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Radical Technological Innovation: Case Study of Cryogenic Machining by 5ME

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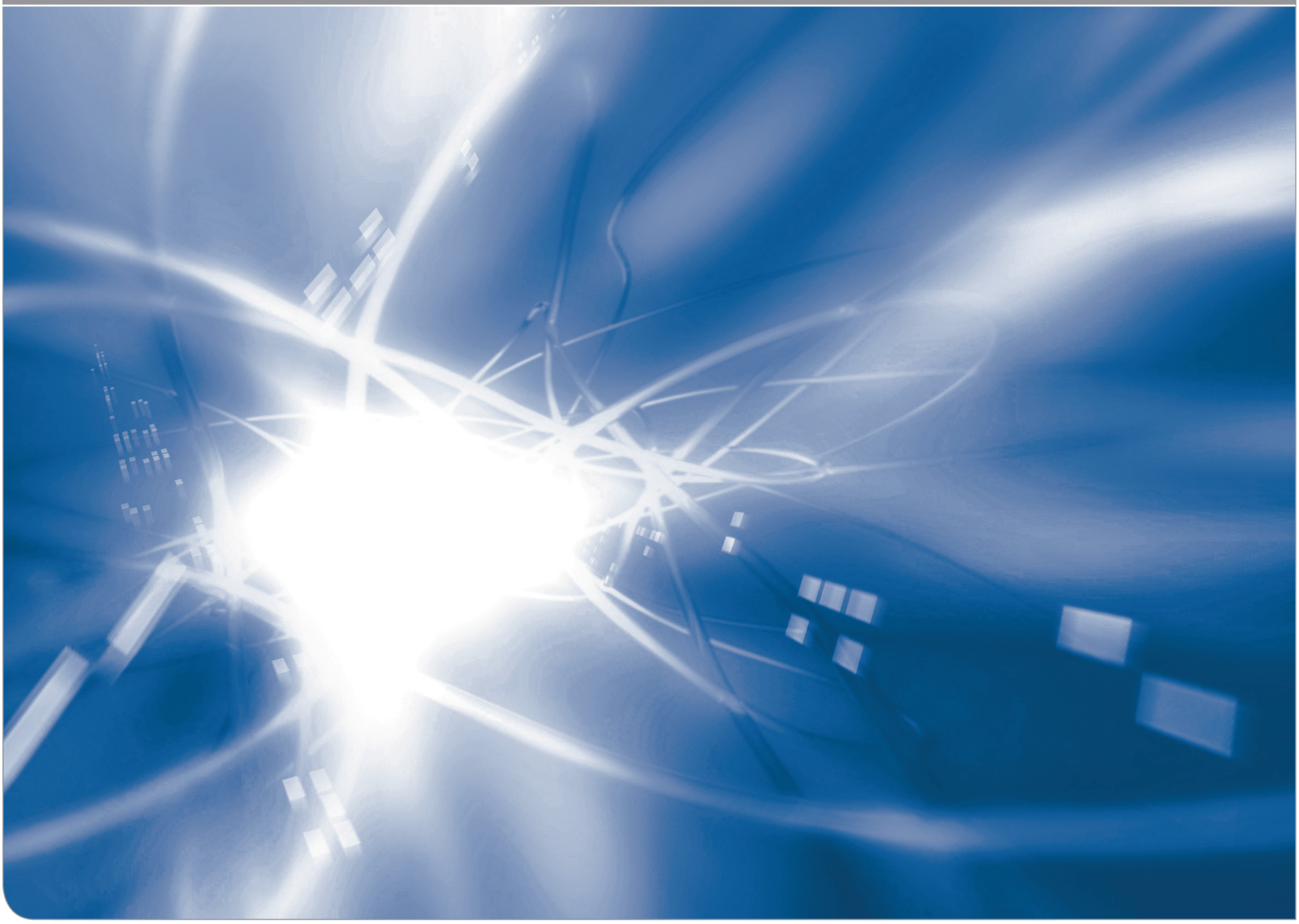

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Abstract

Radical technologies enable companies to gain exclusive market positions. However, the commercialization of such technologies is a very uncertain and risky undertaking. A sound understanding of the decisive factors that shape the circumstances and the process of technology implementation are therefore of great interest. To foster this understanding, the current case study analyzes in depth the commercialization of a radical technology within the mechanical engineering industry. In July 2013, 5ME was founded as a spin-off from the global machine tool manufacturer MAG IAS to develop and implement cryogenic machining in the market. In contrast to traditional flood coolants, the cutting heat is dissipated by means of liquid nitrogen at cryogenic temperature machining. In the focal study the technology, its target market, the organizational characteristics of 5ME, the entrepreneurial team, the innovation process, and its subsequent success will be analyzed.

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Technology

Machining generates heat at the cutting edge due to friction, shearing, and abrasion. The faster the cutting speed the higher the heat. With rising heat tool wear and thus costs increase rapidly. Correspondingly, the heat needs to be dissipated. Any cooling media helps to reduce the cutting heat. Traditional flood coolants operate at ambient temperature (+70°F/+20°C) and provide therefore insufficient heat removal in cases of particular challenging situations. This could be caused by high speed requirements or in case of machining difficult materials like stainless steel and other hard alloys like titanium, hardened steels, or carbon fiber composites (5ME, 2014c; MAG IAS, p. 2, 2012, p. 6).

In such cases, the cryogenic machining technology of 5ME is able to realize extended tool life, faster cutting speeds, and increased material removal compared to conventional coolants. This is possible as the cryogenic system operates at a temperature level of -321°F/-196°C giving the cryogenic machining a -400°F/-220°C advantage in many processes. This significant difference allows up to five times higher processing speeds and a potential increase of tool life by the factor of ten in some applications (MAG IAS, p. 2; 5ME, 2014b, 2014a, p. 1).

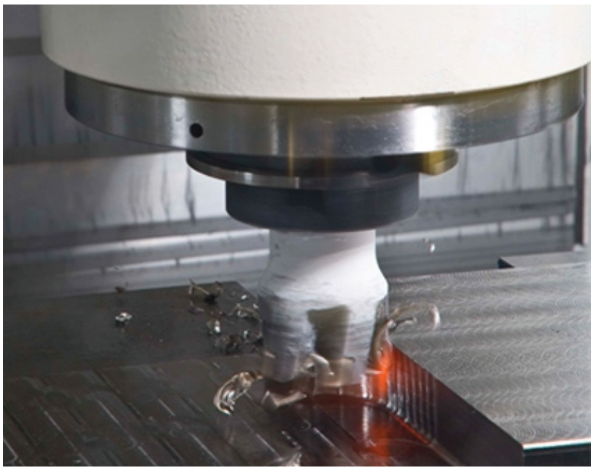

Figure 1: Cryogenic Machining (5ME, 2014i, p. 30)

In the past, cryogenic machining was difficult and costly. Mostly, the liquid CO_2 or nitrogen was sprayed at high volume at the tool and in one ill-fated test the entire workpiece surface had been submerged in liquid nitrogen. Sprayed systems allowed the nitrogen to contact more than the tool and over cool the workpiece and the machine components. Consequently, it was nearly impossible to implement cryogenic machining for larger products (5ME, 2014b).

In contrast, the 5ME technology (cf. Figure 2) utilizes vacuum jacketed feed lines for transmitting small flow rates (~0.04-0.08 l/min/cutting edge) of liquid nitrogen (LN_2) at -321°F (-196°C) through the machine, through the spindle, and through the tool directly to the cutting edge to maximize cooling effectiveness (MAG IAS, p. 2; 5ME, 2013, p. 1, 2014b, 2014i, p. 32).

For an easy handling of the cryogenic sourcing the liquid nitrogen is stored in a central storage location and then fed into the cryogenic machining system. As the system is self-pressurizing, the need for pumps and other additional power consuming assets is eliminated. In principle, there are three options for storing the liquid nitrogen: individual machine storage for standalone machines, cellular storage for small cells of two to six machines, or a centralized external storage for large scale installations (5ME, 2014g).

The feed system consists of vacuum jacketed feed lines from the liquid nitrogen storage to the spindle, ram or turret system, depending on the machine concept. The feed system is critical to seal out ambient heat and deliver the liquid nitrogen at a constant temperature level of -321°F (-196°C) to its point of use (5ME, 2014g).

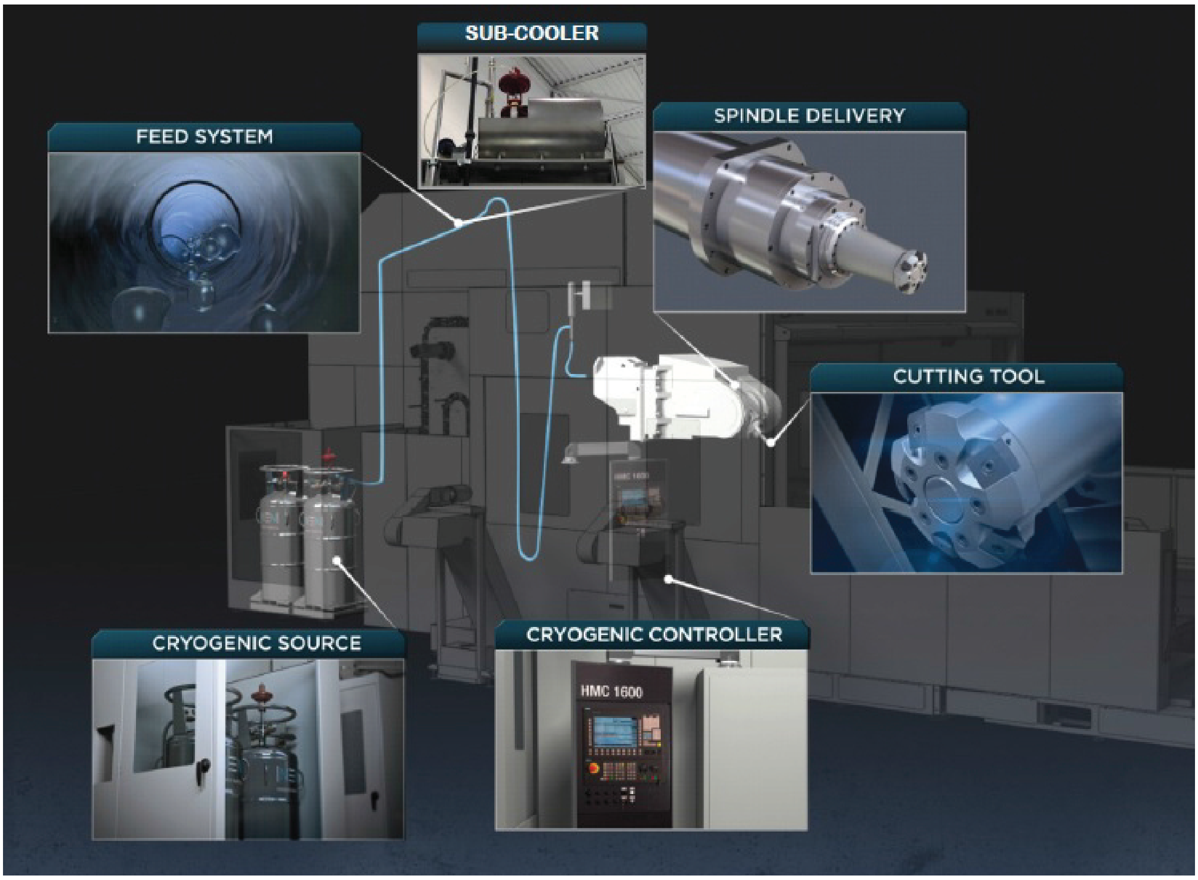

Figure 2: The 5ME Cryogenic-System (5ME, 2014g)

Within the sub-cooler, the liquid nitrogen is cooled down under its average saturation temperature (~-292°F/-180°C at 2 bar) by following the principles of heat exchangers.

The incoming LN_2 is split within a valve. The minor part of LN_2 (-321°F/-196°C at 0 bar) cools down the major part that is piped through a spiral tube within the sub-cooler (previously: ~-292°F/-180°C at 2 bar; and after sub-cooling: -321°F/-196°C at 2 bar). The flow rate of LN_2 within the whole cryogenic system is controlled with an outgoing valve of the sub-cooler which is regulated by the cryogenic control unit (5ME, 2014i, p. 35). The cryogenic control unit is a programmable numerical control based system. It allows operators to program the automatic control parameters for the flow rate of liquid nitrogen through the feed system.

Figure 3: Sub-Cooler (5ME, 2014i, p. 35)

Depending on the appropriate amount of liquid nitrogen for each individual cutting tool type, it is possible to realize the most efficient and cost effective machining process. The control system allows auto override to emergency shut off or avoids an overflow of the system (5ME, 2014g, 2014b).

For the 5ME cryogenic system a specifically designed lance needs to be used. This lance is a vacuum insulated tube that is inserted thru the spindle. As the feed lines and the lance are insulated, the liquid nitrogen can be transferred through the spindle without influencing the functional temperatures of these critical machine components (5ME, 2014g). This can be realized for new machines or for existing machines as the 5ME cryogenic system can easily be retrofitted in form of a kit into almost any existing OEM spindle, turret, or ram (5ME, 2014g, 2014a, p. 2).

The tools for cryogenic machining need to be specifically designed to interface with the cryogenic system for reasons of proper functionality and safety. Correspondingly, 5ME offers a wide range of tools specifically designed and insulated to accept liquid nitrogen in the liquid state and keep it liquid until it reaches the cutting edge. This ensures an efficient use of the liquid nitrogen and optimal cooling at the point of cut (5ME, 2014g).

Table 1: Technical Data of 5ME`s Cryogenic Machining (5ME, 2014i)

Coolant Medium	Liquid Nitrogen – LN_2
System Output	Liquid Nitrogen / Nitrogen gas-mix – LN_2/ N_2
Machining Operations	Drilling, Milling, Turning, Reaming, Boring
Targeted Materials	CGI, Ti, Al, Composites, Hardened/Stainless Steel, Alloys, Inconel
Temperature of LN_2	-321°F / -196°C
Flow Rate	~0.04 to 0.08 l / min / Cutting Edge
System Pressure	~2 bar (self-pressurizing)
Available Tools	Rotary Cutting Tools, Indexable Cutting Tools, Turning Tools, Custom-made Tools
Feed Lines	Vacuum-Jacketed Tube
Coolant Delivery	Through Spindle

Feasibility and Maturity

The LN_2 cryogenic machining has been brought into industrial use at the first customer. Thus, the technology has left the laboratory and testing status. According to 5ME's Cryogenic Engineering Manager, the engineering team managed to bring the cryogenic delivery system from an art to a science. Cryogenic flow algorithms and math models are used to calculate the appropriate flow delivery for the target cooling effect. Now, the system has reached high quality and reliable cryogenic liquid flow. On the other hand, the market is not familiar with the technology in depth. Correspondingly, it could currently be perceived as not fully mature (5ME, 2014j, 2014n).

Technological Alternatives

There are several alternative cooling methods to dissipate the heat generated by the machining process. 5ME will target hard to machine materials like titanium, compact graphite iron (CGI), stainless steel, and alloys. In the following, these technological alternatives will be presented that also address this kind of material. According to 5ME, there are five alternatives to the LN_2 cryogenic machining worth analyzing: conventional flood cooling, high pressure cooling, CO2 cooling technology, dry machining with carbides, and dry machining with ceramics / cubic bore nitride (5ME, 2014k).

Conventional Flood Cooling

Currently, the most common method for dissipating machining heat is the conventional flood cooling technology (cf. Figure 4). Moreover, the flood coolant serves as lubrication medium and facilitates the chip transportation. In general, two types are differentiated: water-based coolants and cutting oils. For the focal comparison water-based coolants will be focused. These are emulsions composed of petroleum-based lubricant oil (<3%) and water as lubricant carrier (>97%). By external feed lines the coolant is piped to the cutting edge at ambient temperature and a high flow rate (~30 l/min – 60 l/min).

Figure 4: Conventional Flood Cooling (McKechnie)

The coolant recirculates but needs to be disposed after a certain amount of time (Pušavec and Kopač, 2011, pp. 639–641; Reich and Böswetter, 2002, p. 8).

High Pressure Cooling

High pressure cooling is a technology that delivers the fluid with high pressure to the tool and machined material. Most common is an internal delivery of the coolant through the cutting tools, toolholders, and spindle interface (Richt, 2011; Diniz and Micaroni, 2007, p. 247). Depending on the application, it is possible to employ different pressures (Sandvik recommends 80 bar) and flow rates (5–75 l/min) by using different sized nozzles (∅ 0.8–1.4mm) (Lawal *et al.*, 2013, p. 211; Sandvik, 2010, pp. 5–6). The high fluid pressure allows a better fluid delivery to the cutting zone, thus providing a better cooling effect and decreasing tool wear through lubrication of the contact areas (Diniz and Micaroni, 2007, p. 247).

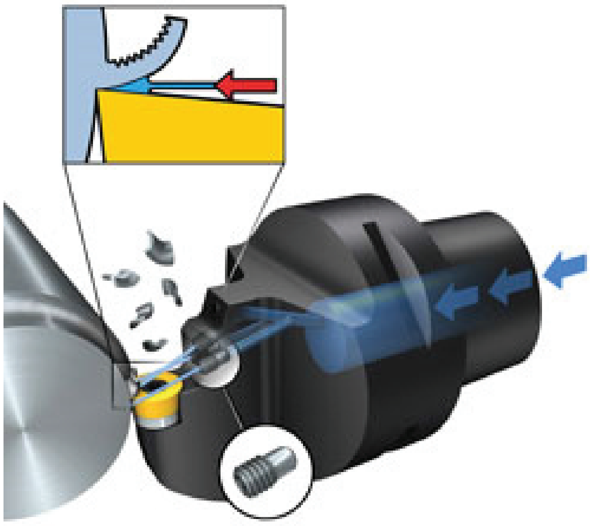

Figure 5: High Pressure Cooling (Richt, 2011)

Furthermore, high pressure cooling has a better chip breakability as the jet has on the one hand a forming effect, and on the other hand, the cooled chip is brittle and easy to break (Richt, 2011).

CO2 Cooling Technology

At the approach of CO_2 cooling technology, compressed gaseous CO_2 is refrigerated into the liquid phase. The chilled liquid is transported through a capillary tube through the machine, spindle, toolholder, and tool to the cutting edge in a liquid state. This is done at a certain pressure and at ambient temperature. The cooling of the CO_2 to a maximum of -99.4°F/-73°C occurs at the nozzle, when the CO_2 expands. This technology gains its biggest advantages at machining high temperature alloys such as titanium, Inconel, stainless steel, and composites (CoolClean Technologies, 2014a; Walter, 2013). With this technology, users can machine faster or receive an extended tool life compared to conventional flood cooling.

Figure 6: CO2 Cooling Technology (Walter, 2013)

Furthermore, the CO_2 cooling technology has advantages with respect to environmental, health, and sustainability issues (CoolClean Technologies, 2014b; Walter, 2013).

Dry Machining with Carbide and with Ceramics / Cubic Bore Nitride

In principle, there are three different tool materials used for dry machining of hard materials: carbide, ceramics, and cubic bore nitride (CBN). Carbide tooling can cut material with hardness up to 55 on the Rockwell hardness scale (HRC). From the hard-to-machine materials, carbides are mainly used to cut titanium. Ceramic and CBN inserts work well when hardness exceeds 50 HRC (CIM, 2011; 5ME, 2014k). For example, ceramic tools are used for machining Inconel 718 and CBN for hard turning processes.

Figure 7: Dry Machining (Machinery Market, 2013)

Furthermore, ceramics and CBN need to be dry, as they may crack in case of cooling due to high thermal differences. As dry machining with ceramics and CBN mainly exhibits the same characteristics, it makes sense to treat them as one single technology category (CIM, 2011; 5ME, 2014k).

At the process of dry machining in general, there is no usage of any coolant. Correspondingly, this is ecologically desirable and offers cost reduction opportunities as the conventional coolant infrastructure is made obsolete. As the friction and adhesion between chip and tool tend to be higher at dry machining, the temperatures and wear rates are higher and consequently, tool lives shorter (Galanis *et al.*, 2008, p. 91).

Just getting rid of the cooling system and simultaneously keeping the previous manufacturing parameters, will not be successful (Reich and Böswetter, 2002, p. 9). For efficient manufacturing the tools need to be specified with respect to materials and geometry (Kissler, 2004, p. 18). To gain reliable control over chip formation, it is necessary to use cutting inserts with especially adapted chip shaping grooves (Galanis *et al.*, 2008, p. 92).

Relative Advantageousness

To gain the relative advantageousness of the LN_2 cryogenic machining of 5ME with respect to the existent cooling alternatives, ten evaluation criteria have been established in consultation with 5ME's Cryogenic Engineering Manager: ability to machine tough material, tool life, cycle time, product quality, health and safety, environment and sustainability, investment costs, running costs, uptime/downtime, and construction change of machine infrastructure. The analysis is carried out with respect to the conventional flood cooling technology as this is the de facto standard technology in the field (5ME, 2014k).

Ability to Machine Tough Material

Advanced engineering materials, such as titanium, special alloy, and some stainless steel offer a unique combination of properties like high strength, resistance to chemical degradation, and wear resistance. Therefore, these advanced materials are being frequently requested in industry. One of the main obstacles towards the fast commercialization of these materials is the difficulty in machining them to required shapes and the related high machining costs. These difficulties are due to the high heat generation at the energy intensive machining process and the relatively low thermal conductivity of these materials (Wang and Rajurkar, 2000, p. 168). The latter attribute makes it difficult to transport heat away from the machining area and consecutively promoting thermally-related wear. Accordingly, the ability to machine these materials depends on the cooling ability of the considered technology (Richt, 2011; Su *et al.*, 2006, p. 760). As the high cutting temperature acts close to the cutting edge, the LN_2 cryogenic machining of 5ME is advantageous compared to its alternatives. The LN_2 is indirectly applied to the cutting edge at -321°F/-196°C. Traditional flood coolants have temperatures around +70°F/+20°C, giving cryogenic machining a -400°F/-220°C advantage (5ME, 2014b). The cooling with CO_2 happens at -99.4°F/-73°C next to the cutting edge what corresponds to a -220°F/-140°C advantage for 5ME`s technology (Walter, 2013). High pressure coolants have the same temperature level as conventional flood coolants, but due to their high pressure and optimized nozzle design the coolant is closer delivered to the cutting edge than with conventional flood cooling. In contrast to carbide, ceramics and CBN resist a high amount of heat and are accordingly appropriate for machining tough material (5ME, 2014k).

Tool Life

Metal machining produces extreme temperatures that are the primary cause of tool failure. By using the cryogenic system of 5ME, an increased tool life of up to ten times the tool life of conventional flood coolants could be realized. Longer lasting tools allow decreased direct costs for each part (5ME, 2014f). Within diverse test runs, 5ME could realize a tool life increase of ten times for compacted graphite iron, three times for titanium, and a 40% increase for diverse composites (5ME, 2014e). For the CO_2 cooling technology, several studies showed a potential tool life increase of 20%-200% depending on the machined material (CoolClean Technologies, 2014d). Similarly, the application of coolant at high pressure could increase the tool life up to three times (Lawal *et al.*, 2013). For dry machining the tool life of ceramics and CBN are comparatively limited, but the tool life of carbide is worst (5ME, 2014k).

Cycle Time

Beside the tool life, the machining cycle time is one of the main factors influencing process profitability. With the 5ME cryogenic machining it is possible to run two to five times faster for hard-to-machine materials than with conventional cooling. For compacted graphite iron a five times increase in finishing cutting speed, for titanium a two times increase in semi-finish cutting speed, and for steel alloys a 1.6 times increase in semi-finish cutting speed could be realized with the LN_2 cryogenic system compared to conventional flood cooling (5ME, 2014a, pp. 1–2). The CO_2 cooling technology enables 20-75% faster cycle times and with high pressure cooling approximately 40% faster cycle times are possible compared to flood cooling (CoolClean Technologies, 2014c; Sandvik, 2010, p. 11). As the machining heat rises with increasing speed and similarly tool wear, just a low cycle time level is realizable with carbide tooling at dry machining. With ceramics and CBN very high cutting speeds and correspondingly cycle times are possible (CIM, 2011; 5ME, 2014k).

Product Quality

As the addressed materials are hard-to-machine, product quality is an important distinguishing characteristic for the alternative technologies. Test results of 5ME have shown that their LN_2 cryogenic machining solution has improved overall surface integrity and part quality. Benefits such as a reduction in white layer, grain boundary distortion and bur formation have been especially important for the aero structure and aero engine customers (5ME, 2014f). 5ME states that according to their tested parts, the LN_2 cooling technology has produced smoother and more reliable finished items than traditional cooling methods (5ME, 2014c). CoolClean technologies, a provider of a CO_2 cooling system, report of their ChilAire System to leave a good finish after machining. According to their website, the system produces a superior surface finish that frequently will not require a finish cut (CoolClean Technologies, 2014c). Due to low cutting forces generated by the improved cooling and lubrication ability of high pressure cooling, surface finish is at a high level and free from physical damages (Lawal *et al.*, 2013, p. 211). In dry machining operations, cooling and lubrication functions are not available. By comparison, wet machining has correspondingly better part quality and less tool wear than dry machining. For carbide tools this difference is significantly bigger than for ceramic and CBN inserts (Galanis *et al.*, 2008, pp. 91–92; 5ME, 2014k).

Health and Safety

In conventional machining, the coolant emulsions are containing mineral oil and surfactants based on petroleum (Pušavec and Kopač, 2011, p. 639). Prolonged contacts of machine operators with these cutting fluids may cause skin and respiratory diseases (Su *et al.*, 2006, pp. 760–761). Therefore, special care needs to be taken in case of conventional flood coolant for reasons of health and safety. As high pressure cooling utilizes the same coolant, these technologies range on the same level. LN_2 cooling has significant advantages with respect to safety and health related issues. When liquid nitrogen touches the air, it evaporates, leaving only nitrogen, a safe, breathable, nonflammable gas which makes up 78% of the air we breathe. There is no contamination of the work environment in the form of fumes and slippery surfaces (5ME, 2014f). The only health concern is that there is too much nitrogen, but this risk is minor (5ME, 2014m). Similarly, the use of the CO_2 cooling technology eliminates these coolant issues and reduces health risks. As CO_2 is a greenhouse gas and less healthy than LN_2, this technology has been ranked below 5ME`s technology. For both dry machining categories there are no concerns with respect to hazardous coolants or further safety issues like technology education requirements (Galanis *et al.*, 2008, p. 91).

Environment and Sustainability

Conventional flood coolants have many drawbacks which negatively impact the environment and sustainability during their production, use, and disposal. Flood cooling may lead to workpiece contamination and environmental hazards (5ME, 2014f). An improper disposal of cutting fluids could result in ground, water, or air pollution (Su *et al.*, 2006, pp. 760–761). Aggravating this situation, there is increased energy consumption with high pressure cooling leading to an even worse evaluation compared to conventional flood cooling. Since the LN_2 cryogenic machining and the CO_2 cooling technology cut without coolant, there is no need for mist collection, filtration, or disposal of coolant waste. Energy consumption is lower without coolant fans, pumps, and drives. In addition, chips and workpieces remain dry and uncontaminated for a safer work area and easier recycling (5ME, 2014f; CoolClean Technologies, 2014b). In contrast to the greenhouse gas CO_2 of the corresponding cooling technology, the evaporated nitrogen of the LN_2 cryogenic machining technology is a non-toxic, breathable, atmospheric, non-greenhouse gas (5ME, 2014b, 2014a, p. 2). By not using any cutting fluid, dry machining (carbide and ceramics/CBN) is ecologically desirable and correspondingly obtains the highest evaluation (Galanis *et al.*, 2008, p. 91).

Investment Costs

The cryogenic system of 5ME could be realized for existing machines just like for new machines. Correspondingly, the investment costs for both business cases need to be distinguished. Existing machines will be retrofitted by adding a cryogenic retrofit kit. Thus, the costs for this kit are an additional investment if you start with a conventional flood cooled machine. Nevertheless, if you want to turn to any of the other cooling alternatives (high pressure, dry, CO_2), there are also changing costs that need to be considered. At the focal analysis, the focus will be on the investment costs for a new machine (5ME, 2014g, 2014a, p. 2, 2014m).

As the cooling alternatives should be compared, the costs for the underlying machine will not be considered. For dry machining with carbides there are no additional elements and accordingly costs. This is the case for dry machining with ceramics/CBN as well, but the cutting tools itself cost more. A conventional flood cooled machine is equipped with a coolant pump, a coolant tank, and a filtration system for the used coolant. According to 5ME's Cryogenic Engineering Manager, the equipment of the cryogenic LN_2 machine (sub-cooler, tank, controller, tools) would currently cost roughly 25% more than a conventional cooling system. While launching this new technology into the market, this issue is one of 5ME`s challenges and the company is continually reducing the costs of its cryogenic system. However, according to 5ME the customers' cost benefit outweighs their investment. The high pressure system would add high pressure pumps to the conventional cooling system and possibly an increased coolant tank. The CO_2 system (tank, pump, controller, tools) costs less, but is slightly more expensive than a conventional coolant system (5ME, 2014k, 2014m).

Running Costs

The running costs for the traditional cooling system mainly include the costs for coolants, coolant disposal, energy costs, personnel costs, and costs for tool exchange. The coolant recirculates at a high flow rate (~30 l/min – 60 l/min), but needs to be disposed after a certain time period (Pušavec and Kopač, 2011, pp. 639–641; Reich and Böswetter, 2002, p. 8). Disposal of these coolants is costly and time-consuming. In case of LN_2, CO_2, and the two dry machining alternatives, these disposal costs do not incur, at high pressure cooling they do. Conventional cooling requires pumps and filters which increase energy consumption.

This is worse for high pressure cooling, as this technology demands even more energy. The cooling methods LN2, CO2, and the two dry machining technologies consume much less energy. Personnel costs incur at all technologies and will not be further considered. Costs for conventional tools are on the same level for the technologies conventional flood cooling, high pressure cooling, and CO_2 cooling. Currently with low production volumes, the tools used for LN_2 cooling are approximately 20-30% more expensive than conventional tools. With higher volumes this price difference can be reduced another 50%. Ceramics are expensive, but carbides and CBN are most expensive. Multiplied with its tool life the corresponding tooling costs for each technology could be calculated. With a flow rate of ~0.04-0.08 l/min/cutting edge and costs of 0.06$/l the LN_2 coolant is comparatively cheap. CO_2 is consumed at high volumes and accordingly high costs. In summary, LN_2 cooling has the lowest running costs, followed by dry machining with ceramics/CBN, CO_2 cooling, dry machining with carbides, conventional flood cooling, and high pressure cooling (5ME, 2014j, 2014k, 2014f, 2014i, p. 51; CIM, 2011).

Uptime / Downtime

One of the critical parameters of process productivity is uptime respectively downtime of a machine. 5ME conducted an analysis of reasons for machine downtime. According to 5ME's Cryogenic Engineering Manager, more or less two thirds of all machine downtimes could be associated with coolant issues: problems with coolant pumps, coolant filtration, or coolant chips. These problems do not occur at LN_2 cooling, CO_2 cooling and dry machining technologies. Nevertheless, 5ME has not run production enough to understand if there are some preventative maintenance issues to consider (5ME, 2014m).

Another important influence parameter on downtime is the necessity of tool change. Each time a tool fails, the machine needs to be shut down, the tool removed, a new tool located, installed, and then the program needs to be restarted. This causes productivity loss and can be directly attributed to tool life (CoolClean Technologies, 2014c; 5ME, 2014f).

Construction Change of Machine Infrastructure

According to 5ME, their cryogenic system is brand agnostic and can be applied to almost any existing process or by retrofitting even to any existing machine (5ME, 2014c). Nevertheless, LN_2 cooling is a new technology with a new system that causes changes within the existing machine infrastructure of 5ME`s customers. Changing an operating system commonly causes difficulties, but occasionally offers opportunities on the other hand.

Most machine tools are designed for wet machining. Accordingly, this is the standard version and causes no changing effort (Kissler, 2004, p. 19). Dry machining requires the least modification effort of the alternative cooling technologies. Mainly the cutting tools need to be adapted. Hereby, ceramic and CBN tools are slightly more work-intensive than carbide tools. Additionally, the cooling system can be left away at dry machining, which is advantageous from the cost perspective. Equally, this could be done for LN_2 cooling and CO_2 cooling. Concerning CO_2 cooling less effort is needed to change the machine tool system compared to LN_2 cooling (5ME, 2014f, 2014m).

There are a few prerequisites for integrating high pressure coolant into a machine. The system`s seals and valves should be able to handle the high pressure. Moreover, special nozzles and high pressure pumps need to be added to achieve the required flow rate. Sometimes an extended filtration system or a bigger tank is needed. Accordingly, an additional infrastructure needs to be added to the existing one for high pressure cooling (Richt, 2011; 5ME, 2014m).

Overview of the Relative Advantages of 5ME`s LN2 Cryogenic Machining

To gain a better overview of the relative advantages of 5ME`s LN_2 cryogenic machining, the alternative cooling technologies have been evaluated with respect to the degree to which they meet the ten evaluation criteria on a ten-stage ordinate scale (cf. Figure 8).

With respect to eight of ten evaluation criteria the LN_2 cryogenic machining of 5ME is top ranked. Especially, for tough-to-machine materials the technology has great advantages regarding tool life, cycle time, and product quality. Accordingly, the productivity of this process is on a very high level compared to its alternatives. This becomes additionally apparent if the low running costs and low downtime rates are focused which leads to a higher profitability of the focal process. Furthermore, LN_2 cryogenic machining is a very green and safe technology. Concerning this matter, the technology is on the same level as dry machining, as no toxic coolants are used and nitrogen is an atmospheric gas.

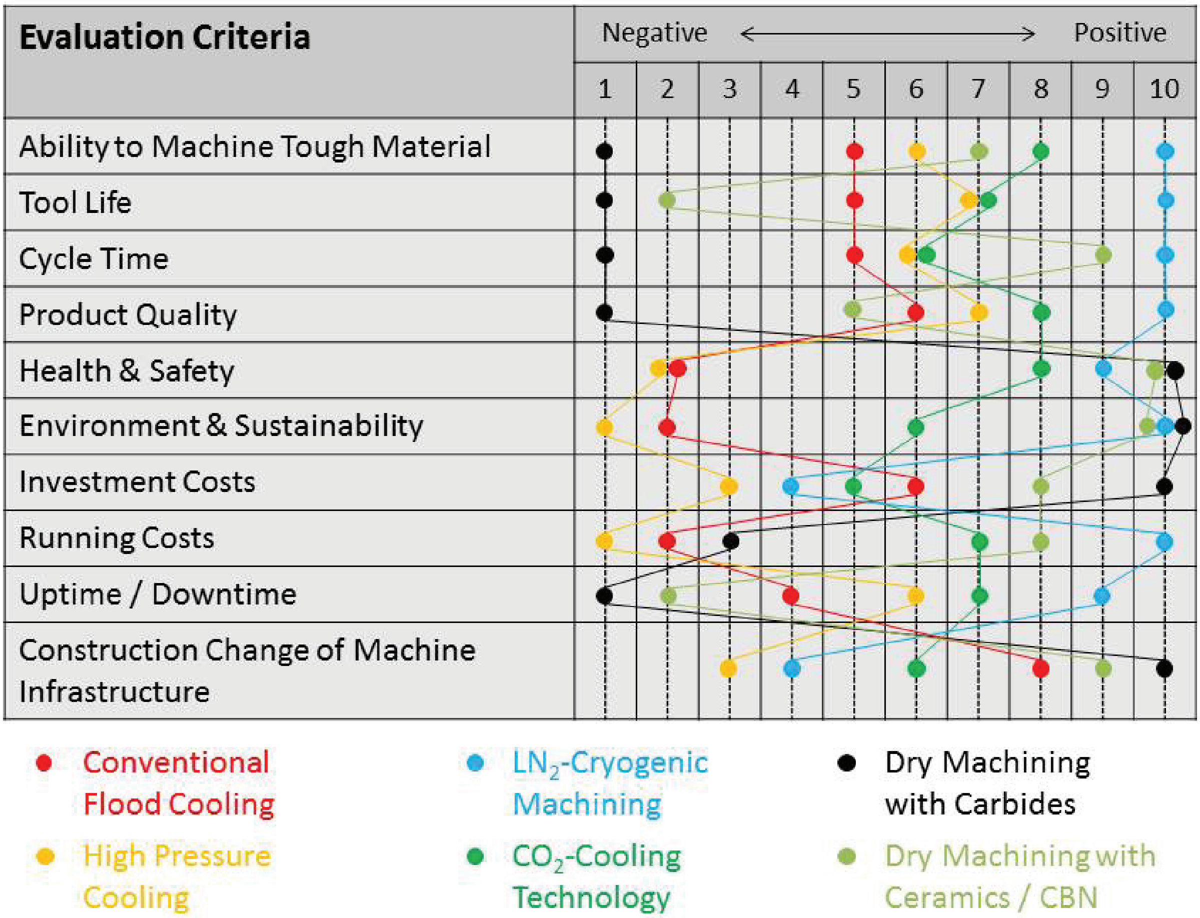

Figure 8: Overview of Relative Advantages of 5ME`s LN_2 Cryogenic Machining (Wohlfeil, 2014)

The two dimensions in which the technology is among the lowest ranked technologies are investment costs and construction change of the machine infrastructure. These two characteristics seem to be typical for a disruptive, new technology as there are several obstacles and barriers in the emerging phase that hamper the market entrance of radical new technologies. According to 5ME's Cryogenic Engineering Manager, 5ME is aware of these issues and is reducing the investment costs for the cryogenic system (5ME, 2014m). Equally, 5ME is working on business models to address these factors.

Moreover, in the current emerging phase of this technology, it is essential to address the right market segment to gain references in the market and to proof industrial application maturity. Therefore, the selected target market for 5ME`s radical LN_2 cryogenic machining technology will be analyzed.

Target Market

5ME's long-term vision is to basically eliminate coolants on every machining operation and shift the market to cryogenic machining. In the short term, the company is focusing on the difficult to machine materials as these applications gain an intermediate effect from the new technology (5ME, 2014j). Initially, the biggest benefits for cryogenic machining were found in materials like titanium, hardened and stainless steel, grey and compacted graphite iron, and carbon fiber composites. These materials are most commonly used for applications such as aero-structure, aero-engines, cylinder blocks and heads, pumps, and turbines. Correspondingly, the prime focus of 5ME contains four industries: aerospace, oil & gas, automotive, and construction and agriculture. Due to the costs of the cryogenic system and the tools, the return on investment is better for larger tools and parts. Thus, medium to large size machines with a table size of 500 mm and larger are addressed. Furthermore, a single spindle horizontal machine is preferred, as the gravity would help to transport away the chips. In contrast to endless cutting processes, interrupted cuts as they are existent in case of milling provide the advantage of tool re-cooling at cryogenic machining (5ME, 2014l, 2014o).

Since, 5ME is located in Cincinnati and Detroit the geographic focus is the Northern American market for roughly the first three years. Due to limited resources, the company is in process of attaining a couple of machines as references and commercial successes into running production in close proximity, so they could quickly support them. This geographic focus corresponds to the location where the machine is brought to production, not where the machine tool builder is headquartered (5ME, 2014l, 2014o).

From a customer standpoint, 5ME follows a two group strategy. One group of customers consists of companies that machine parts. They have machines that are already in production and 5ME would sell the cryogenic system to them in form of retrofit kits. The other group of customers consists of machine tool builders and machine tool distributors. 5ME will work with them to apply cryogenic machining to their machines before they are shipped to the end-user (5ME, 2014n).

According to 5ME's Marketing & Product Manager, the company's target end-users will be those working with expensive or difficult-to-machine materials, employing a large number of assets, with high costs for consumables and energy, and committed to organizational change (5ME, 2014l, 2013, p. 2).

Industry Context

The North American industry has just emerged from one of the deepest depths since the great depression. This has led to a heightened understanding of 5ME's potential customers that efficiency and productivity are important drivers of global competitiveness and having a sustainable business in the end. LN_2 cryogenic machining exactly addresses these needs (5ME, 2014l).

In November 2014, the United States and China agreed on targets for carbon emissions reductions for the next years during a summit of the Asia-Pacific Economic Cooperation in Beijing (Landler, 2014). This is one indicator, inter alia, of the ever stricter laws and regulations addressing environmental impacts within the US market. According to 5ME's Cryogenic Business Development Manager, the European market is quite ahead, but environmental impacts get more and more serious in the US industry as well (5ME, 2014o).

The regulations are not as strict as they should be, but environmental friendliness becomes increasingly a central factor in the American industry (5ME, 2014l).

Compared to its alternatives, LN_2 cryogenic machining has great advantages with respect to its environmental friendliness. Correspondingly, 5ME has not come across any government related regulations that have been a barrier for the technology. In contrast, ever tougher environmental regulations have a positive impact on the commercialization of this technology (5ME, 2014o).

Competitive Situation

The internal cooling technique of LN_2 cryogenic machining is unique to 5ME. Correspondingly, there is no competitive situation with respect to this specific technology (5ME, 2014l). According to 5ME, it is not competing with other cooling solutions or solution providers to win orders. From a product standpoint, 5ME is not seeing a real competitive issue right now. Of course there are a lot of questions relative to alternative coolant methods. 5ME's job is more about educating and convincing the end-user to change the way they traditionally machine parts (5ME, 2014o).

Market Barriers

One of the basic barriers to enter a market with a new technology is obligatory approvals. These differ fundamentally in the different industries. With respect to the primary focused industries of 5ME, the highest requirements for technology approval exist in the aerospace industry, followed by the automotive industry. Oil & gas and construction machinery have the lowest requirements (5ME, 2014o).

Due to the critical nature of the parts that go to an airplane, every change that has been done with respect to the materials or the machining process has to be approved by the aircraft manufacturer. This is a very time consuming procedure and needs to be done with every aircraft manufacturer just the same. For example, it took 5ME two years to get the approval by Lockheed Martin for rough and finish machining of titanium. Once it is approved, all suppliers are allowed to machine parts according to the certified process (5ME, 2014o, 2014j).

Within the automotive industry, there is no formal certification process, but there are multiple phases of technology implementation. After several test rounds, the automotive OEMs run offline production for several months to check repeatability and robustness of the technology. As mentioned above, the oil & gas industry and the construction machinery have the lowest approval requirements. According to 5ME's Cryogenic Business Development Manager, the single issues were operator health and safety. Therefore, 5ME conducted an audit for their first oil & gas customer to remove his concerns if the evaporating nitrogen affects the health of the machine operator (5ME, 2014o).

Apart from the certification requirements, cryogenic machining is a radical new technology that requires a lot of change. It is not just changing the machine, but it is also changing the supply chain, the tools, and the minds of those who operate and manage the manufacturing operation. Furthermore, the process parameters completely change as the traditional manufacturing rules cannot be applied. Understandably, this leads to a great uncertainty on the customer side. Most of the potential customers want to see references. Once 5ME has established references in each industry, it will be much easier to convince new customers to switch to cryogenic machining, but initially this is a barrier to overcome (5ME, 2014o, 2014n, 2014j).

Another barrier to overcome, is the fact that 5ME is a small start-up company with no established reputation. Correspondingly, it takes a lot of effort to convince suppliers and customers that 5ME is viable and stable. The terms and conditions of contracts to be closed are frequently worse than for big companies (5ME, 2014n, 2014l).

Opportunity

By 2014, the American metalworking machinery manufacturing industry has rebounded from recession. Dramatic growth in money supply, high and rapidly growing capacity utilization, strong and improving business conditions, and a historically high durable goods production have led to an increased demand for machine tools. According to the 2015 Capital Spending Survey by Gardner Research, U.S. metalworking facilities will spend $ 8.822 billion on new metal cutting equipment in 2015, an increase of almost 37% compared to the latest estimate for 2014 of $ 6.463 billion (Gardner Research, 2014, p. 2; IBISWorld, 2014). Both, the automotive and the aerospace industry, contribute highly to this development. With respect to aerospace, there is a great ramp up of production all across the new generations of aircrafts for commercial and military usage over the next few years. Boeing is planning to increase the medium-term production of the “Dreamliner 787” and the medium-haul aircraft “Boeing 737” significantly. Similarly, the production of the “F-35 JSF” by Lockheed Martin and the “A350” by Airbus will be started (5ME, 2014o; Janetzke, 2014).

The following table indicates the estimated spending on new metal cutting equipment for 2014 and 2015 of 5ME’s focus industries in the U.S.:

Table 2: Estimated Spending on New Metal Cutting Equipment in different U.S. industries (Gardner Research, 2014, p. 4)

Automotive	Aerospace	Oil/Gas Field/Mining Machinery	Off-Road/Construction Machinery
2014: $ 561.1m	2014: $ 167.4m	2014: $ 235.1m	2014: $ 122.8m
2015: $ 759.3m	2015: $ 307.4m	2015: $ 165.8m	2015: $ 163.3m

According to Kline, roughly 50% of the companies buying a new machine in 2015 are doing this to increase their machine/equipment capacity and roughly 45% want to reduce their costs (Kline, 2014, p. 21). This motivation corresponds to the main advantages of 5ME’s cryogenic machining.

Due to the increased demand for production capacity, these national industry trends strongly support the establishment of cryogenic machining. 5ME initially expects the market for retrofit machines to be bigger than for new machines. As they already have machines on their floor, 5ME’s customers can increase their productivity with a reasonable investment. These customers have historical data on parts that were running on those machines like tool life and throughput. Correspondingly, it is easier for them to compare and calculate their return on investment. Furthermore, there are much more machines in the field that could be equipped with cryogenic machining than new machines will be sold over the next few years (5ME, 2014o).

Several machine tool builders are very interested in 5ME’s technology. However, most of them wait until their customers require new machines with an integrated cryogenic system. Thus, 75% of 5ME’s focus is on retrofitting machines over the next two years (5ME, 2014l, 2014o).

Assuming that the resources are available, there are roughly 100 machines that could realistically be retrofitted just from the four to five customers 5ME is already working with.

From a market opportunity standpoint, 5ME's Cryogenic Business Development Manager assumes that there are probably thousands of machines that fit the criteria of cryogenic machining. 5ME expects tremendous demand, once each of 5ME's focus industries has a cryogenic machine running in production (5ME, 2014o).

By now, 5ME has delivered their first cryogenic system to a customer from the oil & gas industry and has sold another kit to a machine tool manufacturer. Several positive test runs have been carried out during 2014 at 5ME's Tech Center. On this basis, the company expects to get eight to ten incoming orders throughout 2015. If everything goes to plan, 5ME anticipates greater than a 100% order increase every year over the next three years. After that, 5ME estimates to have enough market acceptance to quicker win further orders (5ME, 2014o).

Organization

In July 2013, the non-machinery units of the former MAG IAS machine tool manufacturer were spun-off and emerged as 5ME from then on. The new company consists of the former MAG IAS business units Cryogenics Machining Technology, Manufacturing Software, and Manufacturing Solutions. The company's facilities are in Cincinnati and Detroit (5ME, 2013, p. 1, 2014i, p. 19).

Strategy

Nowadays, manufacturers are under increasing pressure from agile competitors, capacity constraints, material cost increases, and skilled labor shortages. To deal with these immense pressures requires achieving optimal machine performance. Therefore, 5ME wants to increase their customers' manufacturing efficiency to generate profitable, competitive, and sustainable businesses. This vision is reflected in 5ME's brand name. The company aims to address the five "M's" of man, material, machines, methods, and metrics, to improve a manufacturing enterprise's efficiency (the "E") (5ME, 2013, p. 1, 2014d).

5ME composes a suite of technologies, hardware, software, and services to reach higher productivity, improved quality, and lower working capital for their customers. The company follows a brand and process agnostic strategy, and therefore is able to work with all types of machinery and manufacturing systems (5ME, 2014i, p. 19, 2014d).

With respect to cryogenic machining, the long-term strategy of 5ME is to eliminate coolants on every machining operation and establish cryogenic machining as the standard machining process. In the short-term, the company primarily targets the difficult to machine materials (5ME, 2014j).

Structure and Processes

The incorporated former MAG IAS business units form the basic pillars of 5ME's business: Cryogenic Machining, Manufacturing Solutions, and Manufacturing Software. The organization's structure (cf. Figure 9) constitutes accordingly. According to 5ME, at start-up it was difficult to change the culture from the former organizational structure of three separate business units to that of "one" company, 5ME. So while 5ME goes to market with three business segments, its operations and organization is consolidated with functional managers having companywide responsibility. Furthermore, project managers are directly allocated to projects from each business sector. The following centralized functions support 5ME's business: Engineering, Business Development, Project Management, Finance, Regional Sales, and Marketing and Product Management (5ME, 2014d, 2015).

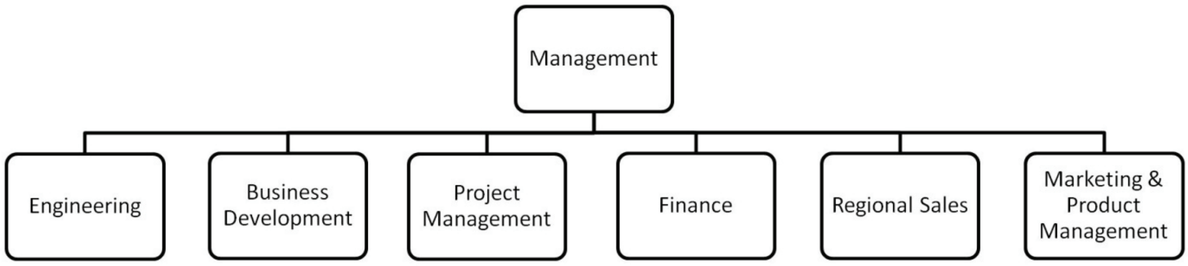

Figure 9: 5ME's organizational structure (5ME, 2015)

5ME's President emphasized that the organization is very flat from an organizational standpoint. For the most part it is two levels and just a few employees are organized in a third level (5ME, 2014n). This becomes apparent when looking at the organizational chart (cf. Figure 9).

Correspondingly, the decision making processes within the company are very lean. Due to the flexibility of a start-up, 5ME is able to adapt its technology goals and strategy roadmap very quickly according to the feedback of its customers (5ME, 2014n).

5ME has defined concrete business processes that its employees follow in their daily work. Furthermore, a business system was established that combines the functionalities of an ERP, CRM, and project management system. Everybody in the company has access to it and every project, purchase, or customer offer needs to be documented within this system (5ME, 2014n).

Company Culture

The innovation climate is very good within 5ME. The management team establishes a kind of thinking among their employees that everyone does his best to push the technology forward and to question the way things have been done traditionally. 5ME's President stated that there is a high risk tolerance and failure acceptance in the company. He said, the team has innovated and developed by mistake a lot. There is no detailed road map for each test. The technology goals are set and then the team can freely innovate to achieve this goal. Afterwards the results need to be documented and understood. 5ME's President emphasized that if you tell people exactly what they should do and not accept any other way, you would limit creativity. By giving them the authority to try things and use their best judgment, great innovations are achievable (5ME, 2014n). Furthermore, the whole team is absolutely committed to the technology and the company. Everybody within 5ME believes in the technological advantages of cryogenic machining and provides the passion and the drive to make it a success (5ME, 2014l).

Another issue contributing to a vital innovation climate within a company is internal communication. 5ME's management team evaluates the internal communication within 5ME as good. When the company was started, there were three separated businesses and the management team worked hard to make it one company. Communication in written and verbal form is very important. Within the projects, there is formal communication on a weekly basis. Additionally for reaching high transparency and visibility among all team members, project reports have to be written and any important information needs to be documented in the business system. This promotes efficient communication as just the decisive questions arise (5ME, 2014n).

Funding and Commitment

During the time at MAG IAS, the development of the cryogenic machining technology was funded as a part of the company's R&D budget. The owner behind the previous company MAG IAS and investor of the technology since the spin-off is the owner of 5ME (5ME, 2014n).

5ME estimates that it will take millions of dollars to take cryogenic machining technology to the mainstream market. Break-even sales will not be achieved in the first two full years of the company's business (5ME, 2014n). In the face of this risky endeavor, strong management and owner commitment is essential. 5ME's owner and the management team are absolutely committed to the technology and the company. It is their vision and passion to commercialize this technology and turn it to the mainstream machining technology (5ME, 2014l, 2014n).

Another funding source for 5ME to develop cryogenic machining is customers. 5ME's goal is to get as much customer funding as possible for financing test runs. Correspondingly, 5ME has primarily been focusing on large OEMs and tier one suppliers, as they typically have funds as a part of their business budget to test new technologies. 5ME managed to get customer money for most of their test runs. Furthermore, 5ME has internal R&D budget. So if the customer funds have been exhausted and no satisfying results have been achieved, 5ME puts in internal money to complete the test runs and come up with a satisfying result. For tool development, 5ME primarily uses internal funding to claim ownership to potential intellectual property (5ME, 2014o, 2014j).

Entrepreneurial Team

5ME has about 45 employees. The team consists of managers, engineers, and employees that have originally worked for the former MAG IAS business units which have been incorporated when spinning-off. Most of them have already been engaged in the disciplines 5ME is executing during their time at MAG IAS (5ME, 2013, p. 1, 2014n).

Within the cryogenic machining discipline, the team has been very experienced right from the start with respect to their machine tool background and the standard machining operations. Correspondingly, they already knew how to make a chip effectively. To profoundly understand the cryogenic part, the theory and physics behind it, 5ME hired a couple of cryogenic experts. Some of them have done their PhD within the field of cryogenic machining. With this combination of knowledge, 5ME managed to bring the technology from an art to a science (5ME, 2014n, 2014j).

The engineering team has to focus on the following four issues: safety, quality, reliability, and costs. As their product designs are the base for the commercialization of the technology, the cryogenic engineers really have a decisive role. On the other hand, there are people in purchasing and sales that negotiate for 5ME to get the costs and profits in the right place (5ME, 2014n).

At selecting the right people to work for 5ME, two areas are essential: professional competence and passion. 5ME's President elucidates that professional competence is an obligatory precondition, but enthusiasm and passion for the focal job are the decisive factors at hiring employees. Potential candidates need to be absolutely committed, passionate, and willing to take risks. By now, 5ME has not grown the employment base, in spite of the fact that the company is planning to grow. 5ME wants to be a 100-million-$-business in five to seven years. However, only after orders are coming in, 5ME starts to add headcounts for not consuming too much money during the ramp up phase. Currently, if people leave the company, 5ME adds employees in those areas the company is investing in (5ME, 2014n, 2014l).

Innovation Process

Opportunity Identification

The through-spindle, through-cutting tool LN_2 cryogenic machining technology was initially developed by Creare, an engineering and development firm located in Hanover, New Hampshire. Between 2003 and 2007, Creare developed and optimized the technology within a U.S. government funded Small Business Innovation Research (SBIR) project together with U.S. Navy, NavAir, and Bell Helicopter to reduce the costs of machining titanium parts (5ME, 2014h; Creare, 2014, p. 1).

In 2007, a visit of the Creare laboratories was made by MAG IAS management. Once they witnessed what Creare was doing with that technology, MAG IAS basically negotiated an agreement with the R&D firm to exclusively license the technology which was primarily based on three patents. With this agreement MAG IAS received the right to continue to develop the technology, to manufacture, use, and sell it exclusively, globally (5ME, 2014n).

From 2007 until 2010, there was a small team formed within MAG IAS to take a look at the technology and to start developing it further. The aim was to figure out, how the technology could be applied to MAG IAS machines and what the benefits would be. This assessment has been done from a technical and a market perspective (5ME, 2014n).

Between 2010 and 2013, there was more effort and budget put into the development of the technology within MAG IAS. A team of four people, three technicians and one marketing representative, was established at MAG America. It was aimed to get closer to application maturity and to specifically address the market. Between 2010 and 2011 MAG Germany also started to get involved in the development of the technology and mainly replicated what MAG America was doing. Within MAG Germany, roughly eight people were involved. The results of technology development have been showcased at the industry trade shows IMTS 2010, imX 2011, EMO 2011, and IMTS 2012 (5ME, 2014n, 2014h).

Finally, the non-machinery company units of MAG IAS were spun-off in July 2013 and emerge as 5ME since that time. Spinning-out was due to two main reasons. The first reason was the former limitation to just one single machine tool manufacturer. Inside MAG IAS, cryogenic machining could not be implemented on machines from other machine tool companies. By taking it outside of MAG IAS, 5ME was immediately open to other brands and opportunities (5ME, 2014n, 2013, p. 1).

The second reason for spinning-out 5ME was the fact that inside MAG IAS, it has not been possible to focus on this new technology. Cryogenic machining is radically new. Correspondingly, potential customers need to be addressed. Now, 5ME advertises itself as a cryogenic company and has a very dedicated marketing focused on the commercialization of cryogenic machining. Within MAG IAS, cryogenic machining was just a minor part of the overall company. Accordingly, just a minor part of the overall communication efforts was put on cryogenic machining. Furthermore, 5ME established a Tech Center in Detroit to show potential customers the technology and to run customer tests. Having a dedicated training and testing center was not possible within MAG IAS (5ME, 2014n).

From a market standpoint, 5ME needs to prioritize which industries to address first. This should be done with respect to the greatest possible opportunity. 5ME is focusing on the aerospace, automotive, oil & gas, and construction industries due to their great opportunities for cryogenic machining. A great chance from a customer standpoint offers the F-35 Joint

Strike Fighter (JSF) program in the aerospace industry. The prime contractor of the F-35 JSF program, Lockheed Martin, has been involved in the development of cryogenic machining right from the start. Lockheed Martin endorsed the technology for machining F-35 titanium components during the SBIR program with Creare as the technology's advantages have been demonstrated. 5ME has good relationships with high level decision makers of Lockheed Martin who help to promote cryogenic machining throughout their supply chain (Creare, 2012, p. 1; 5ME, 2014o).

Furthermore, the timing for commercializing cryogenic machining seems perfect. Beside the opportunities within the aerospace industry, large customers in the automotive and oil & gas industry made significant capital investment approximately 15 to 20 years ago and are up to retooling their facilities in the near term. This could be a great chance for 5ME and cryogenic machining (5ME, 2014o).

Product Development

Lead User Integration

5ME is addressing two entities of customers, end-users and machine tool manufacturers. The end-users play a specific role in commercializing this technology. First of all, persuading a well-known end-user to turn to cryogenic machining will be a very good reference and testimonial in the industry. It will show acceptance by the industry. An installed machine will leverage the technology and can be shown to other potential customers (5ME, 2014o, 2014n, 2014l).

Especially in the ramp-up phase of a radical new technology, it is essential to have a close relationship with the first users of the focal technology. Not everything goes right at the forefront of technology implementation. Thus, it is important to find those customers that have the right culture and mindset to dare the risks. In the early technology phases, constant feedback is decisive (5ME, 2014o).

For 5ME these early customers play another big role as they fund test runs. Correspondingly, they help to offset 5ME's costs. Furthermore, they shape the applications, the portfolio of products, and the types of machines 5ME is targeting on with their feedback. By listening to these lead-users, 5ME understands where to commercialize first (5ME, 2014n).

Within the aerospace industry, lead-users are due to the obligatory certification process even more important. There is no sense for 5ME to go to companies that build aircraft parts and try to offer cryogenic machining. They do not have the authority to make this change. Thus, 5ME directly addresses the aircraft manufacturer and try to get their approval. Once this has been achieved, they would allow their tier suppliers to use the technology. Correspondingly, there is no other chance of commercializing the technology to this industry. On the other hand, this opens up great chances. Typically, supply chains in the aircraft industry a tightly woven of middle-sized companies that are unknown to 5ME. With the aircraft manufacturer leveraging cryogenic machining, 5ME gets access to a huge pool of companies that all supply parts to these aircraft manufacturers (5ME, 2014j, 2014l).

Risk and Quality Management

5ME has not a detailed risk and quality management system, but established some instruments to deal with emerging risks and quality issues. Every cryogenic kit that is shipped to customers is checked accurately to avoid that the kit would not work and lead to negative publicity in the market (5ME, 2014o, 2014n).

Similarly, 5ME starts to market their technology in the USA in close proximity and cooperation with a few well selected customers. 5ME has concrete criteria to select the right customer to work with. In weekly calls, the company supports their customers and wants to figure out if problems occur. If any of the shipped kits would run poorly, it could lead to doubt in the technology and draw back the progress of commercialization (5ME, 2014o, 2014j).

For their technology testing, 5ME does not follow a strict formal structure like design of experiment. 5ME directly tests what they estimate to be a successful target. Nevertheless, the methodology of running a test is much disciplined. Everything is highly documented and the company put a lot of importance on the feedback from the result analysis after the test (5ME, 2014j).

One of the biggest risks of commercializing cryogenic machining is based on the fact that the technology is radically new. The customers cannot compare it to any existing technology. This leads to long sales cycles as the customer needs to be persuaded to take the change and move to the new technology. On the other hand, it takes time to develop and engineer the technology adaption to different machine platforms. If it is sometimes not possible to quickly show the customer positive results based on the parts that they have asked 5ME to test, this may lead to customer frustration. Furthermore, 5ME is the single supplier to provide it. So some customers may be afraid of being locked to just one supplier (5ME, 2014o, 2014l, 2014j).

Platform Strategy and Product Family

5ME is working towards a platform strategy to share common parts. However, everything up to this point has been very unique on the first sets of machines that 5ME has equipped. Once the company has one or two machines in each of the four primary addressed industries, 5ME will be in the position to sell more of similar or alike machines to those customers and set up a common part strategy accordingly. By now, the company has realized standardization as far as possible at this point in time. All the elements that do not change based on the size of the machine have been standardized like the LN_2 storage and the sub-cooler. Apart from that, the lines, the lance, and the tools will all vary in size based on the machine types. Any standardization is volume driven. Correspondingly, the more machines of the same type will be sold, the more standardization will be possible (5ME, 2014o).

On the other hand, tools that have been developed by 5ME are easily scalable. As the design will not change for these applications 5ME has already equipped, it is just a matter of scaling. The applications that 5ME has not done are getting few (5ME, 2014j).

Intellectual Property

5ME puts special emphasize on the protection of its intellectual property. The company is building value as intellectual property is developed. This reduces the risk for 5ME's investors and will pay back the investment in the future. The technology of internal cooling was licensed originally to MAG IAS from Creare. The foundation for this agreement was primarily three patents that protect the internal LN_2 delivery through the spindle and through the tool. These patents were transferred to 5ME and form the base of their technology (5ME, 2014j, 2014n).

As 5ME has developed optimizations, this justified further patents. Since those original three patents, 5ME has added another six addressing the technology to prevent people from copying 5ME's system. Any time 5ME comes up with a good idea that has a vital commercial potential, the company tries to protect it and files for a patent. Most of 5ME's patents are on cryogenic machining (5ME, 2014j).

Commercialization

Value Proposition and Business Model

5ME positions itself on three separate business fields: Cryogenic Machining, Manufacturing Solutions, and Manufacturing Software. Within the Cryogenic Machining, 5ME is evolving its environmentally friendly machining technology to increase throughput, quality, tool life, and profitability for its customers while reducing energy consumption and facilitating a safer work environment for plant floor personnel. Manufacturing Solutions offers the corresponding portfolio of manufacturing consumables like tools and coolants and productivity supporting services. Manufacturing Software uncovers inefficiencies and leads to overall process transparency. The three different businesses do not depend, but complement each other (5ME, 2014d, 2014n, 2014l).

From a customer perspective, cryogenic machining offers faster machining times, better surfaces, and little to no clean up or waste compared to traditional cooling methods. There is no need for mist collection, filtration or collection of waste coolant. Energy costs associated with coolant fans, pumps, and drives do not occur. As the equipment and workpieces are not contaminated, secondary processes are obsolete and no slippery work surfaces or toxic fumes emerge (5ME, 2014c, 2014a, p. 2).

Beside its core product, which is the cryogenic system kit, 5ME supports its customers especially during the first few months of production. Application engineers help to bring up the process to high efficiency. Furthermore, 5ME is working on a handbook with basic rules and parameters for cryogenic machining as the conventional manufacturing rules are obsolete with this new technology (5ME, 2014l, 2014j).

5ME does not manufacture any part of their cryogenic system on their own. Their competence lies in the engineering, the designing, and the assembly of the kits. Each component is shipped to 5ME's facility in Detroit and assembled, tested, and shipped to the end-users. A cryogenic kit is typically composed of the source, feed, the lance, and the control unit. Usually, kits and cutting tools are quoted separately. A general rule of thumb says that the price for a kit accounts to 30 – 40% of the price of a new medium sized or larger machine. Cutting tools are consumables and need to be replaced after a certain amount of time. Therefore, the biggest revenue opportunity for cryogenic machining is cutting tool related. 5ME tries to establish a business model that can be compared to the one of the razors and the razor blades. The razor is sold once and the blades are continuously replaced. With every kit comes years of revenue for the cutting tools, assuming the machine stays in production. As the margins are even higher for the tools, the revenue opportunities of cutting tools will be much higher than for the kits (5ME, 2014o).

The business model would be to generate the main revenue out of the peripheral tooling. Selling the cryogenic kits at an entry cost would additionally help to get established as the barriers would be lower for customers to step in. Especially in the early commercialization phase, getting kits in production and generating market references is decisive. For additionally lowering the entrance barriers and developing further testimonials, 5ME has contemplated leasing kits to special well known customers over a certain amount of time (5ME, 2014j).

Another potential revenue stream could be generated by license fees. By now, 5ME has specific partners that manufacture and supply the 5ME-designed cutting tools to them. They subsequently commercialize the tools exclusively. Potentially, 5ME could offer particular cutting tool manufacturers a license to manufacture 5ME-designed cryogenic cutting tools and market them independently to end-users. This requires an appropriate installed base of kits to be interesting for cutting tool manufacturers. Thus, this opportunity could evolve in the next year or two (5ME, 2014n).

Cope with Uncertainty and Sensitiveness to Market Needs

Especially in the early stages, commercializing a radical technology like cryogenic machining is accompanied by a huge amount of uncertainty (Bullinger, 1994, p. 96). Coping with this uncertainty and being sensitive to the market needs is a precondition for being successful. 5ME is aware of this situation that there are many things that they do not know (5ME, 2014o). As the technology is so new and different to the standard machining approach, it requires much change and a lot of moving pieces. One approach of 5ME dealing with this situation was to set up a Tech Center. This technical center was established due to two reasons. On the one hand, 5ME develops and optimizes the technology within this center. On the other hand, the technology could be shown to customers. Both have not been possible within MAG IAS before (5ME, 2014n).

When approaching the customers, there has been great interest in the technology, but the customers wanted to see the technology in action and get some validated results (5ME, 2014o). Correspondingly, 5ME tries to establish references in each of its target markets. OEMs and machine tool builders are the two best references 5ME can have, as this would show acceptance by the industry. With these customers 5ME is closely working together. The company tries to understand their customer's manufacturing processes in detail and communicate very much on a regular basis (5ME, 2014o). These early customers fulfill two essential roles for 5ME. Firstly, they fund the test runs at the Tech Center and help to cover 5ME's development costs. Secondly, they deliver essential feedback and thus shape the portfolio of applications and machines 5ME is targeting (5ME, 2014n).

Of course, 5ME initially starts with a concrete roadmap of technology goals, but as the company was closely in touch with its customers and constantly asked questions, 5ME altered its roadmap based on this market feedback. In the beginning, 5ME just addressed the tough to cut material like titanium and special alloy. When customers requested hardened steel, 5ME experimented with this material and was able to machine it with significant benefits for the customer. As there are a lot more steel applications than titanium and special alloys, 5ME quickly adapted its strategy to equally target these materials. Interestingly, the first order the company received was on hardened steel and this was completely different from what 5ME initially focused on (5ME, 2014n).

Timing

By the end of 2014, the industry in North America, which will be 5ME's focus over the next few years, has just come out of one of the greatest depths since the great depression. The value of efficiency and the concept of global competitiveness have become very present and this is beneficial for cryogenic machining (5ME, 2014l).

Furthermore, some markets are especially interesting for 5ME's new technology. Above all, the aerospace industry is just in front of a huge production ramp up across the new aircraft generations for commercial and military use. According to customer data, the available production capacity will exceeded what directly affects the commercialization of cryogenic machining. For this industry 5ME's Cryogenic Business Development Manager rated 5ME's timing to be perfect (5ME, 2014o).

The timing to enter 5ME's further target industries automotive and oil & gas are good as well. As several larger automotive and oil & gas customers made significant capital investments 15 to 20 years ago, a lot of them are planning to retool their facilities within the next years. This additionally fosters the commercialization of cryogenic machining (5ME, 2014o).

Marketing

5ME is currently positioning cryogenic machining as a premium solution for niche applications of tough material (5ME, 2014l). Due to the early technology stadium, 5ME started to focus on the large customers with R&D-funding budgets for testing cryogenic machining to offset their development costs. Subsequently, the selling process is slow as the approval procedures within those organizations are time-consuming. By now, the mode has been to approach interested target customers. Then, these customers usually like to see their material being run in the Tech Center to get validated test results. Afterwards, they take these test data and make up a business case by calculating their individual return on investment for selling it to their upper management. Not until the investment is internally approved, a cryogenic system order is placed (5ME, 2014o, 2014n).

Since spinning-out, 5ME does considerably more marketing. The company addresses the market with a new brand-name and positions itself as completely dedicated to manufacturing efficiency and cryogenic machining. Within MAG IAS, this was not possible as the parent company was a machine tool company and cryogenic machining was just a part of it (5ME, 2014n). Now, 5ME has a focused marketing approach. The company established a dedicated website with detailed information and case studies on cryogenic machining. Furthermore, 5ME leverages social media via YouTube and LinkedIn, installed some blogs, and attends several trade shows to exhibit the benefits of cryogenic machining (5ME, 2014l).

Strategic Alliances / Partnerships

5ME has a limited number of strategically chosen partnerships with several customers. The company focuses on these selected customers to fully support them and closely cooperate at bringing cryogenic machining to practice. If any of those projects fails, it could put back 5ME several steps in the process of technology commercialization. Correspondingly, 5ME maintains close relations with its customers and similarly, expects them to be totally committed to commercializing cryogenic machining. Appropriate customers should enjoy being at the forefront of technology implementation, have the right culture, be less risk averse, and allocate adequate resources for the project (5ME, 2014o).

In principle, there are two entities of customers for 5ME: machine tool builders and end-users. The machine tool builders help to leverage cryogenic machining by equipping their machines with this technology and offer potential end-users cryogenic equipped machines as an alternative to the conventional machines (5ME, 2014n). Among the most cooperative machine tool builders are Okuma and MAG Automotive. Both companies have a show room at their facility and showcase cryogenic machining to potential customers on their machines (5ME, 2014l). Between MAG Automotive and 5ME is no legal relation anymore and consequently, there is no difference from a business perspective compared to other customers. Nevertheless, 5ME is familiar with MAG Automotive's product portfolio and MAG Automotive with cryogenic machining. This facilitates the discussion and thus the technology commercialization (5ME, 2014n).

By addressing the end-users of cryogenic machining, the technology could be spread across the entire end-user's supply chain. Especially in case of a very tightly woven supply chain net of mainly middle-sized companies potentially unknown to 5ME, this opens up great opportunities for 5ME (5ME, 2014l).

5ME's business model is to design and engineer all parts of the cryogenic system, but not to produce them. Thus, all components are manufactured by suppliers according to 5ME's specification and shipped to Detroit. In the Tech Center 5ME assembles, flow-tests, and ships the kits to its customers. Therefore, 5ME needs to have competent suppliers. From a component standpoint, the suppliers of the lance and the cutting tools need to be very strategic partners as these parts are particularly demanding. Correspondingly, 5ME's development team maintains a close relationship with weekly meetings (5ME, 2014j, 2014o).

Furthermore, 5ME facilitates strategic partnerships to certain universities and industry trade publications authors. This supports the publication and subsequently acceptance of the technological advantages of cryogenic machining across the industry by scientific and industry specific reporting (5ME, 2014o).

Innovation Success

Performance

Product Performance

Within the Tech Center, the performance results of cryogenic machining have been successful. 5ME had ten to twelve positive test runs for customers during 2014. Different materials were tested to run with cryogenic machining on turning centers, horizontal, and vertical machining centers. The results were robust, repeatable, and thus reliable. Furthermore, the involved customers were very excited with respect to the achieved test results (5ME, 2014o, 2014n).

Accordingly, 5ME brought cryogenic machining into industrial use at its first customer. This machine will be in production in the first quarter of 2015. Thus, no industry performance data are available by the end of 2014 (5ME, 2014o).

However, 5ME received several awards for establishing cryogenic machining: the MM Award for Innovation (2011), the New Equipment Digest King Award (2012), and the Frost & Sullivan Best Practice Award (2013) (5ME, 2014h).

Sales Performance

From foundation until the end of 2014, 5ME continues to grow its revenue for cryogenic machining. Thus far, virtually all of that revenue was generated by customer testing. The first customer and user machine is already shipped and installed and will be going into production in the first quarter of 2015. The second one will be shipped by beginning of 2015. Due to positive test runs in 2014, 5ME expects to win another eight to ten retrofit orders during 2015 (5ME, 2014o).

This would start to cover 5ME's investments. Because of the lead times of these systems, 5ME estimates to reach the break-even-point for cryogenic machining within 2016. From then on, the cryogenic machining business unit will be profitable (5ME, 2014n).

For 2015, 5ME expects cryogenic machining to be 25% of the company's total new business. An equal revenue share of one third for each of the three business segments is anticipated over the next two to three years. By the end of 2018, 5ME estimates cryogenic machining and manufacturing software to account for 75% and manufacturing solutions for 25% of the company's overall revenue (5ME, 2014o).

Efficiency

While there is high investment in development of cryogenic machining technology, 5ME sustains a certain level of income to stay liquid. Therefore, the company has a run rate business of tools and coolant it offers through its manufacturing solution business segment and sells machine monitoring software through its manufacturing software business segment. Exposures are limited within an agreed budget for each year by 5ME's investor. The achievement of these objectives is measured on a monthly, quarterly, and yearly bases and correspondingly adapted (5ME, 2014j).

To keep the costs down, 5ME tries to get test funding by customers. Most of the test runs have been funded by potential customers. For tests that are outside the scope of the customer or tests that do not deliver a satisfying result after the customer money was consumed, 5ME has internal R&D funding. To keep the intellectual property, tool development is exclusively funded with internal R&D-money (5ME, 2014j, 2014n).

Furthermore, the engineering team saves time and resources by following a smart testing approach. Instead of testing a huge spectrum of parameters, 5ME directly targets the highest level of requirements. By following this approach, 5ME was able to set several land speed records on different materials, i.e. machining these materials faster than anybody ever before (5ME, 2014j).

However, commercializing this radical technology takes time, as it has a great level of novelty and differentness. It took 5ME a whole year to get the first customer on board and the cryogenic system into industrial use. Probably, the following ones are faster, but as cryogenic machining requires a high level of change on behalf of the customer, 5ME estimates that each sales cycle will take at least a period of six months (5ME, 2014o, 2014n).

5ME is satisfied with their technological development in the short term of cryogenic machining thus far. The customer feedback has been good and several customers asked 5ME to quote cryogenic systems. However, with respect to the concrete commercialization, the low amount of incoming orders is frustrating as 5ME wants to see things happen much faster. One reason therefor is the reluctant behavior of the technology adopters that have a lot of questions and fear. On a scale from one to ten, 5ME ascribes the technological development a seven and the commercialization a five (5ME, 2014n).

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