Quantifying the Economic and Commercial Potential of a High Strength, Low Thermal Coefficient Super-Alloy

by

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ABSTRACT

Inspired by the importance of having a favourable sheathing material for superconducting wires, a high-strength, low thermal coefficient (CTE) super-alloy has been developed. Known as Incoloy 908, this super-alloy's material properties have been extensively studied, and various mechanical, thermal, magnetic, and elastic properties of it have been researched for many years. In the pursuit of broader applications for this superior alloy, this project seeks to identify the most profitable and realistic applications where the fundamental advantages of this technology, due to its unique combination of properties relative to competitors, can create value and be commercialised. This work seeks to quantify the potential value of Incoloy-908 to the market, and on this basis, explore business strategies in which the value of the technology could be realised.

The quantitative values assigned to the selected application as a saw blade in saw mills is optimistic in the perspective of the saw mill owner. However, business strategies to realise the potential value through start-up companies are challenging with long investment horizons. Recommendations for future work include developing a more refined estimate of the production costs, and exploring alternative business plans in the context of adopting the technology as an existing manufacturer.

Thesis Supervisor: Ronald G. Ballinger

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1. Introduction and Scope

1.1 Introduction

Inspired by the importance of having a favourable sheathing material for superconducting magnets, a high-strength, low thermal coefficient (CTE) super-alloy has been developed. Known as Incoloy ® alloy 908, this super-alloy was researched by [1],[12] and has seen various useful applications in nuclear engineering. Material properties of Incoloy-908 have been extensively studied, and various mechanical, thermal, magnetic, and elastic properties of it have been researched on for many years [1]. In the pursuit of broader applications for this superior alloy, this project seeks to identify the most profitable and realistic applications where the fundamental advantages of this technology, due to its unique combination of properties relative to competitors, can create value and be commercialised. This work seeks to quantify the value that the unique mix of properties that Incoloy-908 could potentially fetch. On this basis, if such an application is viable, resources could be provided to cater the material to the new application.

1.2 Scope of this project

The scope of this project is to identify potential applications, and focus on the most viable, but realistic application where Incoloy-908 could potentially bring value. Focus will be on areas where a strong material with low CTE is required, but for which properties of current materials could not fully match up with in these aspect. Particular attention will be placed on applications at relatively lower temperatures (<400 °C) where "Stress Accelerated Grain Boundary Oxygen Embrittlement" (SAGBO) will not be an issue, as it is an issue with nuclear engineering applications.

On this basis, a viable application is identified, followed by a comprehensive study on the supply-chains related to that application. The dollar amount that the introduction of Incoloy-908 could effectively add to incumbent processes is derived, with the help of reliable and up-to-date data. Holistic analysis is done to assess the viability of different commercialisation avenues where the technology could potentially enter the markets, taking into consideration the IP landscapes as well as influence of competitors. Business plans are then drafted and evaluated, with the supplement of cost models supported by best, available information.

2. Contemporary research and motivation to explore application potential

2.1 Material characterisation and development

Incoloy-908 was developed to meet sheathing materials requirements for internally cooled Nb3Sn superconductor magnets to be used in prototype fusion reactors at cryogenic operating temperatures of -452°F (-269°C/4°K). A comprehensive data handbook [1] is available and the manufactured product bears the following properties depicted in Figure 1.

Physical Constants & Thermal Properties

Table 2 - Physical Constants & Thermal Properties

Density, lb/in^3	0.295
g/cm^3	8.17
Melting Range, °F	2482-2571
°C	1361-1410
Specific Heat, Btu/lb•°F	0.104
J/kg•°K	439
Curie Temperature, °F	539
°C	282
Coefficient of Expansion, 10^{-6} in/in•°F (µm/m•°C)	
70-200°F (21-93°C)	4.77 (8.59)
70-500°F (21-260°C)	4.81 (8.66)
70-800°F (21-427°C)	6.17 (11.11)
70-1000°F (21-538°C)	6.78 (12.20)
70-1200°F (21-649°C)	7.32 (13.18)
70-1400°F (21-760°C)	7.84 (14.11)
Thermal Conductivity[a], Btu•in/ft^2•h•°F	76.68
W/m•°C	11.05
Young's Modulus[a], 10^3 ksi	23.7
GPa	163.3
Shear Modulus[a], 10^3 ksi	9.37
GPa	64.6
Poisson's Ratio[a]	0.265
Hardness[a], HRC	38-40

[a] Room temperature, as aged

Table 1 - Limiting Chemical Composition, %

Nickel	47.0-51.0
Chromium	3.75-4.5
Manganese	1.0 max.
Carbon	0.03 max.
Copper	0.5 max.
Silicon	0.5 max.
Sulfur	0.005 max.
Aluminum	0.75-1.25
Titanium	1.20-1.80
Niobium	2.7-3.3
Phosphorus	0.015 max.
Boron	0.012 max.
Cobalt	0.5 max.
Iron	Balance*

*Reference to the 'balance' of a composition does not guarantee this is exclusively of the element mentioned but that it predominates and others are present only in minimal quantities.

Typical Mechanical Properties

Table 3- Mechanical Properties

Tensile Strength, ksi	170
MPa	1172
Yield Strength (0.2% Offset), ksi	120
MPa	827
Elongation, %	12

Figure 1. Material Properties of Incoloy [1].

Some interesting properties are that it is an age-hardenable nickel-iron alloy which exhibits low thermal expansion, high tensile strength, high fracture and impact toughness, fatigue crack, growth resistance, good ductility, metallurgical stability and weldability. The low CTE is a result of controlling the composition Ni, Fe, and Cr [2]. The composition of Cr varies positively with thermal expansion of the alloy. Hence, by reducing the Cr content to less than 4 wt%, one can achieve a low thermal expansion for the alloy. It must be noted that the alloy has been improved for less susceptibility to "Stress Accelerated Grain Boundary Oxygen Embrittlement" (SAGBO)[2].

2.2 Limitations and technological barriers at high temperature operations (>400°C)

The main technological barrier of Incoloy-908 is its susceptibility to SAGBO in the presence of oxygen at high temperatures (>400°C), when working at certain stress and ambient conditions. This phenomenon is a concomitant draw-back of Cr reduction, together with the effect of high oxidation rates at high temperatures. When the material is used under certain stress conditions, and placed in a high-temperature environment with oxygen, an effect known as "Stress Accelerated Grain Boundary Oxygen Embrittlement" (SAGBO) occurs. When oxygen diffuses along the grain boundary, cracks may occur. The oxygen content that may result in SAGBO is 0.1 ppm, which necessitates a vacuum ambient if Incoloy-908 is to be used at high temperatures.

2.3 Future research focus

Future research on Incoloy-908 will probably continue to be in search of a way to overcome SAGBO. However, if applications that would not require operating this alloy at high temperatures > 400°C, SAGBO will not be an issue. On this basis, it is imperative that an alternative application (if any), be identified so that future research directions could be focused on improving the technology to suit the potentially lucrative, and more meaningful business idea. The author believes that there is fundamental value in the Incoloy-908 technology. This project seeks to quantify the value that the properties of Incoloy-908 could potentially fetch, and identify the risks involved, so that future researchers working on this technology could be informed.

2.4 General application potential

Besides looking at cryogenic applications where the material has superior advantages over other materials in terms of low CTE and durability, another area of interest is that of the tooling industries. Intuitively, one would imagine that in applications where rapid cutting, stretching or hitting of materials is involved, the heat created in the process may lead to undesirable level of expansion of the tools. This, together with the weathering of the tool under demanding conditions, may lead to their frequent replacement and maintenance, where in the long run, could adversely affect the profitability of the business, especially in areas where the throughput of the operation is significantly affected by equipment quality.

2.4.1 Identification of area of focus

Among the shortlisted potential applications in the tooling industry is the employment of the technology in sawmill blades and logging saw blades. The two applications share a common characteristic – they are designed for cutting wood, but inextricably come into contact with harder materials like nails. The fact that sometimes sawmill saws come into contact with nails is mainly due to eco-terrorism. Eco-terrorism is the act of hammering nails into trees, and most eco-terrorists are ironically trying to conserve the forests, by breaking the tools of loggers and saw mills. It is believed that by doing so, logging is discouraged due to the damaging of tools and the reduction of value of the final products. Since sawmills are relatively higher-throughput businesses in the forestry products value chain, it is the chosen area for in-depth analysis.

3. Introduction to the sawmill business

Before going into the technicalities of the technology, it is useful to first understand the various issues in sawmills, and recognise the main concerns of decision makers in sawmills. This chapter serves to inform and suggest how the technology could potentially fit into and bring value to sawmills.

3.1 Types of wood residue and their uses

There are numerous types of wood-processing businesses, and they namely produce lumber, veneer, plywood, pulp, shake and shingle, post, pole and piling. The wood wastes in sawmills are mainly bark and wood residues and specifically, the type that our proposed technology could reduce is fine sawdust waste. Figure 2 shows the kind of wood wastes that typical sawmills would produce in the Washington region. From Figure 2, one could infer that a large portion of fine sawdust wastes are being used as fuel. In the U.S., the wood sawdust wastes are almost never left unused.

Wood residue — by use and county

Economic area and county	Total	Total used	Pulp	Board	Fuel	Other	Unused
	Fine						
Puget Sound							
King and Whatcom	11,608	11,241	0	0	0	11,241	367
Pierce	138,600	138,600	94,500	0	12,744	31,356	0
Skagit	4,330	4,330	0	0	1,933	2,397	0
Snohomish	160,343	160,343	43,961	0	81,691	34,691	0
Total	**314,881**	**314,514**	**138,461**	**0**	**96,368**	**79,685**	**367**
Olympic Peninsula							
Clallam	62,860	62,860	27,410	0	35,450	0	0
Grays Harbor	83,476	83,476	5,702	0	77,774	0	0
Mason, Pacific and Thurston	143,348	143,348	52,661	0	90,655	32	0
Lewis	138,302	138,302	17,360	14,040	79,057	27,845	0
Total	**427,986**	**427,986**	**103,133**	**14,040**	**282,936**	**27,877**	**0**
Lower Columbia							
Clark, Klickitat and Skamania	54,553	54,553	5,029	0	14,806	34,718	0
Cowlitz	66,787	66,787	43,200	0	17,107	6,480	0
Total	**121,340**	**121,340**	**48,229**	**0**	**31,913**	**41,198**	**0**
Central Washington							
Chelan and Okanogan	16,545	16,545	0	4,430	3,888	8,227	0
Yakima	45,673	45,673	40,392	0	264	5,017	0
Total	**62,218**	**62,218**	**40,392**	**4,430**	**4,152**	**13,244**	**0**
Inland Empire							
Ferry, Pend Orielle and Whitman	65,266	65,266	17,018	0	48,248	0	0
Stevens	58,001	58,001	16,408	27,000	14,588	5	0
Total	**123,267**	**123,267**	**33,426**	**27,000**	**62,836**	**5**	**0**
State Total	**1,049,692**	**1,049,325**	**363,641**	**45,470**	**478,205**	**162,009**	**367**

Figure 2. Types of fine wood residues produced by sawmills in the state of Washington [3].

3.2 Geographical Region of Focus

Throughout the analysis, the state of Washington will be the reference region for sawmills. The main reasons for choosing Washington state would be that the state contributes to 7.2% of all forest resources in the U.S., and the sawmill output saw significant throughput increases in recent years. The throughput increases can be inferred from Figure 3, where in recent years, the number of sawmills declined by 60% while total finished lumber produced increased by about 73%. This is an important piece of information because the industry is moving towards higher production scale, and should see more capital investments to improve their equipment for higher throughput.

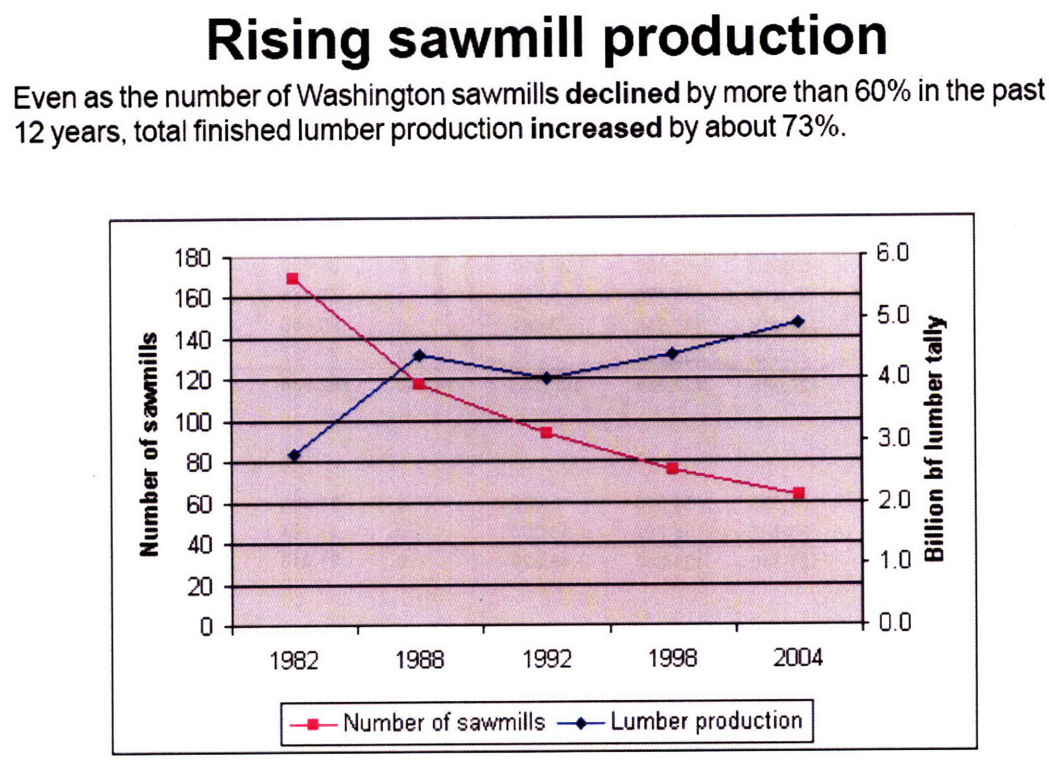


Figure 3. Recent sawmill output trend and number of players[3].

3.3 Usage of sawdust residue

In many sawmills, there are already infrastructure in place to gather and re-use or sell the residues. It is documented in [14] that typical sawmills has obtained 57% of their energy from waste wood, and Figure 4 shows the kind of infrastructure that is available in typical sawmills to treat waste wood. The sawmill wastes are typically directly sold, or dried and channelled to boilers to generate electricity for the sawmill itself. Therefore, there is value in sawdust that has to be taken into account when the technology is valued. It will be referred to as the opportunity cost of sawdust in the valuation process in this work.

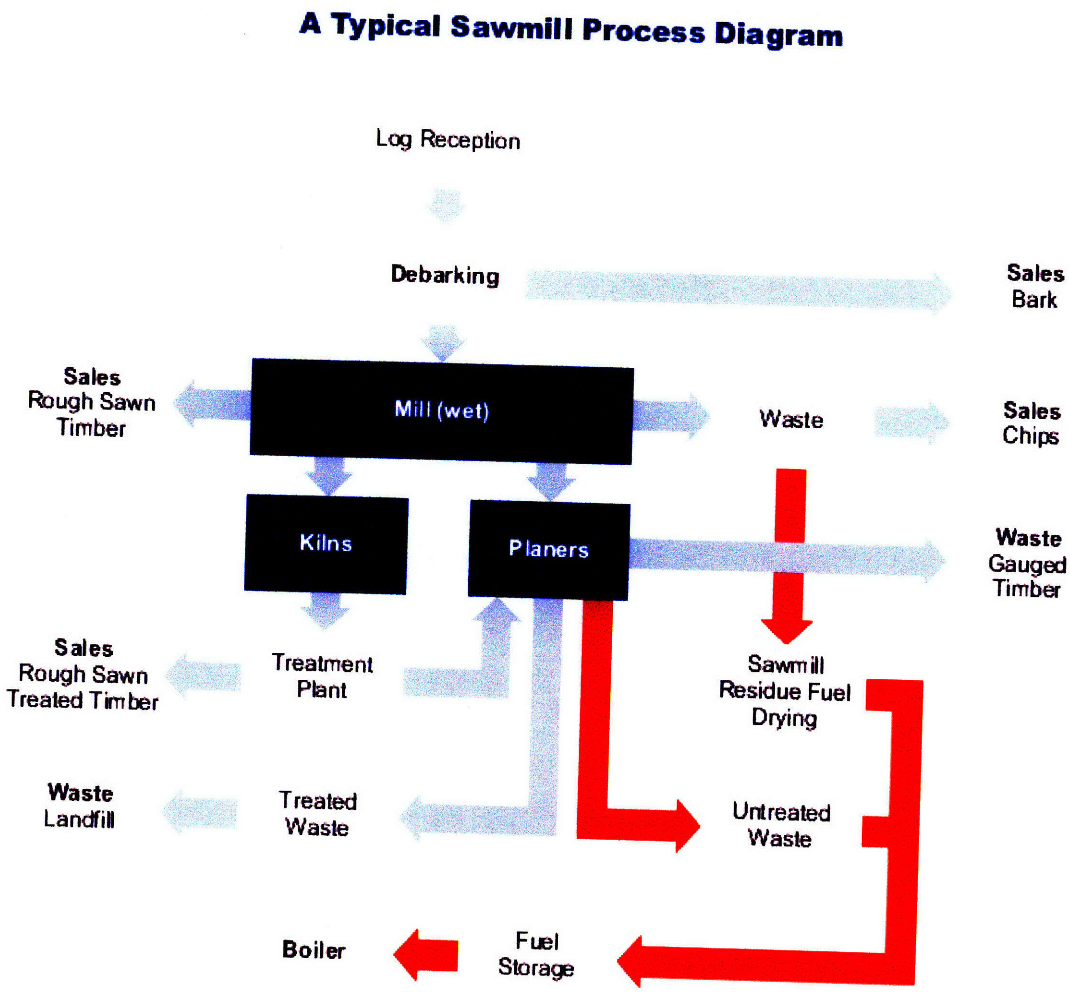


Figure 4. Infrastructure in typical sawmills to treat waste wood [14].

3.4 Incumbent measures to sawmill residue management

The simplest measure to reduce sawmill residue is to directly reduce the amount of waste generated. This could be achieved by using saw blades with smaller saw kerfs, or to manage the sawing process such that the saw-logs are sawn in the most efficient ways. An alternative method, which may be adopted in parallel, is to convert the residue generated into a higher value product while a subtly different way is to change processing so that the residues generated are higher in value. On the other hand, if the above could not be achieved, one could dispose of residues in a reasonable manner.

The proposed technology application in this work is to reduce the sawdust waste by changing the material being used in the blades. With the hypothesized reduction in saw kerfs expansion, there could be potential savings due to direct savings from reduced sawdust production, as the expansion of the saw kerfs against the log that is being sawn is less. Concomitantly, the amount of useful wood (higher value produce) is increased.

4. Technology implications of material properties on woodworking tools.

4.1 The proposed application and context

The proposed application of the technology is a low CTE saw blade with high fracture and impact toughness. The type of saw blade is chosen to be sawmilling band saws, although circular blades could also be used in the context.

4.2 Type of saw in context

The reason for choosing band saw blades for analysis is that there is reliable information source [3] which is a sawmill survey in Washington, depicting the prevalence of band saws. Figure 5 shows that in the key regions at Washington (those that produces most lumber), circular saw produced 1% of all lumber output, while band saws produce 54% of all lumber output.

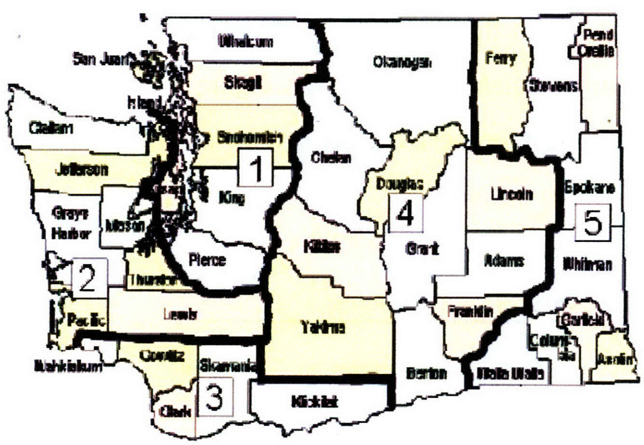
Lumber production — by headrig and county (thousand board feet, lumber tally)

Economic area and county	All headrig types	Circular saw	Band saw	Gang saw	Chipping saw	Scragg double cut saw
Puget Sound						
King and Whatcom	53,743	80	27,200	0	6,800	0
Pierce	641,665	0	135,933	480,732	25,000	0
Skagit	20,044	95	19,949	0	0	0
Snohomish	738,573	10,000	657,528	53,900	17,145	0
Total	**1,454,025**	**10,175**	**840,610**	**534,632**	**48,945**	**0**
Olympic Peninsula						
Clallam	291,018	12,734	83,234	70,500	0	124,551
Grays Harbor	386,462	3,900	317,762	29,700	0	35,100
Mason, Pacific and Thurston	663,648	0	250,208	413,440	0	0
Lewis	631,761	6,498	387,907	44,515	184,111	8,730
Total	**1,972,889**	**23,132**	**1,039,110**	**558,155**	**184,111**	**168,381**

Figure 5. Lumber production by saw type [3].

4.3 Type of wood and specific region of focus

Motivated by the potentially lucrative business of applying the technology in sawmills processing relatively more expensive wood, Douglas Fir is the appropriate choice since it is one of the more prevalent expensive wood being processed in parts of the U.S., especially in the Pacific Coast region. It is also one of the moderately-dense wood at 530 kgm^{-3}[10]. Douglas Fir represents 1/3 of all trees in Washington, and throughput is increasing significantly over the years despite having decreasing number of sawmills. Regions 1 and 2 on Figure 6 (Map of Washington) is the main focus since the two regions produces most of the Douglas Fir species. Referring to Figure 7, in the Washington region, 48.2% of species are Douglas Fir, 52.1% of all wood are processed as lumber and 65.2% of all Douglas Fir Lumber are produced in regions 1 and 2.



1. Puget Sound
2. Olympic Peninsula
3. Lower Columbia
4. Central Washington
5. Inland Empire

Figure 6. Map of Washington classified into sub-regions [3].

Log consumption — by species (thousand board feet, Scribner scale)

Economic area and industry	All species	Douglas-fir	Hemlock	True firs	Spruce	Ponderosa pine
Puget Sound						
Lumber	**688,707**	304,382	292,070	2,090	777	0
Log export	**648,310**	588,121	40,149	8,300	7,540	0
Other *	**107,873**	52,135	37,805	0	0	0
Total	**1,444,890**	**944,880**	**370,024**	**10,390**	**8,317**	**0**
Olympic Peninsula						
Lumber	**1,217,334**	446,000	577,816	11,850	22,745	0
Veneer and plywood	**146,039**	77,393	55,700	0	3,250	0
Shake and shingle	**8,622**	0	0	0	0	0
Post, pole and piling	**12,370**	12,370	0	0	0	0
Log chipping	**166,276**	54,192	59,400	1,560	8,970	0
Other *	**5,500**	5,225	165	110	0	0
Total	**1,556,141**	**595,180**	**693,081**	**13,520**	**34,965**	**0**
Lower Columbia						
Lumber	**282,051**	155,578	10,405	25,834	590	0
Pulp	**0**	0	0	0	0	0
Log chipping	**6,621**	4,635	993	993	0	0
Other *	**262,906**	189,995	41,748	0	18,000	375
Total	**551,578**	**350,207**	**53,146**	**26,827**	**18,590**	**375**
Central Washington						
Lumber	**536,122**	144,449	5,147	250,948	347	65,656
Other *	**83,000**	71,700	0	5,300	0	0
Total	**619,122**	**216,149**	**5,147**	**256,248**	**347**	**65,656**
Inland Empire						
Lumber	**356,045**	99,685	3,500	39,914	2,695	152,729
Pulp	**0**	0	0	0	0	0
Other *	**53,368**	0	0	48,000	0	2,667
Total	**409,413**	**99,685**	**3,500**	**87,914**	**2,695**	**155,395**
State Total						
Lumber	**3,080,259**	1,150,093	888,938	330,635	27,154	218,384
Veneer and plywood	**291,311**	187,155	78,476	5,300	3,250	375
Pulp	**0**	0	0	0	0	0
Shake and shingle	**9,122**	0	0	0	0	0
Log export	**897,949**	769,641	77,558	8,410	25,540	0
Post, pole and piling	**21,941**	18,118	0	0	0	0
Log chipping	**280,562**	81,093	79,926	50,553	8,970	2,667
Total	**4,581,144**	**2,206,101**	**1,124,897**	**394,898**	**64,914**	**221,426**

Figure 7. Lumber and species processed by distribution of sub-regions [3].

4.4 Model to estimate the potential amount of savings due to lower CTE

To the best of the author's knowledge, there is limited literature at present directly addressing the effects of CTE on saw-mill blades. , nor any which addresses its effects on throughput in sawmills. The following model aims to aid in envisaging the amount of possible savings due to the using of Incoloy-908 instead of typical steel blades. The result of this model should be interpreted as being the more optimistic scenario among the possible outcomes of the amount of savings in sawdust waste.

4.4.1 Assumptions of the model

The assumptions are as follows:

i. The difference in amount of linear expansion directly translates to the difference in volume of sawdust generated.
ii. The saw width represents the effective width of the blade including the kerf.
iii. The saw log is in the shape of a cuboid.
iv. The thicker band saw blade (3mm) will be used for analysis since the effect of CTE would be more pronounced.
v. Saw blades are heated by up to 100 degrees Celsius above room temperature.
vi. The equivalent number of cuts along the cross-section of the saw-log portion of the tree in typical operations is estimated based on rough comparison of typical dimensions of saw-log [17] and sawn lumber [18].
vii. The amount of savings is compared to the expanded volume difference out of sawn lumber, which is 55.4% of the saw-log portion, by empirical estimates. The relevant calculations in theory are as follows, which further justifies the measured yield of lumber from saw-log:

4.4.2 Estimation of lumber yield

For Douglas fir, the weight of dried lumber per unit volume can be calculated with equation 1, and the ratio of green weight to dried weight can be calculated as with equation 2.

$$\frac{W_d}{V_g} = \rho(w)G_b \qquad (1)$$

$$W_g = W_d\left(\frac{1+M}{100}\right) \qquad (2)$$

Where W_d is the dry weight, V_g is the green volume, ρ(w) is the density of water(62.4 pounds per cubic foot), G_b is the basic specific gravity, W_g is the green weight, and M is the numerical value of the moisture contents (%). For Douglas Fir, ignoring the bark values, and ignoring the heartwood portion (heartwood refers to the darker wood in the centre of the stem, but can be safely ignored, since it is only present to a significant amount in trees that have not been cut down for many hundreds of years and Douglas Fir are usually felled after 50 years), G_b = 0.45 and M=115% (sapwood). Therefore:

$$\frac{W_d}{V_g} = 28\ lbft^{-3}$$

$$\frac{W_g}{W_d} = 2.15$$

With the above, one can visualise that for each cubic feet of green lumber, there is only 28 pounds of dried lumber, and after drying, the weight of the lumber would actually be reduced by 46%. The above verifies that for the empirical estimate of 55.4% volume yield (for over 54000 actually measured Douglas Fir saw timber sized trees standing in Washington State's forests) is reasonable because the weight has to be decreased by around 50%. For weight to decrease by half, the volume should also have decreased by around the same amount since the log density should not be varying to a large extent along the log.

4.5 Description of model

For every °C of linear expansion, Incoloy-908 expands by 8.59 μm/m while tool steels on average expand at around 12 μm/m (as shown in Table 1), with the relevant temperature range (changes of 100° C from room temperature). The expansion process could be simplified as a geometric progression. To illustrate, let the CTE be α μm/m°C for the temperature range of interest, and the beginning thickness of the blade be t meters. After 1 °C of temperature increment, the width becomes t(1+ α), and after the second °C of increment, the thickness becomes t(1+ α)^2. The final width reached after 100°C of expansion is t(1+ α)^{100}. With this in mind, the volume saved from one cut will be

$$V_{saved} = [(1+\alpha)^T - 1] \cdot t \cdot b \cdot b \text{ cubic meters} \quad (3)$$

where b is the assumed cross-sectional length of the cuboid saw-log.

Specific Tool Steels	CTE (μm/m/°C) for 0-100°C
Water-hardening tool steel	9.8-10
Molybdenum high-speed tool steel	10-11
Tungsten high-speed tool steel	11
Cold work tool steel	11-14
Mold tool steel	12
Air-hardening medium-alloy cold work tool steel	11-13
Oil-hardening cold work tool steel	10-13
Low-alloy special purpose tool steel	11
Shock-resisting tool steel	11

Table 1. CTE of typical tool steels [8]

If the original volume of the wood is $(b \cdot b \cdot h)$ cubic meters, and there are a total of n cuts operated, the fractional savings will be

$$\frac{n \cdot V_{saved}}{(b \cdot b \cdot h)} \quad (4)$$

A worked example is shown in Table 2. It is important to note that the expected amount of savings per saw log cut into lumber when Incoloy-908 blades are being used, is only around 0.01%.

	CTE,α (μm/m°C)	Total expanded (cubic m)	Wastage(%)
Incoloy	**8.59**	**3.59E-06**	**0.0203%**
Tool Steels	**12.00**	**5.02E-06**	**0.0284%**

Table 2. Amount of wastage due to direct expansion

Although the above model is based on many assumptions which may not be true, but the order of the degree of accuracy should be as expected. This will mean that in the best case, at most 0.1% of saw-log could be saved by using a saw-blade with lower expansion. This also implies that the focus on the technology should not only be on the direct savings due to expansion, but also on other properties such as uniform heating issues, fracture toughness and tensile strength. The heating effects that may be related to CTE should also be considered.

4.6 Further heating effects that may be CTE related

In a typical band sawmill with moderate throughput [3] of around 100 thousand board feet per 8 hour shifts, the uptime of blades are especially important. The functioning time is usually reduced by blade replacement intervals due to failure or maintenance, which saw serious impact on throughput. Frictional heating of the saw is the prime reason for blade failure, as acknowledged by Munkfors in [15]. Sources of heating in a typical circular powered blade are from the cutting operation that involves extricating the sawdust, the friction between the blade and the working surface, the friction between the blade and the blade guide, and shaft bearings. This heating not only directly increases waste wood due to expansion, but also results in unbalanced deformation of the blade. This unbalanced deformation may lead to direction of cutting force being instantaneously displaced, prevent a straight cut.

4.7 Maximising operational rotating speed of a circular saw

If Incoloy is being used as a base material for circular saws, the operational rotating speed allowed could be higher. The minimum destructive rotational speed of a circular power saw is constrained by the material properties of the saw-blade. Equation (5) from [21] is a widely used equation in the industry which is a guideline to specify the operational rotational speed maximum, relating it to geometrical parameters of the saw and more importantly, the ultimate tensile strength and the density of the material:

$$n_{des}^{min} = \frac{30}{\pi}\sqrt{\frac{3\sigma_m(R-b)}{\rho(R^3-b^3)}} \qquad (5)$$

where ρ is the density, σ_m is the ultimate tensile strength, R is the external radius, while b is the internal radius. Since incoloy has a comparable density to materials used as saws (typically tool steel), and also a much higher ultimate tensile strength, the minimum destructive rotational speed could be potentially increased if Incoloy is being used. As mentioned in previous sections, the operational speed affects throughput, which is the most important factor affecting profitability in the sawmill business.

Critical rotational speed theory further justifies that there is a resonance frequency which would be reached if the saw is operated at high rotational speeds. Equations (6),(7) and (8) from [22] govern the behaviour of rotating saws. Equation (6) and (7) are the forward and the backward travelling wave in a rotating saw. As the rotational speed of the circular saw increases, the frequency of the backward travelling wave becomes zero, and the saw will vibrate at resonance. When such a condition is met, a small lateral force on the saw may cause a large lateral deflection of the saw blade, which could pose safety issues and yield loss.

$$f_{nf}(N) = f_n(N) + \frac{nN}{60} \qquad (6)$$

$$f_{nb}(N) = f_n(N) - \frac{nN}{60} \qquad (7)$$

$$n_{cr}^{min} = \frac{60f_n(0)}{\sqrt{n^2 - K}} \quad (8)$$

where K is the centrifugal force coefficient, $f_n(0)$ is the natural frequency of the stationary blade, N is the rotational speed, and n is the nodal diameter. Table 3. is an extract from [16], mentioned by Munkfors of the possible troubles that are being identified when sawing in sawmills, along with their possible causes.

Problem	**Possible cause**
Excessive blade wear	Low feed speed Too high blade speed Dirty logs
Vibrating saw	Incorrect band speed Wheel out of balance Incorrect adjustment off saw guide Incorrect adjustment off saw Incorrect pitch in relation to log/timber thickness Log/timber not held firm enough
Poor surface finish	Too short pitch Uneven or stellite swage Uneven blade joint
Blade overheating	Too thick blade Highly dense wood Worn saw guide Uneven wood side clearance
Premature blade breakage	Too high feed speed Too high blade tension Too thick blade in relation to wheel diameter
Poor yields	Low feed speed Using blade with too short pitch
Snaking blade	Worn blade Too high feed speeds Log/timber not held firm enough Uneven blade tension

Table 3. Different sources of blade failure [16].

Problems such as blade overheating and feed speed overdrive as shown in Table 3, could be improved when Incoloy-908 technology is used. Although it is difficult to estimate the amount of throughput improvement that this technology could bring by improving blade durability, it would be assumed to be around 0.5% of overall throughput, which is slightly above the amount of wood savings due to direct expansion of blades.

4.8 How incumbent technologies minimise the effects of expansion in saw blades.

This section evaluates the likelihood that low CTE saw blades are desirable in the industry. Current measures to address the problems that are related to heating are presented.

4.8.1 Reducing the saw kerfs

Intuitively, one would imagine that minimising the saw kerfs by producing thin blades would be sufficient to address the problem. Indeed, the thinner the saw kerfs, the higher the throughput. However, there are important points that should be noted as follows. There is a limit to the minimum size of the saw kerfs depending on the type of sawing process, the feeding speed, the rotational speed, and the desired amount of sawing variation. This necessitates the consideration of the type of sawing process and type of blade used in the overall analysis. In the industry, different sizes of saw kerfs are being used for different processes, but generally, the kerf size is chosen on the basis of weighing the importance of throughput increase with the quality of work, which may be limited by the type of wood too.

4.8.2 Reducing heat

With reference to various scientific journals and patents, the incumbent technologies address the problems by mainly using exotic saw designs. Table 4 summarises examples of patented designs of saw blades to reduce heating

Patent Number	Assignee	Description
United States Patent 3872763	Ihara Koatsu Tsugite Kogyo Kabushiki Kaisha (Tokyo, JA)	A special saw is designed which isolates the edge portion from inside portion of blade. As a result, heat produced from toothed peripheral is prevented from

		being transmitted to inside portion
United States Patent D382786	Black & Decker Inc. (Newark, DE)	Circular saw blade with heat vents
United States Patent 4148236	Norsk, Treteknisk Institutt (Oslo, NO)	Method and a device for controlling thermal stresses in a power saw blade by continuously measuring the temperature in two or more zones on the saw blade and determining the temperature difference between the zones

Table 4. Patented designs addressing saw blade heating.

4.9 Incoloy-908 as a suitable candidate for wide-band-saw blade

Band saws are the most widely used machines to cut logs in many regions, such as in Washington [3] because their small kerfs results in high timber yield, low amounts of sawdust, accurate cutting and good processing economy. Band saws require strong blades to be tensioned constantly because the blade is driven and stretched by the wheels that rotate them on a band mill. They also should have impact toughness that could withstand unintentional contact with hard materials that may be intentionally introduced to timber by eco-terrorists (tree spiking). Band saw blades are usually made of tool steels as they have relatively high tensile strength with suitable toughness. The continual flexing of the blade causes metal fatigue and failure of the blade. Each revolution flexes the blade to near the elastic limit of the steel, which causes the metal to fatigue and brake quickly. In sawmills, the profitability of the business depends highly on the throughput of the saw mill. Incoloy-908 would potentially compete very well in this aspect. A success story analogous to the technology application in this work is the successful implementation of Sandvik Durashift™ blades, which is an advance material saw blade. It proved to improve the profitability of sawmills even with the drawback of higher blade costs [13].

4.10 Cost of current saw blades

Band saw blade costs, including maintenance, accounts for only 1% of sawmill running costs. Figure 8 show the breakdown of the cost structure in sawmills [6]. Since the cost of saw-logs contributes around 70% of the cost structure, blade costs should be around US$400,000 annually. This is calculated from the average pond value of Douglas Fir Trees (US$300/mbf, refer to Appendix 2), the average throughput rate of 120mbf per 8-hour shift, and the 228 working days per year, according to [3].

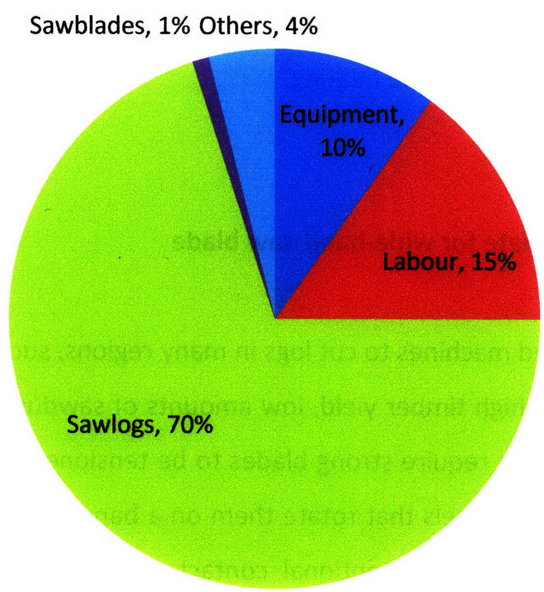


Figure 8. Typical sawmill cost structure [6].

The blade lives of band-saw blades are relatively short in sawmills. Figure 9 shows life of blades with different standards. The best blade could only last for 220 hours. A sawmill using better band saw blades could have each blade replaced in about a week of full operation (24 hour shifts). This serves as a good starting point to estimate the price of advanced material steel blades. Assuming that there are around ten simultaneously working saws, each saw blade would cost around US$1000, based on the total annual cost of blade materials (US$400000) as aforementioned.

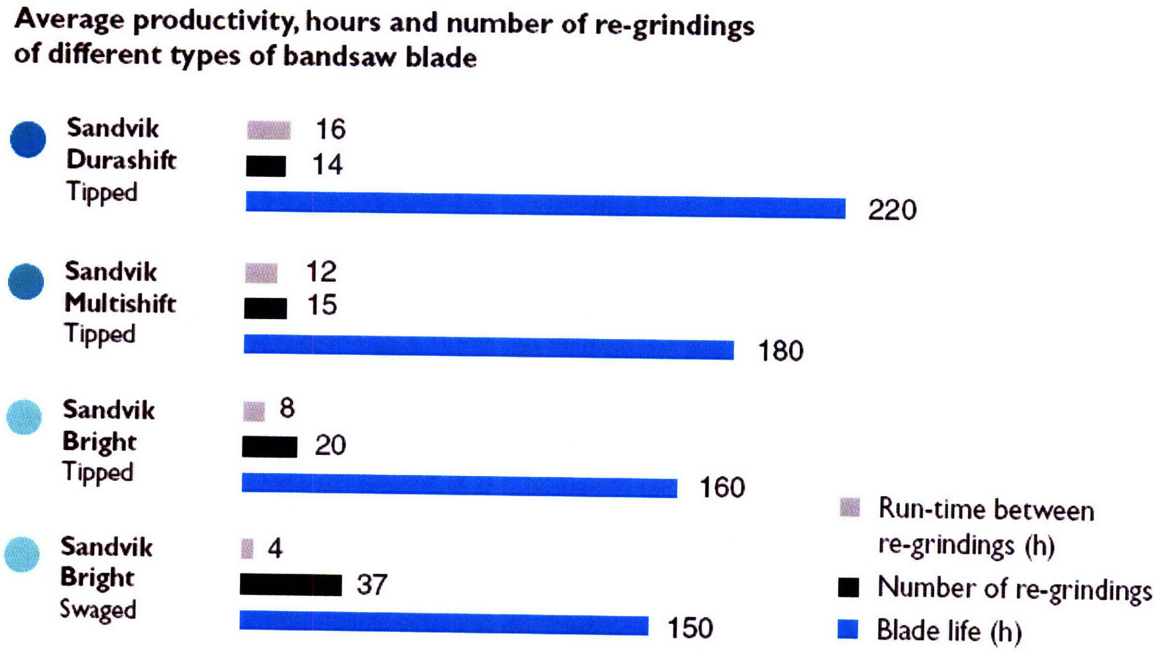


Figure 9. Specialised blade performances in sawmills [7].

4.11 Price Comparison – tool steels versus incoloy-908

The prices of different grades of tool-steels are averaged and compared with the price of Incoloy-908 (appendix 1). As one would expect, the cost of producing Incoloy per kilogram base material for saw blades would be around 1.5 times that of tool steels. The price of Incoloy-908 is calculated using an alloy calculator based on compositions (Appendix 1). The price obtained for Incoloy-908 is US$16 /kg, while the average price of tool steels is around US$11 /kg as shown in Table 5, depicting the different grades that are being averaged out.

Tool Steel Type	Price/kg
D2	2.2
H11	1.9
H13	2.3
M1	8
M2	7.8
M3 (class1)8	8
M3(Class2)	4.6
M4	8.4
M7	8.9
M10	7.7
M30	13.3
M33	17
M34	16.6
M35	12.8
M36	16.3
M41	12.4
M42	17.2
M43	16.8
M44	20.5
M46	17.8
M47	13.7
M48	19.2
M62	11.9
Average	**11.53478**

Table 5. Average prices of base material for tool steels.

4.12 Summary of potential advantages and assessment of assumptions

The aforementioned potential advantages of using Incoloy material as a saw blade material are mainly theoretical arguments with respect to the material's superior fundamental properties such as low CTE and high fracture and impact toughness. Namely, the Incoloy blade should be more *durable, safer (higher resonance frequency), and able to reduce the amount of sawdust or other waste wood produced.* This work acts as a preliminary feasibility study and the methods and calculations used should not be used without assessing the assumptions during the actual implementation.

The most important assumption to note is that the average values of tool steels' properties are used in comparison with that of Incoloy. Since the exact compositions and the manufacturing techniques of the actual materials being used in saw blades are usually trade secrets kept by the companies, therefore, the assumptions are based on the best of the author's knowledge. Since in this project, the targeted commercialisation route is not within the original scope where the material is designed for, the technicalities would involve speculations. Nevertheless, meaningful conclusions could be drawn from the discussion by assuming the material would achieve a slight advantage over competing technologies, and the risks of technical barriers involved would be taken into account.

5. Value Chain and Intellectual Property

5.1 Timber sawmills and lumber

The entire value chain starts at the forests, where trees were initially felled. Before they were cut and transported to the saw mills, their value is known as stumpage value. The typical stumpage value of Douglas Fir (the tree species chosen for analysis) is estimated and explained in Appendix 2. After the trees are felled and transported to the saw mill (being scaled in the process) they will have a pond value (which is named after the mill pond where the transported log are placed –appendix 2). Figure 10 summarizes the value chain related to saw mills and their saw blades.

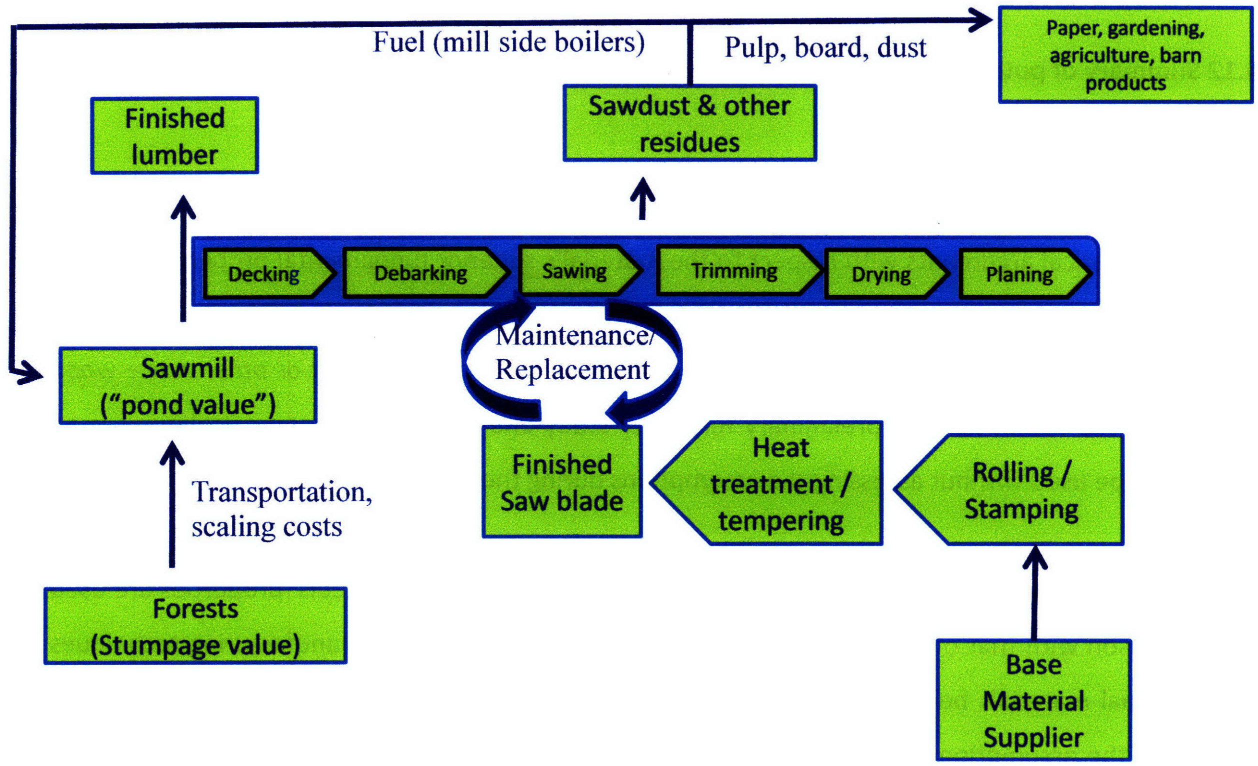


Figure 10. Illustration of value chain in saw mill and saw blade industry.

At this stage where the timber is in the saw pond, the timber only has a saw-log portion of the tree left which is of interest in this project. The saw-log price is the feedstock price for sawmills, which will be used in subsequent analysis. A series of processes are carried out in the saw mill – decking, debarking, sawing, trimming, drying and planning. The only value-added process that involves the band saws is the sawing process. Therefore, in the subsequent analysis, only the sawing process is taken into account in the quantifying of value-added.

Finally, after the sawn wood is dried, planed, they will have a higher value, and the finished lumber is sold to distributors for various uses, such as building materials. In the series of processes that happen in the saw mill, sawdust and other residues are produced. A well-established infrastructure to collect the residue and feedback to the sawmill energy providing systems, or to be sold for money is mostly in place and not much of it is unused.

5.2 Blade manufacturing and base material supplying

Blade manufacturers typically buy base materials from suppliers, and through a series of rolling, stamping, heat treatment and tempering, the finished saw blades are sold regularly to the sawmills since sawmill blades wear out very often. The specific processes to manufacture industrial-grade saw blades are usually trade secrets of saw blade companies. By providing the specialised products to sawmills, they maintain a rapport with their clients and provide maintenance services for the saw mills such as re-sharpening or re-hardening. Base material suppliers such as Special Metals are at the bottom of the value chain.

5.3 Intellectual Property Landscape

To the best of the author's knowledge, there are basically 2 categories of patents found that are related to the relevant industries – patents for saw blades and patents for base material. The patents, of which some are owned by reputable saw blade companies, are ways to potentially add value at the blade manufacturing and the base material optimisation level. In the perspective of a base material manufacturing companies, although there are apparently no close competition to supply low-expansion, high-toughness base materials, it may not be profitable to operate as a base material manufacturing company since it is at the bottom of the value-chain, and at the same time may be relatively more difficult to protect ideas with intellectual property. Table 6 and Table 7 shows the typical patent coverage for saw blade manufacturing and base material manufacturing, and their assignee companies involved.

Patent Number	Assignee	Description
United States Patent 6520722	Simonds industries	Asymmetrical cutting tool tooth form
United States Patent 5033237	Kobelco Compressors	Method of numerically controlled profile grinding
United States Patent 5074078	Fritz Studer AG	Device for circular and/or profile grinding
United States Patents 5,308,367 and 5, 139,537	The Orbital Saw Co	TiN-coated grinding wheels (Golden Wheels™)
United States Patent 7121180	Yugen Kaisha Marushimo Machine Saw	Band saw, band saw processing apparatus and band saw manufacturing method

Table 6. Patents covering blade manufacturing processes.

Patent Number	Assignee	Description
United States Patent No. 981125	Carl Aug. Picard GmbH & Co. KG	Base material for producing blades for circular saws, cutting-off wheels, mill saws as well as cutting and scraping devices
European Patent EP0155314	The Peerless Saw Company	Saw blade or blank having self plugging stress relief means
European Patent EP1389503	Boehler, Uddeholm Prec Strip GM	Base material for saw blades or band saws

Table 7. Patents related to base material production methods.

6. Sawmill Value Assessment

In order to analyse whether changing from steel to Incoloy saws would add value to sawmills, one should isolate the part of the value chain of interest, and assess its value-adding process with and without the employment of Incoloy technology. Based on the preliminary information on sawmills, the additional value that Incoloy could bring would be equivalent to equation (9).

$$\begin{aligned}
&\textit{Additional value offered by Incoloy blades per year} \\
&\quad = \textit{Savings due to a reduced consumption rate of sawlog} \\
&\quad - \textit{opportunity cost of selling sawdust waste} \\
&\quad - \textit{additional equipment and maintenance costs incurred by using incoloy} \\
&\qquad = \left(T_{dried} \times P_{dried} - C'_{sawlog} \times P_{sawlog}\right) \\
&\qquad -\left(T_{dried} \times P_{dried} - C_{sawlog} \times P_{sawlog}\right) \\
&\qquad -(Q_{residue} \times P_{residue}) - AC_{incoloy} \qquad (9)
\end{aligned}$$

Where

$T_{dried} = \textit{Annual throughput of dried lumber},$

$P_{dried} = \textit{Price of dried lumber},$

$P_{sawlog} = \textit{Price of sawlog inputs},$

$C_{sawlog} = \textit{Original consumption rate of sawlog},$

$C'_{sawlog} = \textit{New consumption rate of sawlog},$

$Q_{residue} = \textit{Amount of wood residue},$

$P_{residue} = \textit{price of residue}$

$AC_{incoloy} = \textit{Additional cost of incoloy}$

In order to ignore the added costs involved with subsequent processes such as drying and planning, and only look at sawing, one could imagine that the increase in profitability in this value-adding stage is in the form of saving inputs, rather than adding to output. ([11] provides an overview of the value adding process in sawmills). Since with the new technology, one could produce at the same level with lesser inputs consumed, one could calculate based on a new consumption rate associated with using Incoloy-908 band saws. The value of sawdust that is being lost in the process (although it may not seem to be significant) should also be taken into account because the useful finished lumber that is saved is at the expense of these residues. The additional cost of installing and maintaining Incoloy-908 saws should be included too. However, this value could be negative if the blades turn out to be more durable than incumbent steel saws, which in turn reduces replacement and maintenance costs. The consumption rates are based on average throughput in sawmills (based on [3]) divided by the amount of lumber yield. Lumber yield is interpreted as the volume of dried lumber obtained divided by the volume of green lumber before the drying process. As previously mentioned, it is around 50%. The effective throughput improvement $\left(C'_{sawlog} - C_{sawlog}\right)$ is calculated as $\frac{Average\ Throughput}{Lumber\ yield} \times \%savings$.

6.1 Feasibility flowchart

Before proceeding to put in numbers to equation (9), it must be noted that the quantitative analysis is executed with the macroscopic view to analyse the feasibility of the application. Using the feasibility flowchart shown in Figure 11, this work seeks to, in a quantitative manner, justify whether or not using Incoloy saws would add value. The important considerations would be the geographical location, the species of trees, the throughput of sawmills as well as the additional step required to prove that the technology works. Through an iterative process of eliminating implausible geographical areas, the state of Washington is chosen due to the high production of Douglas Fir trees, which are relatively more expensive and very prevalent in the region.

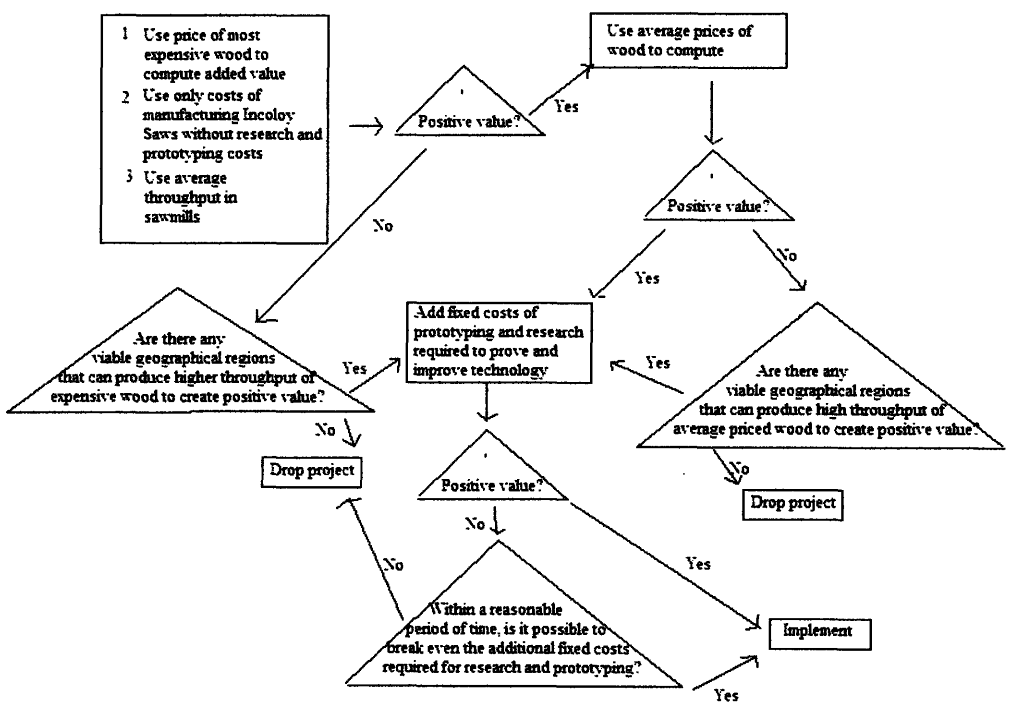


Figure 11. Feasibility flow chart of value assessment.

Based on equation (9) three scenarios that are expected of the value adding process in the two regions in Washington is as follows, with the number of work days standardized at 228 based on [3].

Optimistic Scenario

It is assumed that in an optimistic scenario, the business would be able to engage sawmills producing at high throughput (1Mmbf/8 hr), using very expensive Douglas Fir of pond value ($700/mbf), and no excess Incoloy saw expenditure. The amount of savings to saw log consumption rate is high at 1%.

$$Value\ calculated$$

$$= \frac{US\$700 \times 1000mbf\ per\ shift \times 3shifts \times 228days}{0.55\ lumber\ yield} \times 1\%\ savings$$

$$- US\$0\ incoloy\ expenditure$$

$$= US\$9.58m$$

Moderately Conservative Scenario

In a conservative scenario, throughput of sawmills is assumed to be at 500mbf/8hr, average Douglas Fir pond value ($350/mbf), high Incoloy additional costs of US$0.9m, and mediocre savings (0.5% /mbf).

$$Value\ calculated$$

$$= \frac{US\$350 \times 500mbf\ per\ shift \times 3shifts \times 228days}{0.55\ lumber\ yield} \times 0.1\%\ savings$$

$$- US\$0.9m\ incoloy\ expenditure$$

$$= US\$297{,}000$$

Pessimistic Scenario

In a pessimistic scenario, average throughput of sawmills is taken to be only 120mbf/8hr, low Douglas Fir pond value of US$200/mbf is used, high additional Incoloy cost of $1m, low savings of 0.01%/mbf),

$$Value\ calculated$$

$$= \frac{US\$200 \times 120mbf\ per\ shift \times 3shifts \times 228days}{0.55\ lumber\ yield} \times 0.01\%\ savings$$

$$- US\$1.5m\ incoloy\ expenditure$$

$$= -US\$1.5m$$

6.2 Discussion of value assessment

The moderately conservative scenario well reflects what is expected of the paybacks of employing the technology in a year. This amount, although insignificant in this calculation, could potentially be increased due to better durability. The important assumption is that Incoloy saw blades would incur around US$1m of extra costs to the clients annually, which could be over estimated. This means that if Incoloy blades were to be priced exactly at the cost of the tools that are initially used by sawmills, a cost saving amount of US$1.3m could be offered.

7. Market Environment in the U.S.

The macroscopic view of the business and also the related businesses in the supply chain is crucial to the assessment of technology commercialisation. An overview of the saw mill and tooling industries gives a complete picture to the feasibility of the business.

7.1 Sawmill and Wood

The sawmill industry represents a substantial portion of the analysis by [19]. The data presented in [19] is an accurate representation of the economic environment of interest in this project.

7.1.1 Industry overview

Understanding the nature of the industry as well as developing a sense of the economic environment provides a macroscopic view of the profitability of the demand side of the analysis in this work. Although the general cost structure of sawmills is largely in favour of the proposed application, the industrial nature and economic environment plays a part in understanding the objectives and general behaviour of sawmill managers.

7.1.2 Correlation to other industries

The nature of sawmill and wood industry is at a stage of decline, according to [19]. Falling at an average rate of 1.9% during the last five years (up to December 2008), the overall industry is becoming smaller and the number of enterprises within the industry is estimated to be 3530 by December 2008. Demand of the industry's products is reliant upon strong activity in housing and furniture construction, which more often than not suffer from fluctuations due to macroeconomic conditions. Moreover, price competition from markets like Canada, Japan, and Europe exerts great pressures to the industry.

7.1.3 Level of competition and success factors

Generally, firms can enter easily without high barriers to entry. The market is very competitive with only a few firms with significant market power. The success factors in such a market structure largely depend on pricing, quality, versatility of production, and technological efficiency. Among these factors, two factors have direct implications on the feasibility of sawmills adopting Incoloy saws. Firstly, since being able to produce a wide variety of lumber that could cater to changing demand patterns is the concern of sawmill managers, the ability of Incoloy saws to be able to fit into a wide variety of sawing processes is important. This is an important technological risk factor. Secondly, being technologically efficient would require operating at high throughputs so that they can produce as effectively as imports where large scale production is more common. Incoloy saws are likely to be a good selling point as the potential benefits of adopting the technology align with the overall industrial goal. An example to further support this point is that [19] estimates that the investment in new plant and equipment by the industry will increase at an annual average rate of 4.7%, to US$1.13 billion.

7.1.4 Cost structure and profits

The main production cost contributors are purchases (66%) and wages (15.6%) while utilities occupies only 2.2% of the total costs. Profit margins are declining but are generally high at around 9.1% of total revenue. The trend of increasing investments in modern, highly mechanized equipment means that the industry is switching to lower level of labour cost.

7.2 Hand Tool Cutlery Manufacturing

This section, relative to the industry analysis of sawmill operators, should less accurately reflect the actual market for sawmill band saw blades because specialised saw blades may be substantially different from the overall cutting tool industry. Nevertheless, sawmill and handsaw products represent 11.1% of industry revenue in the data presented in [20]. Therefore, the management and operations of specialised saw blade manufacturers should bear the basic resemblance to the overall industry.

7.2.1 Industry overview

The hand tool and cutlery manufacturing industry is an industry in its declining stage, according to [20], with saw blade and handsaw products declining at an average annualized rate of 3.6%., while value added is expected to contract at an average rate of 4.2% annually. This is attributed to decreasing domestic demand over the period, further aggravated by price competition with imports.

7.2.2 Level of competition and success factors

The industry competes on the basis of product reputation, product quality brand recognition and commitment to customer service. Larger companies have an edge in terms of breadth of product lines. Unlike the saw mill and woodworking industry, the industry has both large small firms competing. Due to the strong brand name recognition, new entrants need to overcome established product brands. Moreover, new entrants have to overcome existing distribution and production capacities, making the barriers to entry much higher than that of sawmill and woodworking industry. This implies that starting a blade company will see high barriers to entry, if the product is targeted at sawmills who already have established a good relationship with established blade company. Therefore, bigger scale sawmills may be more reluctant to switch, while smaller mills who are not equipped with advanced equipments could be the best target buyers.

7.2.3 Cost structure and profits

Purchases (43%) and wages (21%) contribute substantially to the cost of production. This implies that base material cost would be important. Being substantially more expensive than tool steels, Incoloy do not compete well in this aspect. Overall profit margins are low at 6% as compared to saw mills and woodworking industry. Therefore, one should not expect high margins from operations in this industry. Table 8 shows the summary of the industrial research.

Comparison point	Sawmill and Wood Industry	Tooling Industry (blades and equivalent)
Life cycle stage	Decline. Cost competitiveness losing out to imports due to market structure.	Decline. Decreasing domestic demand with pricing pressure from imports.
Competition	High	High
Market Structure	Low concentration. Bigger firms downsizing.	Low concentration. Large scale production likely to survive.
Barriers to entry	Low.	High (brand names, production scale, cost competitiveness).
Cost structure	Highly sensitive to input prices and wages.	Highly sensitive to input prices and wages.
Investment in equipment and technology	Increasing investment to remain cost and hence price competitive. This is done mainly to combat decreasing demand.	Reduced due to low operating income. However, current players invest substantially in R&D for market leadership.

Table 8. Summary of industrial research [20].

8. Business Plan

The main business plan is divided into two stages, the first being the research stage, while the second stage is the setting up of the company itself. During the research stage, further testing and prototyping would be required, and the associated costs are estimated to be at least US$1 Million. The estimates are shown in subsequent sections.

8.1 First Stage – research and testing of prototype

This section aims to quantify the amount of capital that may be required at the seed stage of the startup, which could span between one to two years. Firstly, the proving of concept and technology requires the help of industrial experts who are already in the business of special materials saw blades. The process know-how and costs of production of such a specialized market is highly exclusive. To fully appreciate the technicalities and the overall business, it would be advantageous if the startup could employ an industrial expert to be the chief technical officer. A budget of USD$100-200 would be dedicated to employment of an expert. The next step would be to purchase enough raw materials for fabrication, and lumber for testing. The amount of saw log that is required would cost around US$0.1m, which is estimated based on relatively cheaper wood ($100/mbf). There should also be capital set aside for renting of equipment and buying of material for the manufacturing of prototypes. The costs associated are estimated to be US$0.5m. Further, a mini sawmill would be required to test-run the blades. If second hand portable sawmills could do the job, the estimated cost will be around US$20000. Finally, after taking into account building, floor space and power supply costs, the total funding required to start would be US$1m.

8.2 Subsequent stages

8.2.1 Scenario 1 – Product company: Saw blades Manufacturer

As a saw blade manufacturer, the company would have to start small. The associated cost model of starting a small saw blade company, estimated based on typical manufacturing industrial costs (equipment, floor space, labour, smithwork, feedstock etc). The exact process of manufacturing wide band saw blades is still elusive (trade secrets kept by most sawmill wide band saw blades company). The author's best estimate with a cost model for the saw blade company is shown in Figure 12. This cost model is embryonic and should only be taken as a visualisation of the set up. The actual cost of production could be very different depending on the actual processes involved, which may be misrepresented in the assumptions.

VARIABLE COST ELEMENTS	per blade	total per year	percent
Base Material Cost Feedstock	$ 131.61	$ 13,161.17	8%
Labor(smithwork) Cost	$ 1,490.00	$ 149,000.00	87%
Energy Cost	$ 100.00	$ 10,000.00	6%
Total Variable Cost	**$ 1,721.61**	**$ 172,161.17**	**100%**

FIXED COST ELEMENTS	per blade	total per year	percent
Equipment	$132.83	$13,283.33	6.04%
Building/Floorspace Cost	$330.00	$33,000.00	15.01%
Maintenance and Inspection Cost	$14.50	$1,450.00	0.66%
Total Fixed Cost	**$477.33**	**$47,733.33**	**21.71%**
Total Fabrication Cost	**$2,198.95**	**$219,894.50**	**121.71%**

Related Variables & Calculations

Variable Cost Parameters		
Feedstock price of Incoloy	$ 16.00	$/kg
Energy Consumption	$ 10,000	$/year
Labour Cost	$ 149,000	$/year
Fixed Cost Parameters		
Price of Bandsaw Grinder	$ 7,000.00	
Price of Tensioning and rolling bench	$ 7,500.00	
Price of Bandsaw Sharpener	$ 1,000.00	
Other machines	$ 20,000.00	
Equipment Lifetime	3	years
Maintenance cost of equipment	$1,450.00	$/year
Overall Floorspace Requirement	500.00	sq feet
Related Calculations		
Yield	95.0%	
Production Rate	10	blade/hr
Number of Planned Working Hours	8	hrs/day
Unplanned Downtime	0.55	hrs/day
Number of Working Hours per Day	7.45	hrs/day
Density of Incoloy	8170	kg/cubic m
Density of tool steels	7800	kg/cubic m
Cost of blades	$ 13,161.17	$/year
Floorspace cost	$ 33,000.00	$/year

Sawblade production

Operating Characteristics		
Targeted Production Capacity	**100**	Blades/year
Operating Days	**225**	days / year
Blades per day	**0.4**	Blades/day
Exogenous Cost Factors		
Wage	**88.89**	$/hr
Electricity Cost	**0.07**	$/kWh
Cost of Floorspace Rental	**5.50**	$/sq feet per month
Blade Characteristics		
Blade thickness	**0.08**	inch
Blade Width	**16**	inch
Blade Length	**48**	inch

Figure 12. Cost model for small saw blade company.

Due to the nature of the industry, as mentioned earlier, starting small would be a better choice because it is unlikely that initial demand would start off at the high end until the technology is proven to be able to substantially profit saw mills. A more realistic plan would be that the company produces at low volume (100 blades/year), and hence very high costs of around $2000/blade. Figure 13 shows the unit cost versus production volume of the cost model. One would realise that unit cost could only be reduced substantially at high volumes (thousands per year).

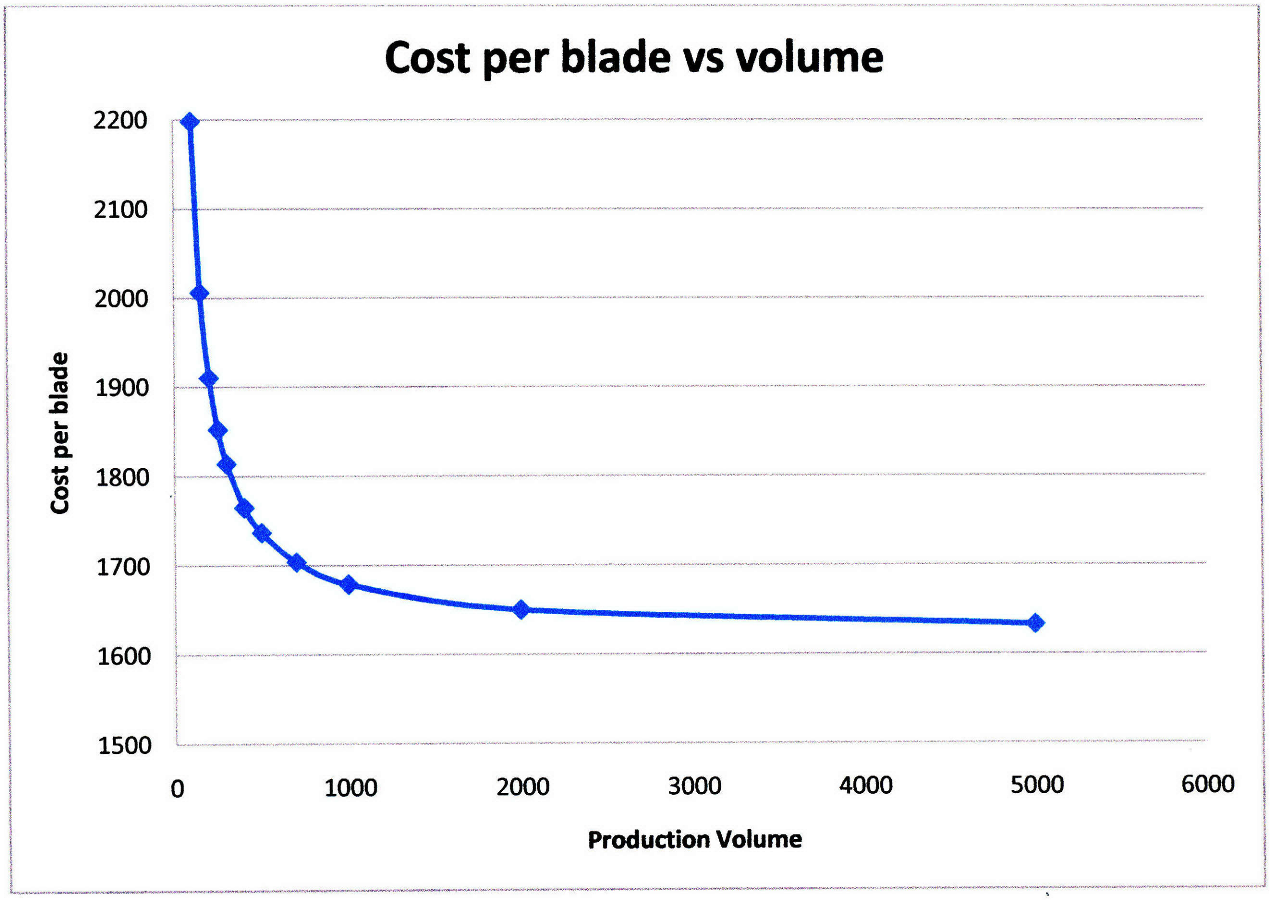


Figure 13. . Cost versus production volume of small saw blade company.

The suggested business plan that would employ the above business model is as follows. Firstly, the start-up should approach only sawmills operating at substantial throughput (at least around 100mbf per 8 hour shift. This is so as to ensure the blades are subjected to sufficient stress, wearing, and heating. Another possible suggestion is to approach only sawmills which operate at least 2 band mills, so that parallel comparisons between incumbent technology and the Incoloy blades could be made. By selling the blades at a low price initially, sawmill operators would be more willing to adopt them. Once their throughput is enhanced, the additional profits in a conservatively predicted scenario should be around US$0.3 million, according to the value assessment equation. The sawmill operators should be willing to pay out part of this additional earnings for investment in Incoloy blades. This is a win-win situation for the start-up as the price and profitability of Incoloy company grows with the client's. Furthermore, once the technology is widely adopted, larger scale productions would result in economies of scale. It is estimated based on the cost model that if production could increase up to 500 blades annually over 5 years, it will take another 5 years to break even the initial investments.

8.2.2 Scenario 2 – IP company

An alternative to producing saw blades is to start a company in the form of an intellectual property (IP) and Research company. As an IP company, one would not be producing blades but instead, the business will be geared towards engaging established saw blades companies to modify their existing processing steps (if necessary) to produce Incoloy saw blades.

A substantial portion of the investment will be siphoned for on-going research and development of the product. The long-term goal of such a company is to secure a portfolio of patents which are fundamentally and technically valuable. The initial research and prototyping costs of US$1 Million would have to be incurred as well so as to develop the product and convince the saw blade companies that the technology works, at least at a small scale.

It is reasonable to assume that the existing brand-name companies would be able to attract a large number of sawmills to adopt the technology. 50 sawmills is chosen as the benchmark that could be reached in a year or two. Thus, by charging a 2-5% licensing fee, a rough estimate would yield around 200,000 per year (assuming that the employment of Incoloy blades for each sawmills could enhance profits by $0.3M/year, and that they are willing to pay at least 1/3 of the extra profits on blades). At this rate, a payback period of around 10 years will be required.

In order to stay in the business, an IP company in a matured industry is not as well placed as one which is in the growth sectors, such as nano technology. This vertical integration into the supply chain would mean that IPs are the most important assets of the company. However, when the Incoloy's fundamental values are exploited and technically refined, the bigger companies may have the ability to come up with even better designs. Moreover, saw blade manufacturers are in a much better position to earn margins because of the market structure. Lastly, the payback period could be too long for any venture capitalists to be interested in pursuing. Therefore, a holistic analysis would see an IP company being less feasible than a saw blade company.

9 Conclusion

The analysis and business plans indicate that if research directions should switch towards proving the technology, around US$1 Million would have to be invested, and this amount may not be recovered in the near term. The analysis also showed that being an IP company is unfeasible, essentially because base material supplying companies are at the bottom of the value chain and IP protection is difficult. On the other hand, if the business takes the form of a saw blade production company, it may have to look forward to a 10-year horizon if the saw blades could not help save a substantial amount of useful wood. The risks involved are too high for most venture capitalists to hold such a position. Moreover, with the assumed cost model, one would expect that the small-scale production would incur an annual cost of $1 Million. With the present analysis, the project could only be continued at high risk.

9.1 Future work

Industrial band saw blade manufacturing process and associated prices may deviate significantly from assumed, which may lead to a different conclusion. To prove that the proposed technological application is a failure would require a more holistic analysis. The present information at hand is still not enough to prove that this project will definitely be a failure. Exclusive information of the process know-how related to sawmill wide band saw blades production has to be garnered before one could build a reliable cost model. Gathering such information, however, may require exchange of information with the related companies, or consulting a professional. Further work needs to be done to better characterize the production process so that potentially lower risks and faster breakeven could be justified. Alternatively, instead of analyzing the profitability and investment horizons of start-up companies, one could explore alternative business plans in the context of adopting the technology as an existing manufacturer.

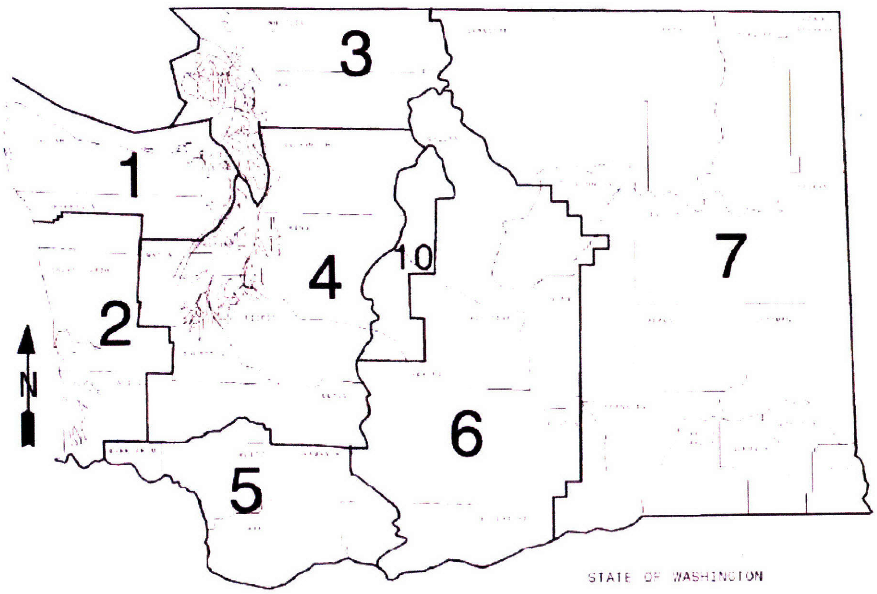
Appendix 1 – Method of calculating price of base material alloy based on composition [9]

Element**	Range %	Calc %	Value $/kg	Last Price	Last Update*^
Nickel LME	42.5 - 43	49.5	31.641	31.200	Oct 29, 07
Chrome in Aluminothermic Chrome	12.5 - 13.5	3.9	8.598	7.826 - 9.370	Oct 10, 07
Moly in 99.9 Vacuum Consumer Scrap	5.7 - 6.1	0.02	77.161	72.752 - 81.570	Oct 10, 07
Iron in 18-8 Consumer Scrap	34 - 35	40.7	0.298	0.287 - 0.309	Oct 15, 07
Ti Pure C	2.4 - 2.7	1.6	0		
Aluminum LME	.25	1	2.555	2.478	Oct 29, 07
Copper LME	0.1	0.01	7.865	7.865	Oct 29, 07
C	0.05	0.01	0		
B	.01 - .02	.003	0		
Si	0.4	0.15	0		
Mn	0.45	.04	0		
Total Virgin Value:		**96.93**	**16.1607**		
		Scrap %	100		
US Dollar		Scrap Value:	**16.1607**		
lb • kg		Calculate	Reset	History	

*Indicates Maximum.
**Place cursor on Element Symbol to view detailed description.
*^ LME Prices are updated twice daily with Official and Unofficial (close) prices.
***This value defaults to the daily scrap discount for 304 Stainless (18-8) established by Metalprices.com.

Appendix 2 – Stumpage and pond prices of Douglas Fir in the Washington state

Data from [3][4][5]



Average of stumpage prices at Western areas (regions 1,2,3,4,5 and 10) is 282 /mbf (scribner)

Average of stumpage prices at Eastern areas, 6 and 7

Differentiated into 4 quality classes with following prices:

Code 1: $561

Code 2: $434

Code 3: $415

Code 4: $184

The higher stumpage prices of Douglas Fir is around $500 /MBF

Estimating the Pond value of Douglas Fir

What adds on to the value of stumpage are logging costs, which includes falling (cutting the tree down), bucking (cutting the tree into logs), yarding (transporting the log from the woods to a road), loading (taking the log from the road and placing it on a log truck), hauling (transporting the log via log truck from the road in the woods to the mill), and scaling (measuring the amount of wood in the log and grading it). Rule of thumb is that these costs usually run anywhere from \$125 to \$225 per mbf, depending on the difficulty of getting the trees out of the woods and the distance to haul them to the mill. These allows us to estimate that pond value of higher-valued Douglas Fir should be around \$700 /mbf (scribner) This estimate reflects the pond value of Oregon logs which is available in a published report.

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