Canada's Additive Manufacturing Landscape

Introduction/Background

Additive manufacturing is a multi-billion dollar opportunity, that will transform and disrupt global manufacturing. It is also widely misunderstood and misrepresented. By conducting interviews with many of Canada's additive experts this report set out to understand how Canada might adapt, adopt and exploit the new paradigm of additive manufacturing.

Sales of additively manufactured parts grew globally from $5.7 billion to $6.8 billion in 2019[1], and the 20% growth rate has been sustained for years. However, this figure is still only a tiny fraction of the $14 trillion global manufacturing added value, and it is tempting to dismiss additive manufacturing as unimportant. The same argument could be made for electric vehicles as a small percentage of the total transportation market. But electric vehicles have changed everything, from manufacturing, through to distribution and even ownership models. For example, will decades of excellence designing, manufacturing and assembling 6-cylinder engines count for much going forward into an electric future?

How exactly additive manufacturing will transform and disrupt is not yet clear. What is known is that additive manufacturing can produce much better solutions to certain problems. It can offer reduced waste and increased agility - critical factors in *any* value chain, from manufactured goods to healthcare to energy.

Additive manufacturing has the potential to attain 1% of global manufacturing revenue in the next five years.[2] For Canada this would translate to $2 billion GDP. Even more significant for Canada than the direct revenue from additively manufactured parts, is the recognition that being fluent in the language of additive manufacturing will be an order qualifying requirement, in the same way that tools like CAD, CNC and email are today. Creating the appropriately fluent will necessitate an integrated training program across Canada in polytechnics, engineering schools and business schools, supported by a strong industry based skills development regimen.

Many people equate additive manufacturing, or 3d printing, with low cost plastic filament extruding platforms seen in schools, libraries and makerspaces. In truth additive manufacturing spans multiple methods of adding materials, from plastics to composites, metals and ceramics. Machines and infrastructure can be million-dollar propositions, not just a few hundred dollars from Amazon. Selecting the "right" solution (to the right problem) can be a confusing proposition, technically and commercially.

[1] Wohlers Associates (2019) *Wohlers Report 2019*
[2] 3D Printing Trends Q1 2019 report *3D Hubs, 2019*.

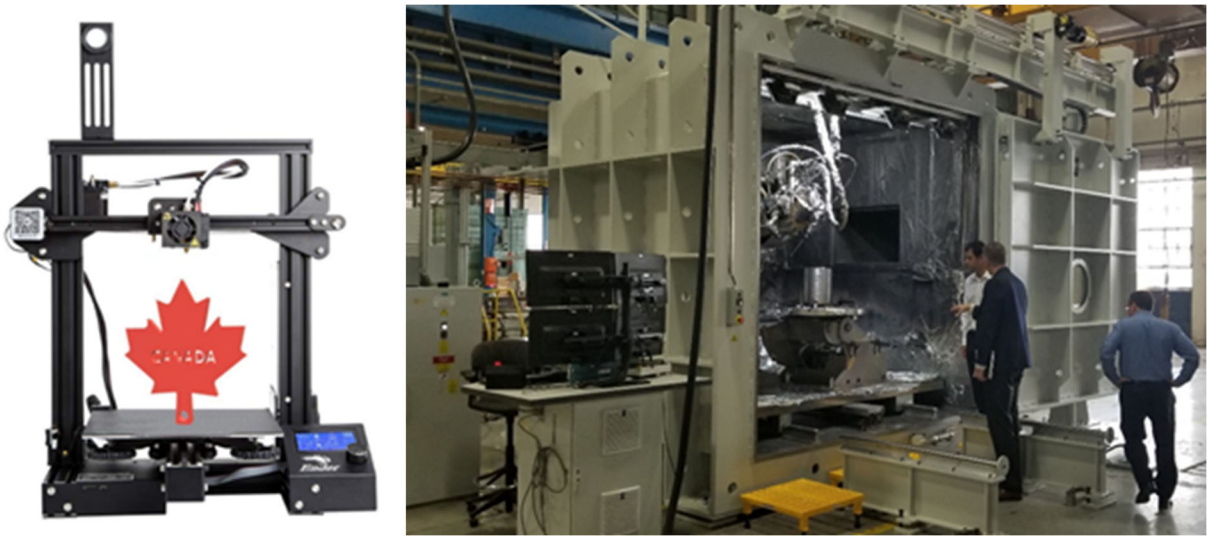

Figure 1 Additive manufacturing – the technology spans vast capability and cost, and as a result is often misunderstood

Additive manufacturing provides “tool-less” capability for both prototyping and legacy part production. Because parts can be printed without investing in expensive, long leadtime molds, the economics are attractive at both ends of a product’s life cycle. For new designs, performance advantages come from organic load bearing geometry as well as part consolidation. For supply chains the promise of being able to produce at, or close to, the point of consumption remains an elusive promise.

Market sectors are diverse, with differing requirements and timescales to adoption. Aerospace and medical have high regulatory burdens, but equally high rewards from lightweighting and customisation. Dental aligners and hearing aids are two market sectors that were transformed (almost overnight) by plastic printing. GE’s aero engine fuel nozzle is the poster child for metal printing, with many parts consolidated, better performance and lower maintenance costs.

The USA is arguably the biggest geographic market, and has the highest installed base of 3d printers, estimated at over 400,000. Although Canada has far fewer printers, capability exists from coast to coast.

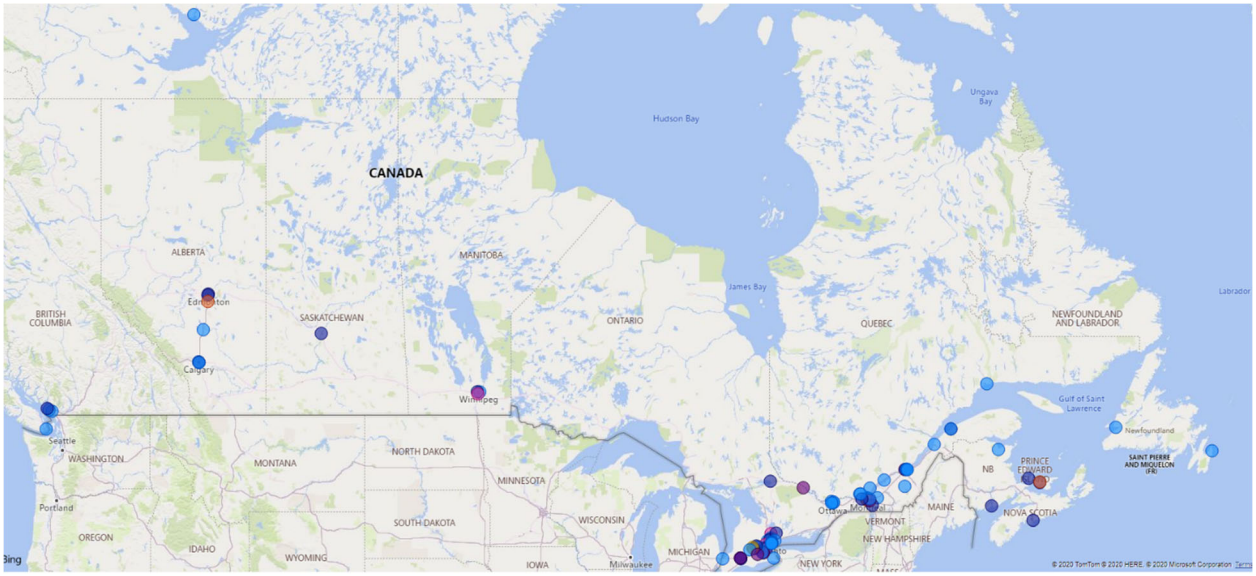

Figure 2 Map showing additive manufacturing equipment at industrial, academic and research facilities across Canada

Canadian industry success stories include MDA's satellite communication applications, Exco's conformal cooling of massive die-casting tools and Covid nasal test swabs from Precision ADM, now the highest output printed medical device in the World.

Figure 3 Canada's Precision ADM has now 3d printed millions of Covid-19 nasopharyngeal test swabs, becoming the highest output printed medical device in the World

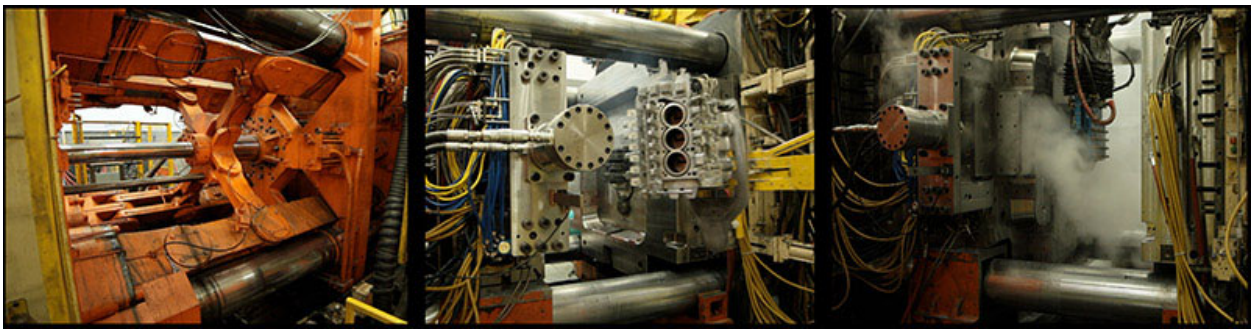

Figure 4 Exco Engineering is a world leader in advanced cooling of die cast tools using printed metal inserts

While additive manufacturing is a massive opportunity for Canada, businesses are poorly informed and siloed. Applications and know how need to be developed to grow the market. Supply chains are being rethought and Canadian businesses needs to be fluent in additive manufacturing as this is truly the mother lode in the digital thread. Canada's plethora of smaller businesses (compared to the United States) could potentially allow for competitive advantage through more customised, locally delivered solutions. Alternatively, the lack of multinational enterprises in Canada may be a significant structural weakness.

To better understand the major issues, and develop an action plan, a diverse group of stakeholders in Canada's additive manufacturing ecosystem were surveyed and interviewed.

Survey Results: Executive Summary

Two themes emerged from the survey/interviews:

1. The need to grow the market/applications, by sector and clusters.
2. The need to develop the people in it, both customers and suppliers.

There was consensus that collaboration would underpin growth, despite many participants potentially being competitors.

The Canadian AM landscape is currently fragmented. A full-time commitment would be needed to focus on strategic theme initiatives and grow the market, and no individual leader or company could provide this resource. The formation of new industry led, not for profit, vertical AM cluster organisation(s) was therefore recommended as a first step to growing the market and specific technology applications.

Training for additive manufacturing - from K12 through to professional development - is also fragmented and lacking completely in some areas. A similar picture emerged in the UK, and significant resource (several years, $100K's) was committed to defining required additive manufacturing roles and developing new training programmes to support these roles. Licensing some of these online training modules could provide an immediate nationwide solution for basic familiarisation with additive manufacturing. There will also be the need for hands on training across sectors and technologies. A working group has been formed to focus on regionalised training delivery.

NGen could also better connect industry with Canada's additive ecosystem by developing an AM portal.

"One of the core problems is everyone is obsessed with additive, and the need for an AM strategy. But really what is needed is a manufacturing strategy. Absolutely nobody wants to buy an AM part - what they want is a solution."

"Some knowledge is earned not learned. It would take a lifetime to learn all that needs to be known in each discipline, and nobody has 3 lifetimes."

"Do I care about AM in Canada? No. Do I care about competitiveness in Canada? Yes!"

"Students do not ask why enough. In industry new hires are even less likely to challenge a senior engineer."

Survey/Interviews: Detail

A fairly large group of stakeholders in Canada's additive ecosystem were asked to participate in an online survey, followed by in depth phone interviews. Over 30 surveys were completed from stakeholders representing powder producers, machine manufacturers (Canadian), service bureaus, researchers, academia and industry users. The group was diverse, highly experienced and distributed across Canada, with plastic and metals, prototype and end use parts all important to the group.

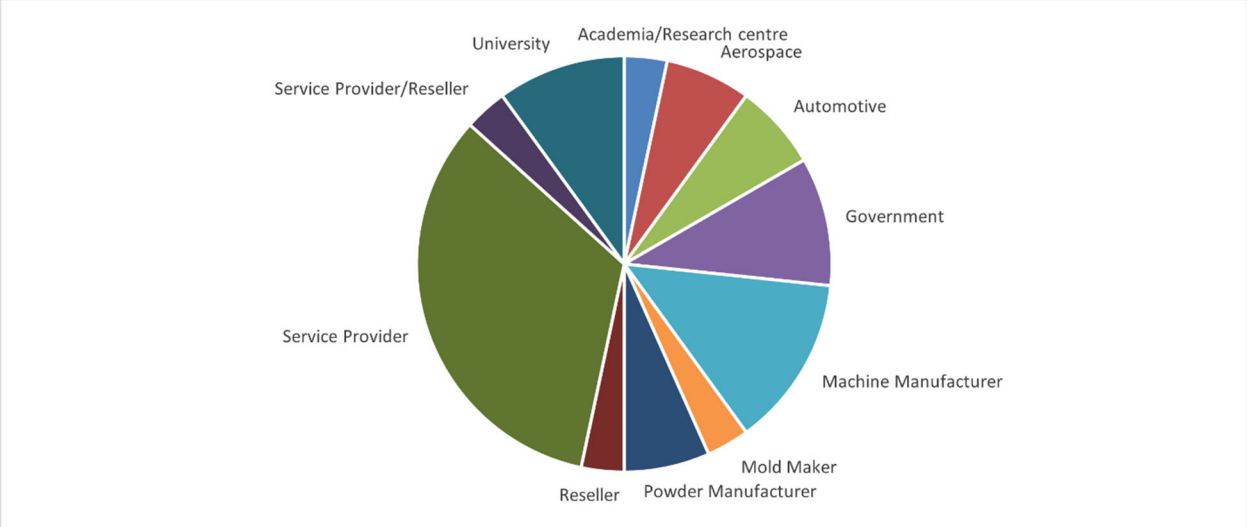

Figure 5 Composition of AM survey group stakeholders

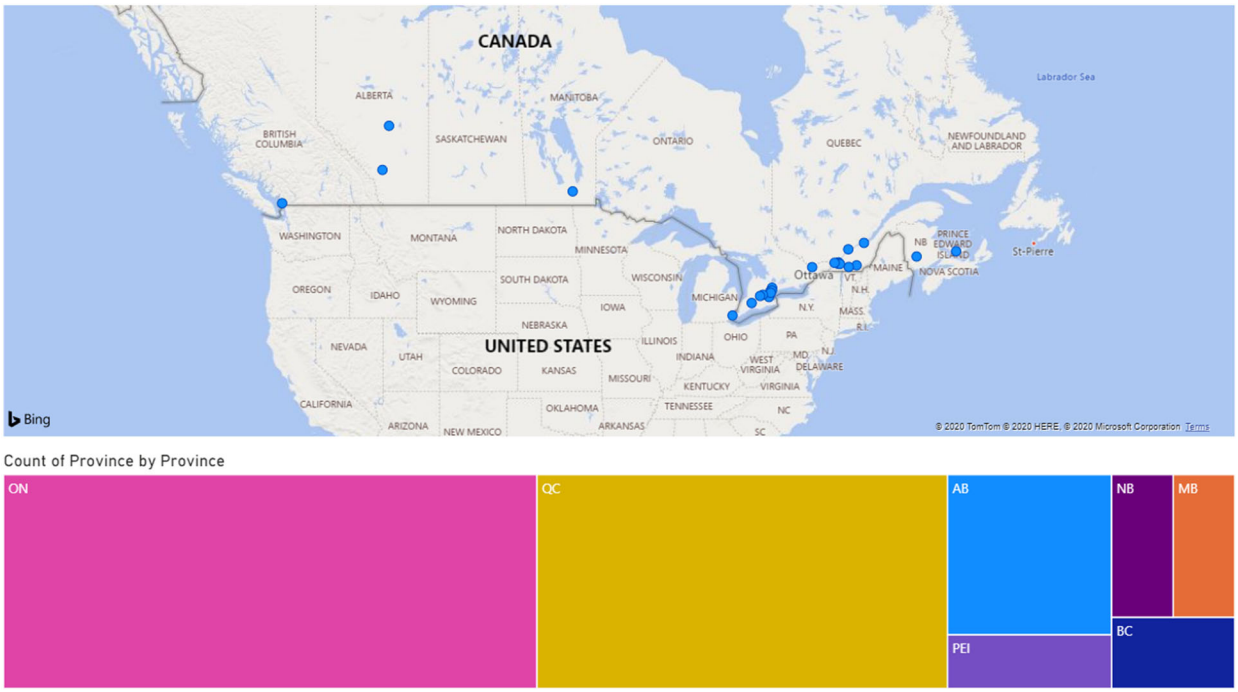

Figure 6 AM survey geographic distribution of respondents

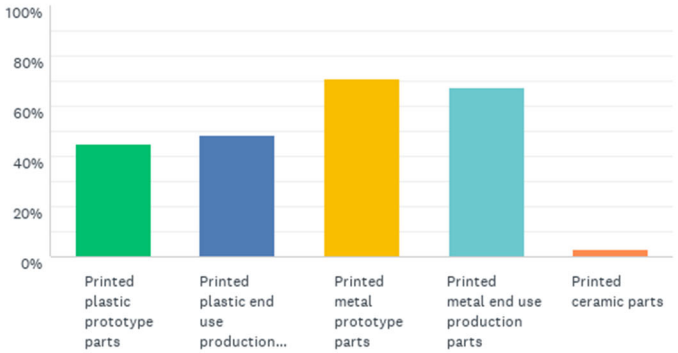

Figure 7 Additive manufacturing focus for survey group

The survey and interviews were designed to gather expert opinion on the big issues around adoption of additive manufacturing and obtain specific ideas on actions to improve the AM ecosystem in Canada. A SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis was used to explore opinion on the major issues impacting additive manufacturing in Canada.

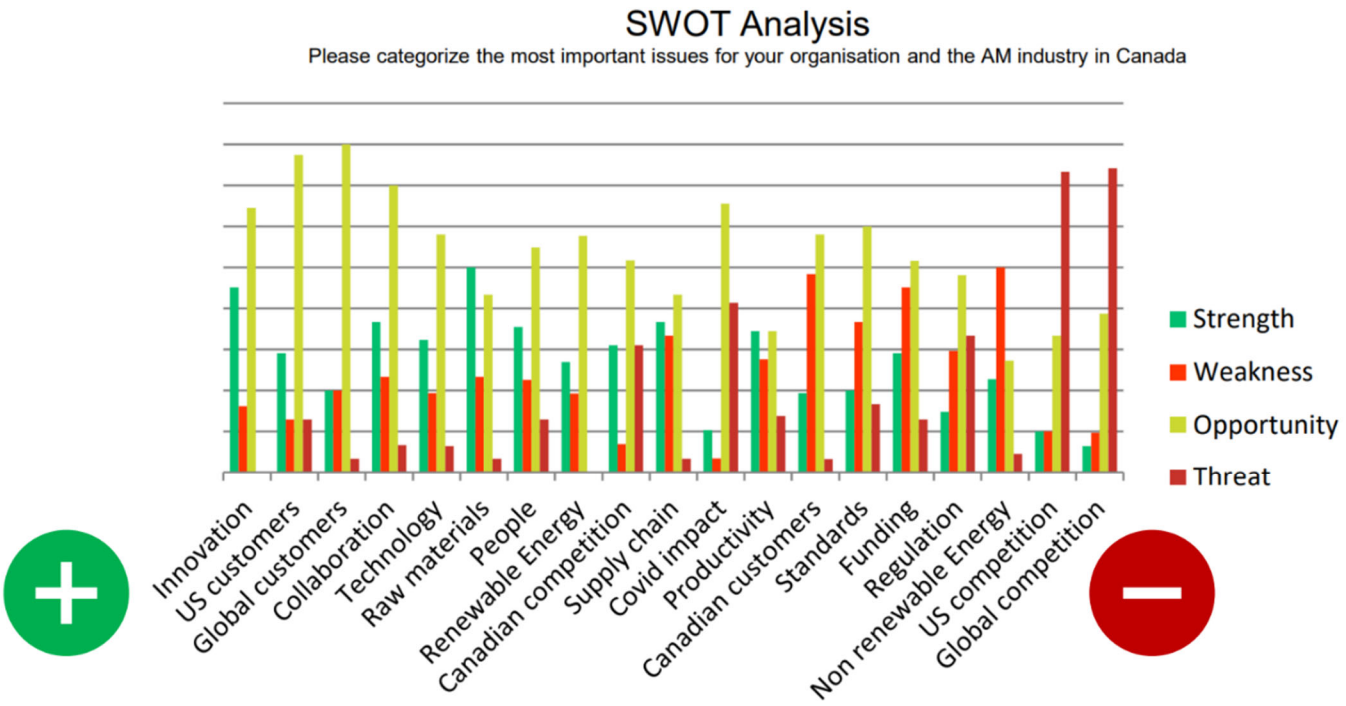

Figure 8 SWOT issues (ranked from positive to negative)

Innovation was ranked the most positive issue (either as a strength or opportunity). Nearly all respondents (94%) said they had innovated in the past 5 years, but innovation was described and measured very differently across stakeholders.

Figure 9 Measures of success for innovation

After innovation it was customers, collaboration and technology perceived as the most positive factors, with US and global competition ranked as the most negative factors.

Structural advantages for Canada in additive manufacturing often mentioned materials and education:

"Highly educated workforce that has the potential to adapt quickly to AM innovations. Lower cost structure vs. the US. Favourable tax environment."

"Access to US market, low cost of Canadian Dollar, educated workforce, skilled immigrants"

"Areas with clean energy. Ample raw material suppliers. High level of education (not necessarily in AM)."

"Globally known cluster of machine, tool, die and mold companies is considerable structural Canadian advantage."

"Strong raw material presence, couple strong OEM divisions, great knowledge institutions."

Structural weaknesses for Canada in additive manufacturing often mentioned the smaller market in Canada compared to the US, and fewer OEM's:

"Small market, an economy of SME. Not so many big Fortune 500 companies that can drive innovation"

"Lack of OEM in Canada with their research centers. Insufficient R&D spending."

"Small market in Canada. We are not great as exporting finished value-added products."

"Lack of MNEs with headquarters and decision power in Canada"

"Market size; limited product design (OEMs)"

"Lack of AM national organization leadership and advocacy like America Makes with access to significant funding to innovate in AM. Also, there is a significant lack of large OEMs in Canada that are innovating with AM for end use products."

Nearly all the survey respondents (87%) had invested in capital equipment (with a value more than $100,000, within the past 10 years). What was unexpected was the pioneering thinking behind these investments, with ROI or payback only rarely mentioned as the measure of success for the investments.

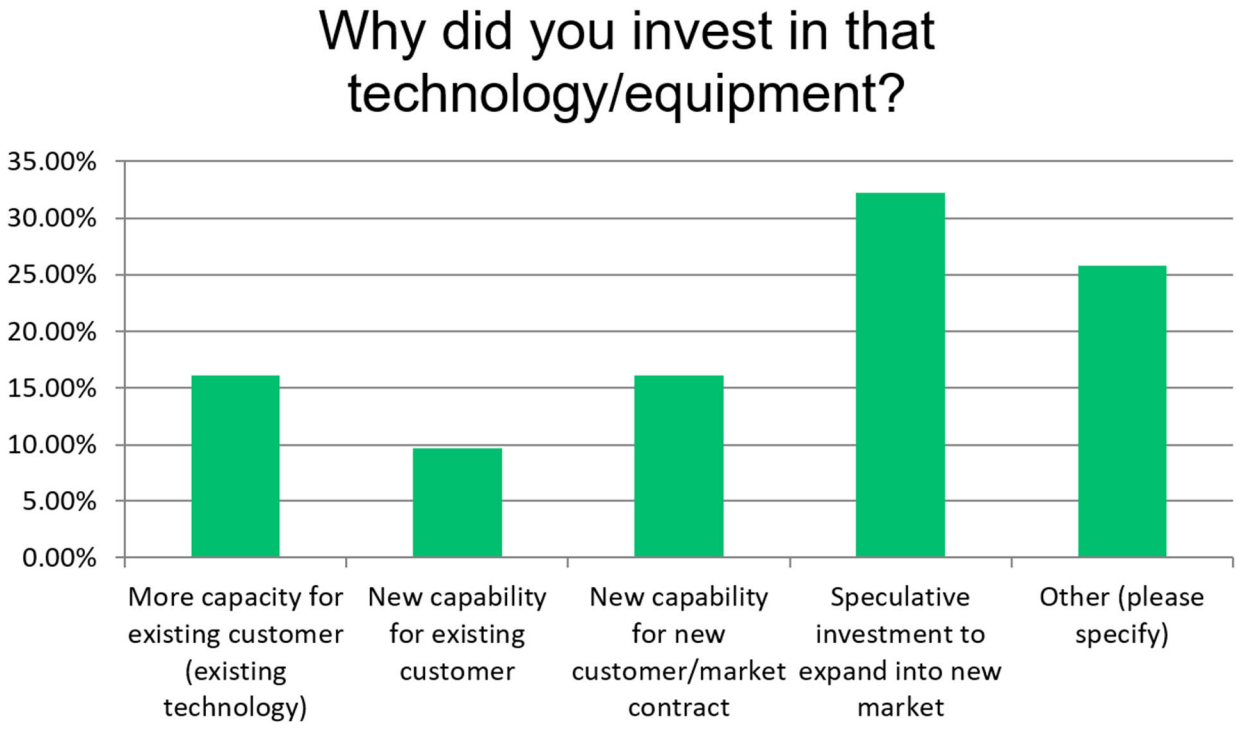

Figure 10 Reason for investment in capital equipment

Figure 11 Measure of success for investment

Survey respondents slightly disagreed with the statement that Canadian industry was well connected and informed about additive manufacturing. (Note: Survey respondents dragged a slider from a neutral position of 50, towards either they agreed with statement, position 0, or disagreed with statement, position 100. The solid blue box in the images shows the opinion range for half of the respondents, with the whisker lines above and below the box showing the total opinion distribution.)

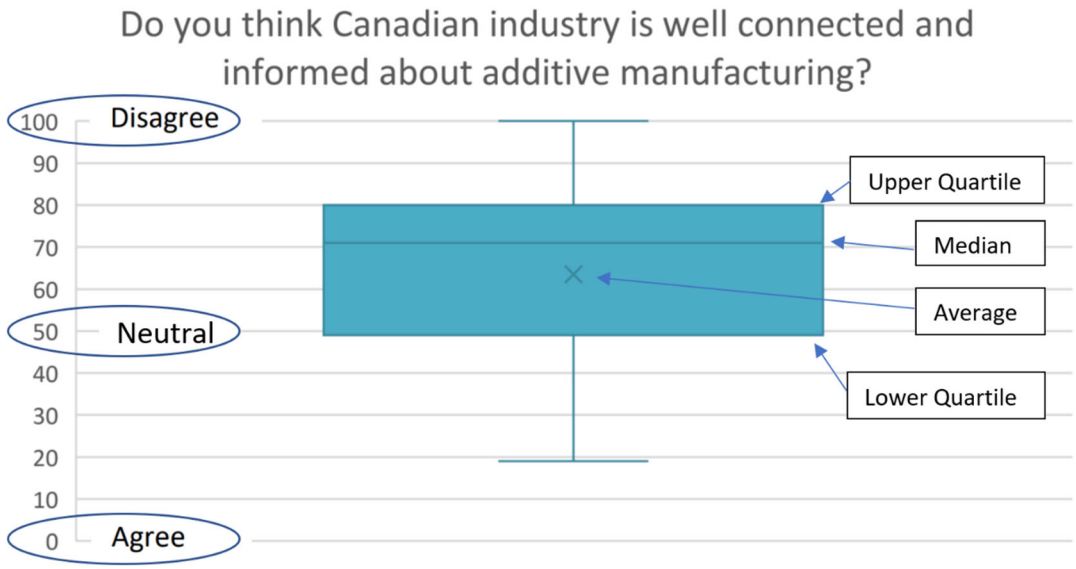

Figure 12 Opinion: Canadian industry is well connected and informed about additive manufacturing

Opinion on whether collaboration between customers, additive industry and academia was effective was again slightly negative (median score of 66), but with an even wider spread of opinion (from 0 to 100!).

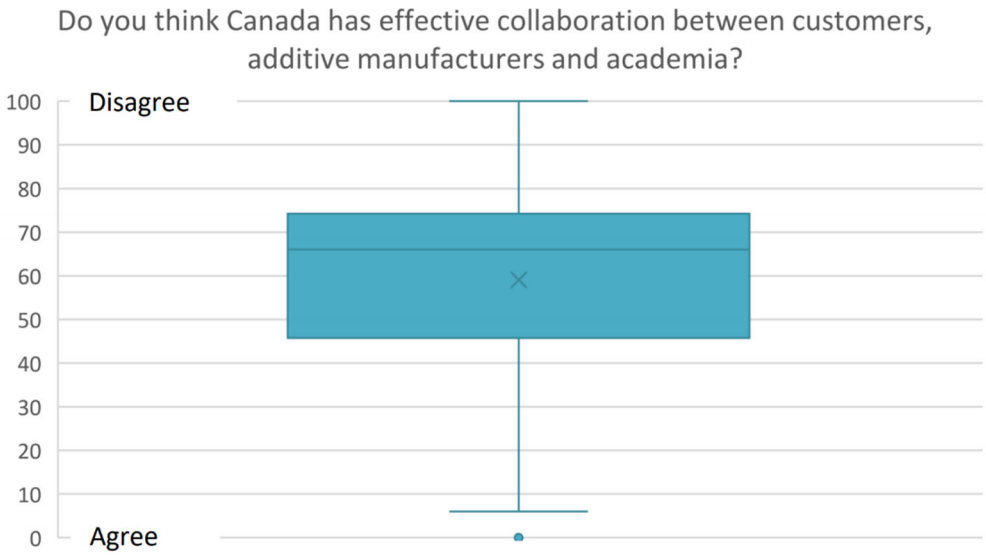

Figure 13 Opinion: Effective collaboration

Suggestions for improving connections and collaboration were explored both in the survey and during the follow up phone interviews.

How should connections and awareness be improved?

“Particular attention needs to be paid towards educating and informing designers and engineers responsible for product designs as they can propel the use of AM. Canada Makes or a similar organization needs to be strengthened as the key national coordinator for AM.”

“An ongoing central database of Canadian manufacturers is required for better awareness and connection. This database should include information on manufacturing capabilities, quality systems in place, contact information etc. At this time, it is difficult to identify Canadian manufacturers specific to various industries, and therefore difficult to make connections.”

“Have a portal with extended information such as non 3D printing companies looking for 3D solutions.”

“We have limited resources. Let's focus them in 1 place and be effective.”

“Complete and well connected AM supply chains within Canada - Powder production (certified power producers and testers - conventional and novelty alloys), AM manufacturers with certified processes, Certified sub-contractors (for thermal and surface post-processing for AM, NDT, inspection, etc.)”

How could collaboration be improved?

“It would be easier for industry to fund Academia and collaborate if there was less risk around the IP and if industry did not view Academia as a potential competitor. Government should better fund the Academic institutes such that they are more self sustaining to ease the above cash generation issues. For industry the IP developed needs to be with the company or there is little point in outsourcing research.”

“Co-locating serious additive manufacturing organizations near universities with programs allowing academia to collaborate with additive manufacturers could create an environment for the next generation to learn the true potential and improve the ecosystem in the long run.”

“Joint collaboration on development or "showcase" projects.”

“Collaboration exists but is limited to a relatively small group of end customers. Outreach programs are needed to attract more end customers which will likely create more additive manufacturers and expand academic AM programs.”

More than half the survey respondents felt that multi national companies (MNC) were necessary to drive demand for additive manufacturing. The logic behind this is twofold – not only do MNC have more money/market than SMEs, they also have design authority with their own products and can therefore maximise the potential benefits from (re)designing for additive manufacturing.

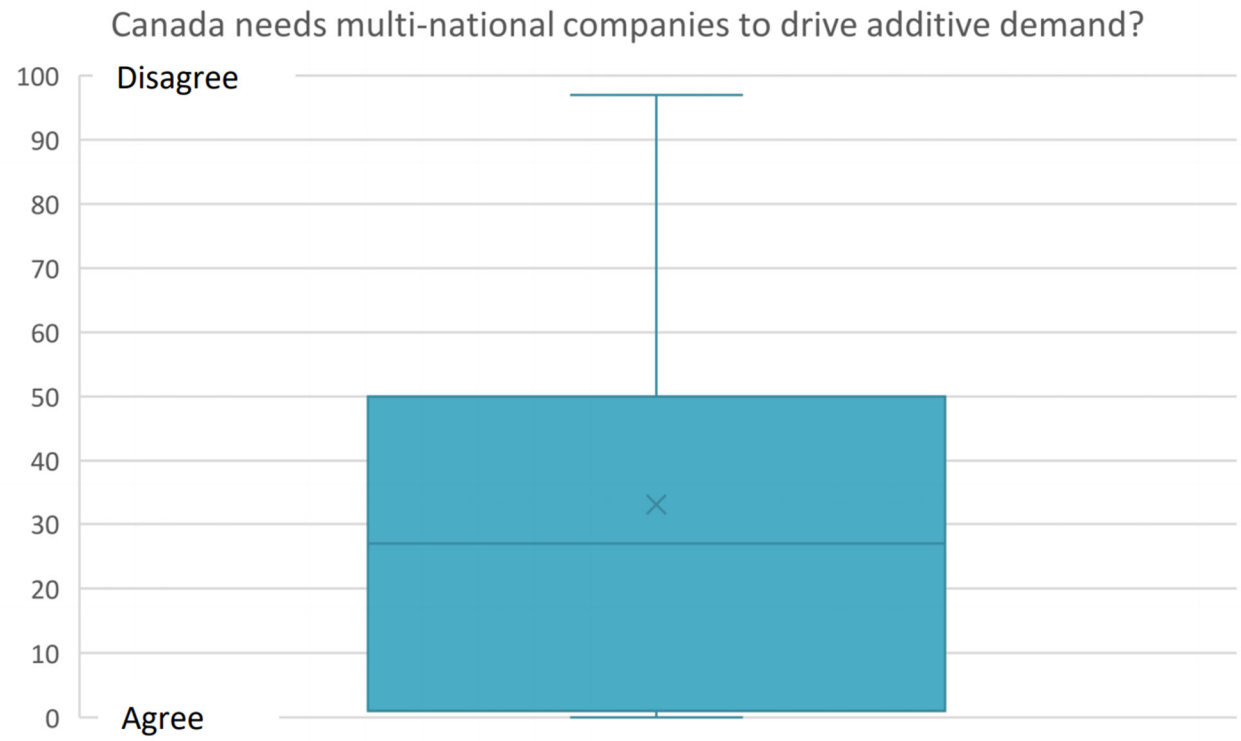

Figure 14 Canada needs multi-national companies to drive AM demand

There was a wide range of ideas to incentivise MNC's to do (more) business with Canada's additive manufacturing sector.

What would encourage multi national companies to work with Canada's additive industry?

"As we have limited multinationals headquarters and R&D centres in Canada, we don't have the natural demand that would drive the growth of Additive in Canada. If we had a special incentive to help pave the way for collaboration between these multinationals and Canadian SMEs, we could see our expertise grow. In Europe, the advances are financed by 'prototype' orders from Airbus, EADS Space, SNECMA, Safran, Eurocopter, Dassault, Renault, PSA (PeugeotCitroen), the F1, F3, Rallye racing teams, etc. Lots of money to buy prototypes that finance the learning around Additive. In the USA, you have all the major Defense contractors in addition to the GE Aviation, Boeing, GM, Ford, FCA, Honda, Toyota, Tesla, SpaceX, etc... In Canada, we have... Suncor, Magna, MDA... We need to be able to convince any of these American or Europeans to do business with Canada. We need to match up a Canadian SME with a major player to allow them to grow and become integrated into their supply chain. We also need to be able to support the SME through a bonding program that will shield the Major in the event the SME faces financial difficulties, similar to the Performance bond that EDC offers, or the 'government seal of approval' that the Canadian Commercial Corporation gives SMEs with foreign governments"

What would encourage multi national companies to work with Canada's additive industry?

"Rigorous enforcement of ITC/ITB/IRB programs to ensure companies are spending the money and making Canada an attractive place to do business (Low taxes etc)."

"National Incentives programs to attract companies to work with Canada's AM Industry as well as Pan Canadian Industrial pitch on Quality of Canadian manufacturing"

"A strong emphasis of focus in the sector"

"Lower price of development, resources (powder and feedstock) and talent"

"Recognizing the synergies of the various AM players and the impact these companies can have on developing high skilled well-paid employment and can repatriate jobs from Low Cost Countries, the government should support the AM industry in the same manner that it supports the Automotive and Aerospace industries."

Opinion was divided on whether Canada had adequate training and skills programmes to support the future of additive manufacturing, with the majority slightly disagreeing.

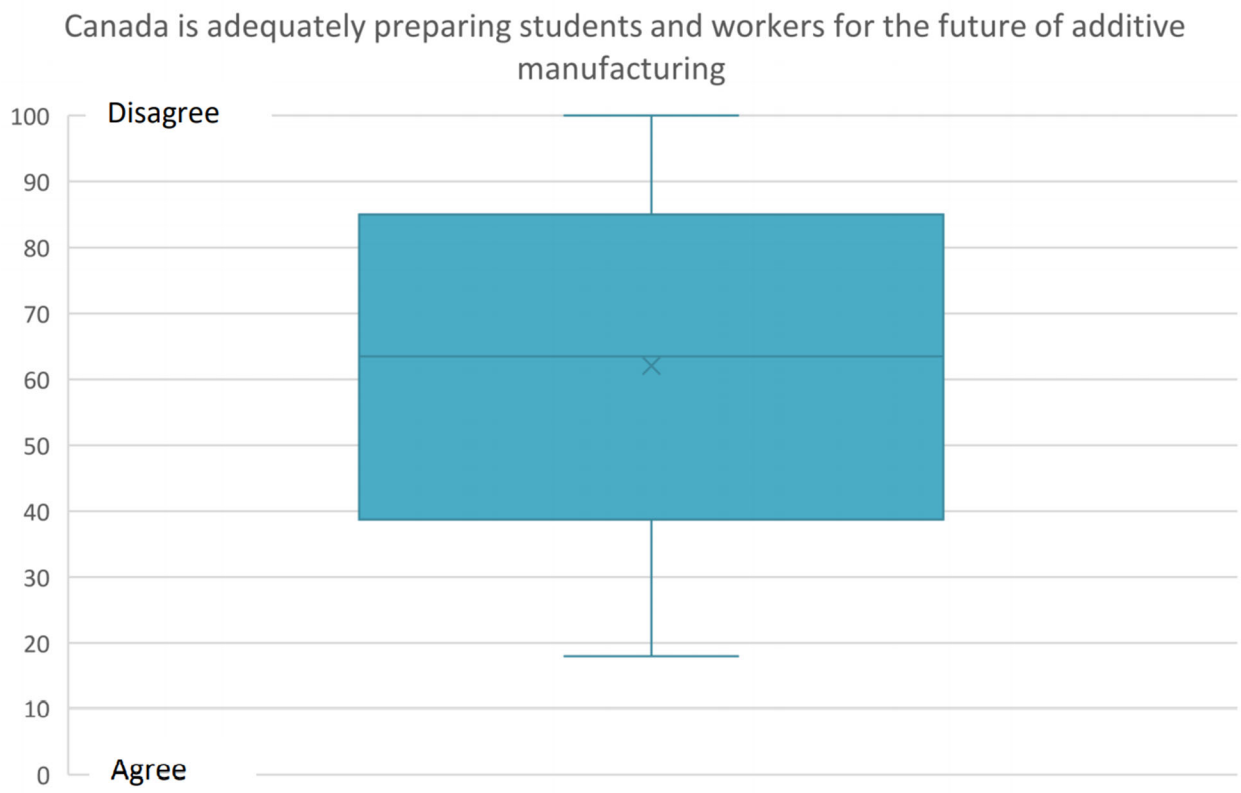

Figure 15 Students and workers are adequately prepared for the future of Additive Manufacturing in Canada

Survey respondents were asked what skills were needed and how gaps could be addressed. Except for STEM, all core additive skills, especially design for AM, were highlighted as needing improvement, or critically hard to find.

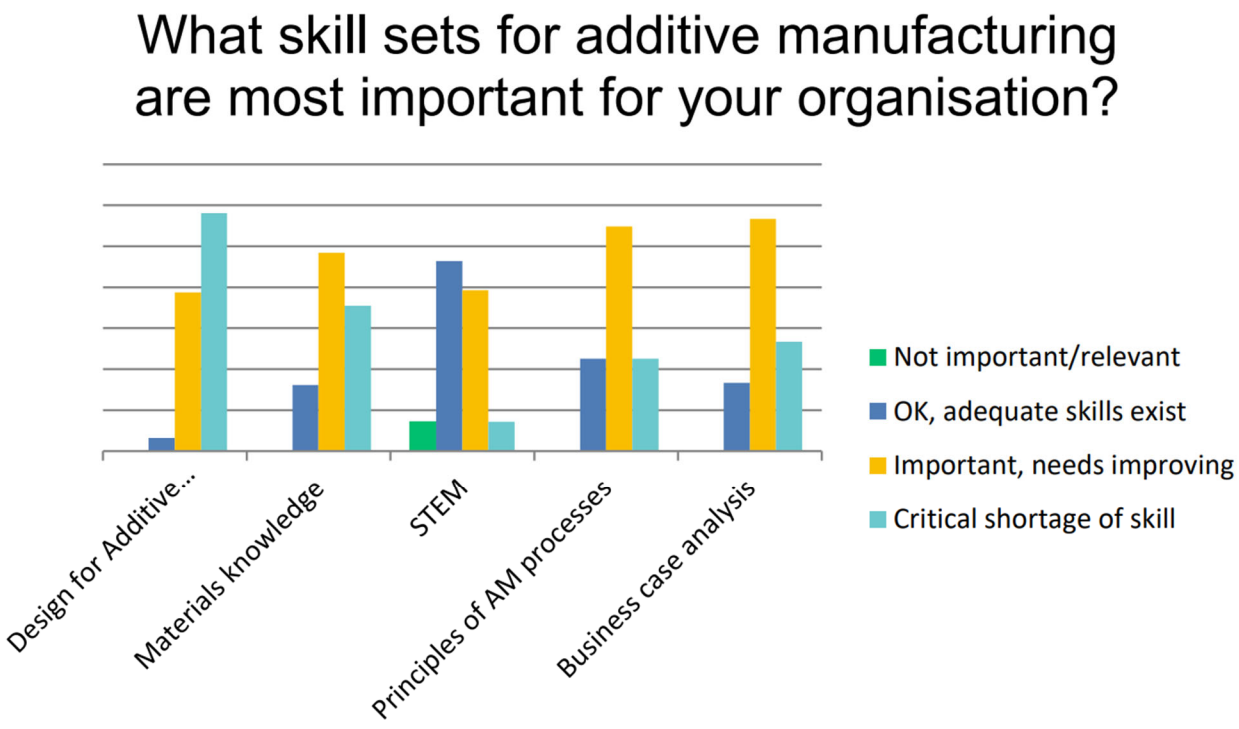

Figure 16 Skills sets needed

How can NGEN help improve additive manufacturing skills?

"Develop (a) bottom up awareness with a National AM organization to advocate to and educate industry on AM technologies"

"Training workshops that will provide credential certificates through colleges and universities"

"Better training and education of decision makers in industry, government and universities"

Main Themes – Discussion

From the survey and follow up phone interviews 2 main themes and clusters of proposals emerged – how to grow/stimulate the AM market and the training/skills needed to enable profitable growth. These themes were underpinned by better collaboration/connection both across Canada, and internationally where appropriate.

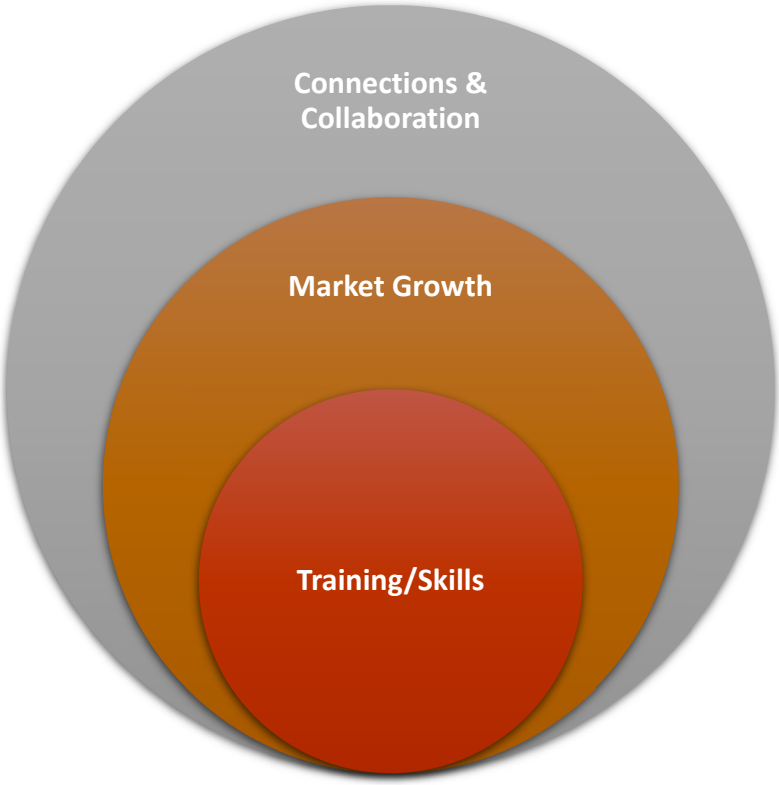

Figure 17 Main themes from AMAB consultation

Ideas for incentivizing AM adoption varied widely, from government subsidy and bond guarantees, to requiring defense/federal procurement programmes to have a required percentage of additive parts incorporated or be produced from Canadian feedstock. For example, in the UK, BAe has targeted 30% of its next generation Tempest fighter aircraft parts will be 3d printed, and 50% of assembly will be robotic, vs just 1% printed on the current Typhoon, with zero assembly automation.

Incentives were suggested to make the cost of developing new additive manufacturing suppliers outside of eg USA or Europe attractive. Since most additive processes are currently not regarded as easily "portable" between suppliers (who may have different equipment, materials and procedures) this may mean an unacceptably high risk for the customer if the supplier runs into eg financial difficulties, hence the suggestion for a bond guarantee.

There was broad agreement that hype and a bad first experience with 3d printing can cause lasting damage to adoption. The first sale is the hardest, both for the seller and the buyer, and tax credits were proposed to encourage this critical first investment. Starting with easy, low cost wins, for example in

printing of tooling jigs often means a company comes back for more equipment (as use cases multiply internally), and then later higher capability investment. Companies also often move into new markets as a result of adding printing capability.

Socialising the success of 3d printing within a company is critical to adoption. Even within large companies there are very few additive champions, and so success needs to be broadcast internally using company wide platforms like Yammer.

Risk sharing additive demonstration programmes that allow Canadian companies to understand value add for their market applications were viewed positively. It was suggested that more in depth studies (higher budget than approx $5k for Canada Makes) should be performed to allow companies to gain firsthand knowledge of process and benefits, at the same time adding to Canadian market sector case studies. Canadian SME's in sectors such as automotive tooling will need to invest more in engineering, design and simulation capability, following a similar business evolution to their larger customers.

While nearly all agreed that Canada has a strong raw materials capability for additive manufacturing, there was no consensus how to leverage this structural advantage. One automotive industry user stated that typically metal printing added capability to their value equation, but raw material prices still needed to fall from 10x premium to maybe 2x in order to unlock high volume applications. For some components having 80% material performance for 20% of current cost would be acceptable. Another respondent stated that cost calculations should not use the same spreadsheet for evaluation of a fastener vs a printed part. A system view was needed – "how does this $10 part add value to the $10,000 system?" For plastic printing the value equation is typically not added capability but part consolidation/replacement/customisation. As a result, plastic printed parts at a 10x premium (compared to injection molded) were viewed unfavourably for automotive high volume adoption. There were suggestions that Canada should look to collaborate with the petrochemical industry to achieve more vertical integration in plastic feedstock. There was also support for Canada developing specialist/next generation metal feedstock materials capability, although market demand for these materials are typically with US customers currently. There was a suggestion that "Made in Canada" should be associated with the highest quality product and feedstock.

" We need to move from applications we know are technically possible into proven machine applications. Bridge the gap between one or two off prototyping and high volume. Making 100 consistently can be harder than 1 or 1 million. Build out as proving ground here in Canada for new materials/applications and then take learning to global market."

Learning From, and With Others

> "The government should do things individual companies cannot do by themselves, eg I cannot establish a collaboration with Germany or Israel with bilateral agreements. We can/should learn from other country's journey. A single city in Germany might have more printers than all of Canada – what did they do, what are the common elements of strategy?"

The view from one of the World's largest contract manufacturing operations (all processes, including additive) was that distributed manufacturing was inevitable and would be enabled by excellence in managing both the digital thread and uniformity of material supply. The transformation was underpinned by design for additive manufacturing skills. Having competitive advantage with control points, for example in materials was important, as was managing varying scale of production. "Every time you cross a border it costs money", so the advice was to develop and serve domestic consumption. This mirrors a comment from the survey: "Additive technology users tends to chose from the local market. Cross border shipping and clearance is always a deterrent. Buying a 3D printed part halfway around the world defeats the purpose."

In the UK the Manufacturing Technology Centre has conducted a comprehensive and rigorous review of training needs for additive manufacturing. This process identified 8 core roles in Additive needed to evolve from a situation where early adopters were forced to have PhDs cleaning machines or post-processing parts with a Dremel. These core roles were then cross mapped to what was currently offered in academia or as short courses, and by equipment manufacturers. MTC found that courses did not exist for many requirements, and so device and process agnostic courses have been developed by the MTC (at considerable cost, typically over $30k per course, involving professional engineers and Learning/Development specialists) to provide a comprehensive range.

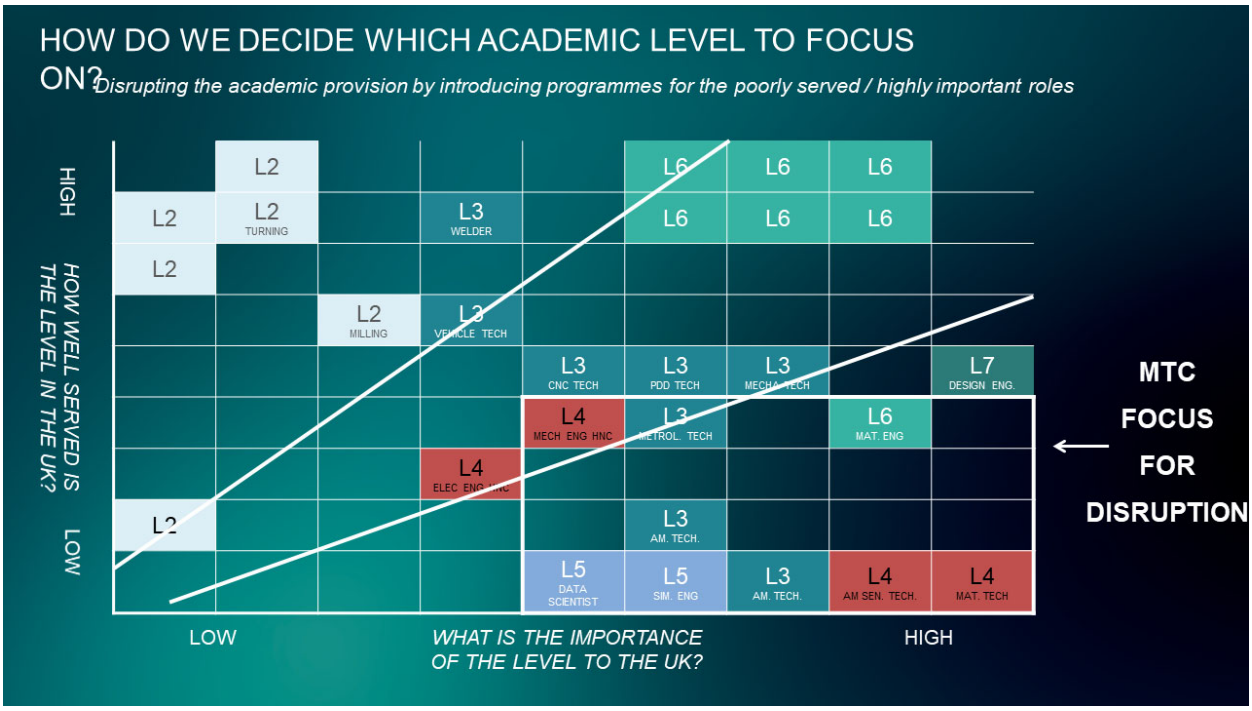

Figure 18 Additive manufacturing training needs (MTC)

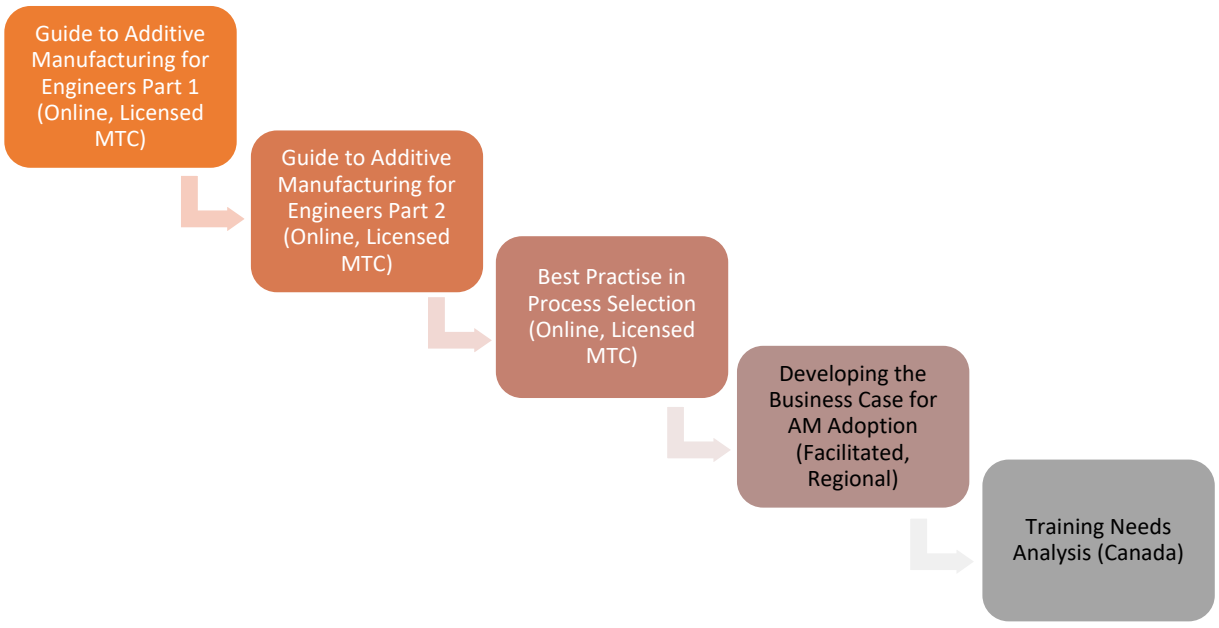

Figure 19 Example AM Design Engineer Training path (online and regional delivery)

In a 2018 report (http://reports.weforum.org/future-of-jobs-2018/) The World Economic Forum predicts that on average workers will need 101 days of additional learning in the 4 year period to 2022. In Canada anyone who entered the workforce more than 5 years ago probably never had any exposure to

additive manufacturing at college/university. More training is going to be required as digital manufacturing technology continues to evolve rapidly. A specific example was the lack of experience/exposure in high productivity binder jet technology and resulting low readiness to “hit the ground running” in industry. The same is true of multi laser (powder bed) experience. When deployed industrially “AM is learn by doing” and one suggestion was student internships at well equipped business hubs. Another proposal was a national network of regionalised customer experience centres run by Value Added Resellers who, it was drily observed, have everything to lose if technology is not adopted.

In the US programmes such as those offered by Penn State, Purdue, MIT and others, seek to address this retraining/upskilling requirement.

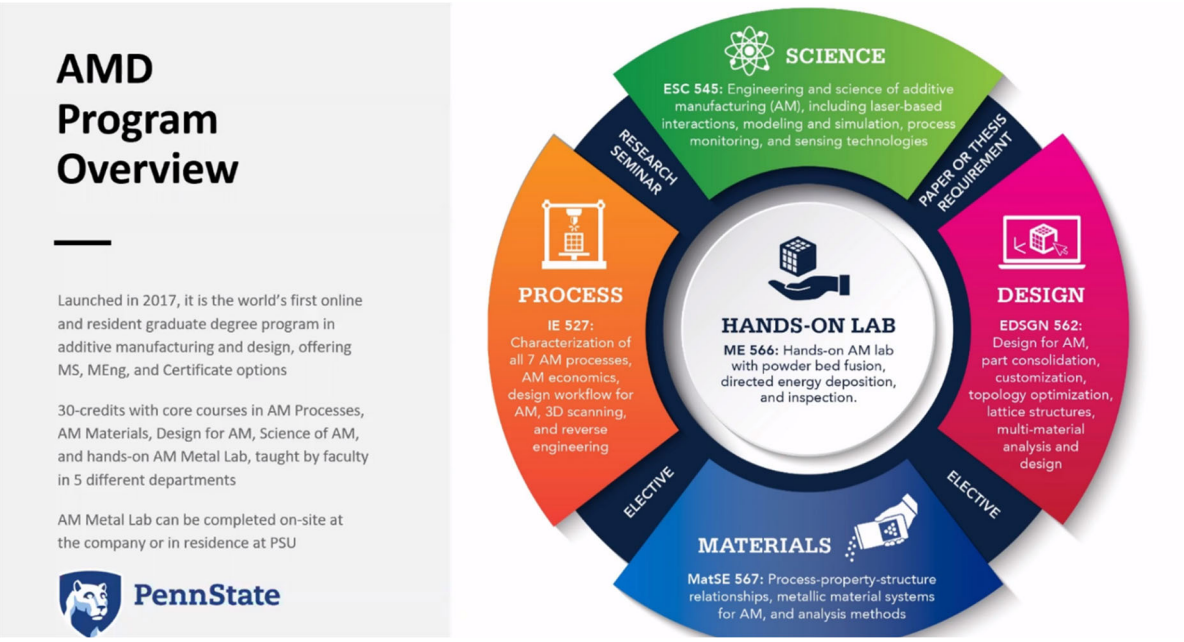

Figure 20 Penn State example Masters AM program

Next Steps

After a (virtual) round table preliminary review of the AM survey results there was widespread support for the formation of industry led, not for profit, vertical AM cluster organisation(s). The opportunity cost for Canada if its additive market is not developed will be in the billions. In order to grow the industry, it was agreed a full-time commitment was needed that no individual leader or company could provide. The "elephant in the room" was that all were possible competitors. Regional organisations (WD, AIC etc) would still allow a local connection, but benefit from being "stronger together" with strategic theme leadership from the AM Clusters. These clusters would be responsible for developing their sector business case and funding proposals.

The roundtable also saw agreement that more resources should be devoted to addressing the current piece meal training landscape in Canada (not unlike the MTC/UK scenario), and a working group was established to review training strategy/proposals, including licensed online training.

A web based hub would better connect businesses with existing additive manufacturing talent across the country. Current information is piecemeal, hard to navigate, and does not provide frameworks for adoption or personalised coaching. The proposed AM hub would provide Canada with a multifunctional tool to facilitate market growth.

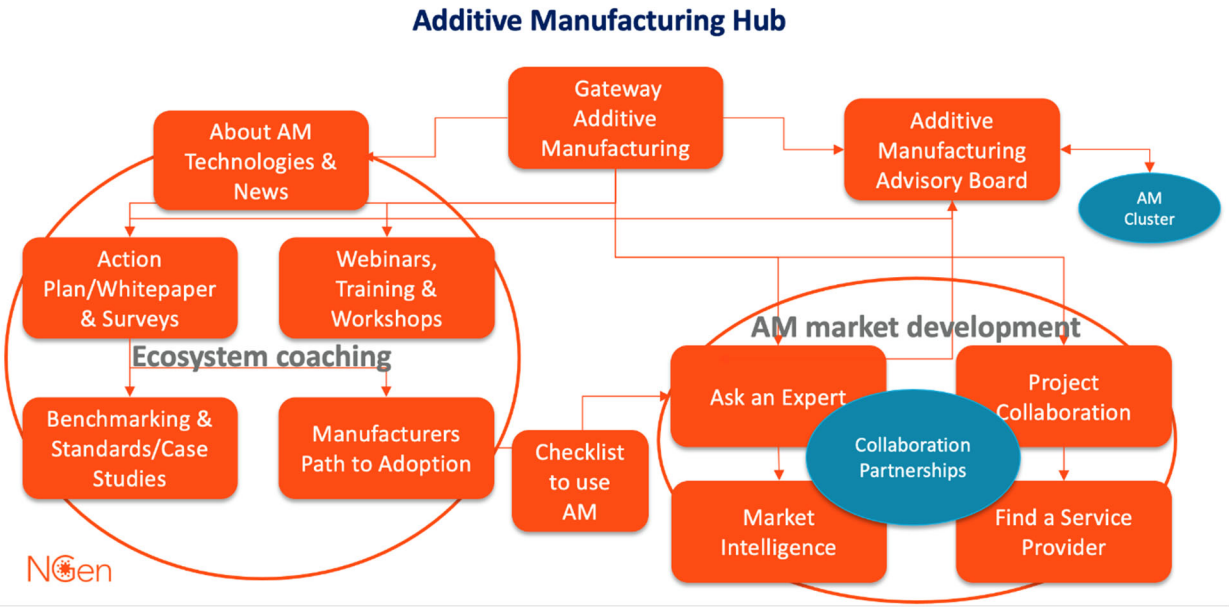

Figure 21 Possible future structure for AM hub