advantages, limitations and basic design principles is essential to the various stakeholders at all levels (government, industry management and for the workforce) to understand the technology, its potential and limitations, as well as to set expectations for the benefits of adopting AM. Actions must be focused on bringing together industry, academia and government to work collaboratively in reducing the barriers to technology adoption, for example in an industry-led consortium to create an innovation and technology centre, similar to the Centres of Excellence in Ontario or to the Technology Access Centres that can be found across Canada.

5. List of Appendices

Several tools, lists and other instruments were used or developed by the consultant in the context of this project and are listed in this section. The appendices will be distributed as appropriate through Innotech Alberta to supplement the information contained in this report.

5.1. AM Evaluation Tour Objectives

A document which was prepared to inform Alberta Innovates and other organisers of the objectives and context of the AM evaluation tour.

Filename: IA-Creadditive_AM-Evaluation-Tour.pdf

5.2. Brainstorming Questionnaire

A questionnaire which was develop to stimulate thought on the subject of AM, which was distributed to participating companies before the visit to allow them to gather the required information and understand the premise of the visits.

Filename: IA-Creadditive_Questionnaire

5.3. List of Interviewed Companies

A list of the interviewed companies during the AM evaluation Visit and Tour.

Filename: IA-Creadditive_List-Interviewed-Companies.pdf

5.4. AM Evaluation Tour Executive Summary

A two-page executive summary of the report’s discussion and conclusions, to brief interested parties which do not require the full-text document.

Filename: IA-Creadditive_Executive-Summary.pdf

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As part of the Alberta Additive Manufacturing Network, the following entities have contributed towards the report:

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