Manufacturing Design and Cost Analysis for Production of NANUQ® High Temperature Wire

A study in the large-scale production of NANUQ® wire developed by Composite Technology Development, Inc.

Rodrigo Gonzalez

COMPOSITE TECHNOLOGY DEVELOPMENT, INC.

Table of Contents

Figures

Tables

I. Executive Summary

Composite Technology Development, Inc. (CTD) of Lafayette, Colorado, has requested that we perform a scale up study and analysis for manufacturing NANUQ® high temperature wire. The economic scale up study is carried out through three plant capacities: pilot (50,000 feet per year), pre-production (500,000 feet per year), and production (1-25 million feet per year). The smallest three capacities are completed in the first few years of plant operation, building up to the largest scale by the third year. The plant will be housed in a pre-existing facility in Atlanta, Georgia, and profitability analyses have been performed to determine the selling cost per foot of wire after incorporating material cost, utility use, equipment requirements, and other miscellaneous costs and investments.

Based on our analysis, the plant should run eight hours per day, seven days per week. This schedule necessitates sixteen production lines of equipment to meet the demand of 25M feet per year. The economic feasibility was studied over a 20-year period which includes one year for plant design and two years for the smaller scale productions. Total permanent investment of capital into the project is approximately $3.6M with a working capital $299K requirement. In order to achieve a 16% investor's rate of return, the selling price of the insulated wire is $0.22 per foot. Returns on investment and corresponding payback period are 19.8% and 5.0 years, respectively. The net present value at the end of each year is $4.66M. The higher initial capital investment required for a shorter work day is compensated over time and results in a higher return on investment.

A similar high temperature wire on the market insulated with ethylene propylene diene monomer is rated for similar temperatures as NANUQ® wire but is more expensive at $0.67 per

foot (1). NANUQ® wire outperforms this wire in corrosion resistance, mechanical integrity, and service lifetime in harsh conditions making it an obvious choice for high temperature applications. Manufactured at large scales, NANUQ® wire can compete with a cheaper cost and better performance than existing high temperature wires. The full production plant should be pursued because it will prove to be profitable in a high demand market.

II. Project Description and Scope

The purpose of this project is to investigate the economic feasibility of NANUQ® wire manufacturing which meets large-scale production demand. The NANUQ® composite insulation system developed by CTD will be used to coat copper wire for high temperature applications.

CTD is mainly interested in a profitability analysis concerning the method of manufacture for three production scales. The three levels of production are given as follows (2):

- A pilot scale of 50,000 linear feet annually
- A pre-production scale of 500,000 linear feet annually
- A production scale of 1,000,000 to 25,000,000 linear feet annually

III. Background Information

In recent decades, the world has seen an exponential increase in energy consumption due to a large population increase and to a new globalized industrial economy. As the demands for energy sky-rocket, the world is continuing its dependence on green-house gas emitting fuels by building new coal-fired power plants to meet the growing energy demands.

Since the Industrial Revolution, planet Earth has experienced major climate change. From detailed ice-core analysis, experts agree that atmospheric carbon dioxide concentrations have increased into uncharted territory (3).

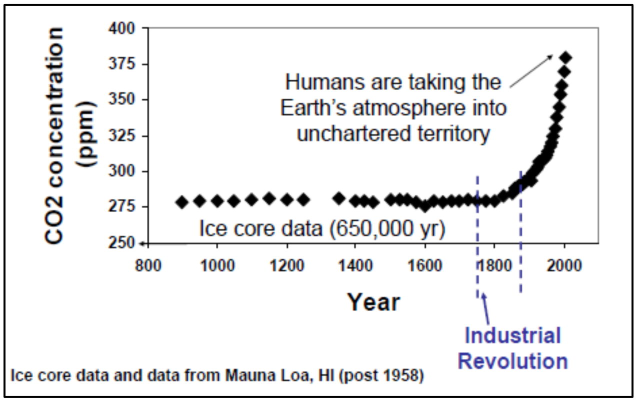


Figure 1 Ice Core Data Representing Unprecedented Atmospheric Carbon Dioxide Concentrations (4).

Advanced computer models predict that the surface of the Earth could be increased by 10 °F by the year 2100 due to increasing CO_2 concentrations (3). Though the trend in Figure 1 implies irreversible and potential devastating change to the World's climate; there are several existing technologies that are paving the path towards a clean and sustainable future. Specifically, Enhanced Geothermal Systems (EGS) have proven their capacity to harness the Earth's energy in order to supply communities and industry with electricity free from green-house gases. Along with electricity, 25,000 Americans were supplied with high paying jobs related to EGS in 2008 (5). In addition to a clean energy supply, EGS provide a potential means to tap into an estimated 500,000 MW of energy in the Western U.S alone which sums to half of the current U.S electricity generating capacity (5).

EGS are engineered reservoirs created to convert liquid water to high-pressure steam from geothermal resources deep within the Earth. The high pressure steam produced in this process is expanded across a turbine to produce electricity. Figure 2 diagrams a typical Enhanced Geothermal System.

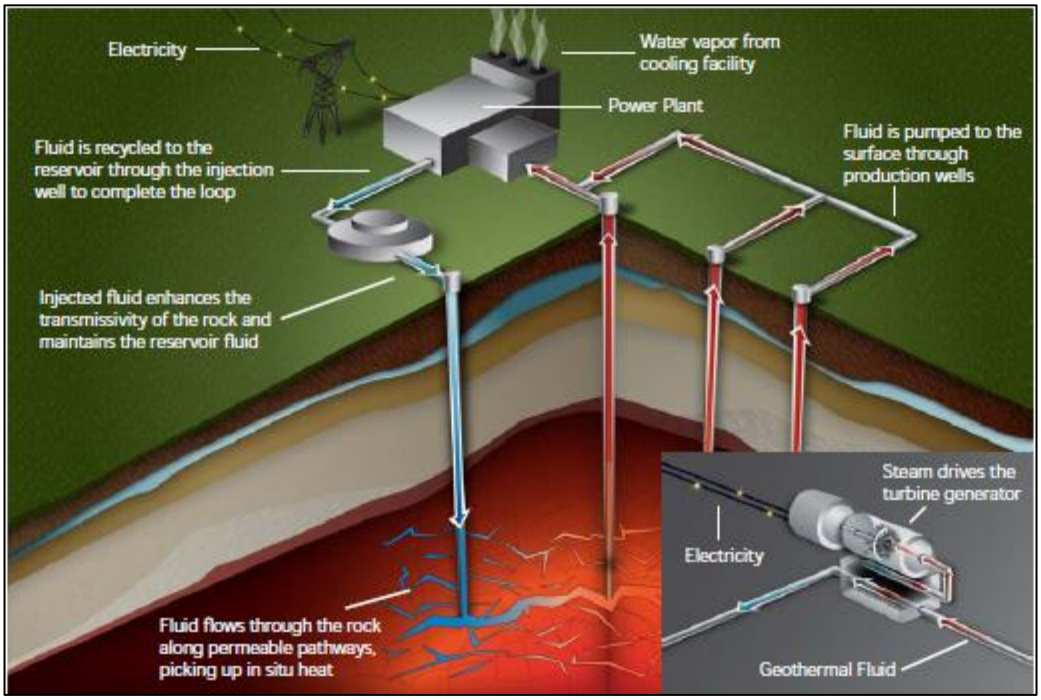


Figure 2 Typical Enhanced Geothermal System (5)

Enhanced Geothermal Systems carry several benefits that are currently being assessed by the U.S. Department of Energy (DOE). These benefits include: little to no green-house gas emissions, ability to produce electricity around the clock, and the potential to create high paying and long-term U.S jobs (5). Though EGS have the potential to become an important contributor to the U.S energy portfolio as a source of clean and renewable energy, there are several technical challenges that need to be addressed. Due to the thermally challenging environment observed in geothermal systems, experts on high temperature composites such as Hooker et al. (2010) (6) assert that "the development of highly reliable down-hole equipment is an essential element in enabling the widespread utilization of Enhanced Geothermal Systems (EGS)" (6). The equipment utilized in these systems is required to carry high voltages in a thermally demanding environment ranging in temperatures from 200-300°C (6). Thermoplastics currently used in these high voltage and temperature applications are operating above their practical operating thresholds and are therefore limiting the lifetime of motors, cables, and other high voltage components used in current down-hole systems.

Need for High-Temperature Wires

Since geothermal energy is located deep within the Earth's crust (4-10 km), electrical submersible pumps (ESP) are installed to these depths in order to pump geothermal liquids up to the surface where they can be used to generate electricity (6). The power required to operate these pumps comes from a high voltage alternating current source (3-5 kV) located at the surface of the down-hole. Harsh environments are common in down-holes, so the electrical wire providing high voltage current to ESP systems are engineered to withstand high temperatures and corrosive gases. In addition to thermal and corrosive environments, the wire must be able to handle the mechanical stresses that are associated with manufacturing and installing the wire. Current wiring systems are commonly manufactured in a flat or round configuration with additional metal shielding as seen in Figure 3.

Figure 3 Various Power Cable Configurations Used in ESP Systems (6)

Temperature extremes and corrosive contaminants are the primary causes of early motor or system failure. Wiring and motor failures amount to 53% of total ESP system failures which are further broken down by system component in Table 1.

Table 1: Failures in ESP Systems (6)

System Component	Percent of Total Failures
Assembly (non-specific)	1
Cable	21
Sensor	1
Gas Handler	1
Motor	32
Pump	30
Intake	4
Seal/Protector	10
Other	1

Common types of wires and windings currently used in ESP systems are Ethylene Propylene Diene Monomer (EPDM) or polyetheretherketone (PEEK) (6). Though materials insulated with PEEK exhibit some of the best high temperature properties compared to other currently used thermoplastics; its volume resistivity decreases rapidly at temperatures above 150°C, which effectively reduces its insulation performance (6).

To counter the inadequacy of current thermoplastics in high voltage and temperature applications, Composite Technology Development, Inc. (CTD) has developed a composite solution to the high temperature problem. High strength fiberglass reinforcements are coupled with CTD-HTM, a high-viscosity polymer derived Elastomer resin. When both components are brought together and cured between 150°C and 175°C a product called NANUQ® is formed which exhibits fantastic thermal and electrical insulation properties. Similar technologies have already proven their capability to handle extreme temperatures in high-field magnets (7) (8) and high temperature heaters for the in-situ production of oil shale (9). It is this manufacturing process that CTD has asked us to scale up.

Polymer Overview

Polymers are long chains of different atoms which are linked together in a regular, repeating pattern. Each sequence is unique for different polymers and forms what is called the polymer backbone (10). In most polymers, the backbone is composed primarily of carbon atoms (C). However, oxygen (O), nitrogen (N), and sulfur (S) atoms can also be incorporated into the backbone. Polymers can be designed to exhibit various physical and thermochemical properties depending on the intended application. Polymers have shown their capability to offer broad ranges of tensile strength, modulus, heat resistance, and electrical conductivity which can be tailored to its desired application. Figure 4 shows a segment of a typical polymer chain (polyethylene) in detail.

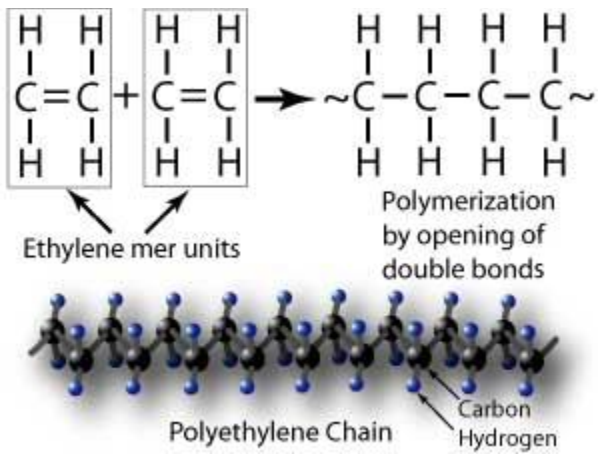


Figure 4: Microscopic View of Polymer Chain (11)

Polymers fall into four categories: thermoplastic, thermoset, elastomers, and thermoplastic elastomers. The two-part resin designed by CTD is a thermoset elastomer. Thermoset polymers form an irreversible solid when cured at a high temperature while elastomers are elastic polymers that can stretch and return to their original form. Combined together, the NANUQ® polymer can stretch and conform until heat is applied at which point it becomes permanently fixed. In our application, the new polymer is formed by heat initiated cross-linking. After addition of heat, adjacent polymer chains form bonds that join them together (10). Although we are unaware of the mechanism of polymer formation specific to the NANUQ® resin system because of trade secrets, we will discuss the typical mechanisms in detail in the next section.

Polymer Formation

The two main mechanisms used in polymer formation are addition (chain-growth) polymerization and step-growth polymerization. In addition polymerization, the polymer grows linearly with sequential growth of monomeric units at the reactive site. Step-growth polymerization involves the addition of oligomers or short polymer chains resulting in a larger growth rate than addition polymerization. This polymerization mechanism exhibits exponential growth of the polymer chain (12).

Addition Polymerization

There are three main steps in addition polymer formation: initiation, propagation, and termination (13). An initiator contains an active site (free radical, anion, or cation), which "initiates" the reaction with another monomer to form an active chain shown in the following equation where I* is the initiator, M is the monomer, and I-M* is the active chain.

$$I^* + M \Longrightarrow I - M^*$$

As a result of the initiator reacting with the monomer, the active chain forms a second active site. This causes monomers to add sequentially to the active chain, otherwise known as propagation. A symbolic representation of this process can be seen in the following equations.

$$I - M^{*} + M \Longrightarrow I - M - M^{*}$$

$$I - M - M^{*} + M \Longrightarrow I - M - M - M^{*}$$

$$I - M - M - M^{*} + M \Longrightarrow I - M - M - M - M^{*}$$

$$\vdots$$

$$I - (M)_{n} - M^{*} + M \Longrightarrow I - (M)_{n+1} - M^{*}$$

From the previous equation, monomers (M) continue to add to the active site and may grow to n units long. This will continue until the final step, or termination, when the reactive site is consumed (14).

Given that the growth of the polymer chain depends on addition to the free end of the activated polymer, the reaction kinetics will vary linearly. This growth rate is fundamentally different than exponential step-growth polymerization, which is addressed in the following section.

Step-growth Polymerization

The growth of polymers via the step-growth mechanism is usually a product of reactions between multi-functionalized monomers (15). Unlike chain-growth polymerization, no initiator is necessary and there is no termination of the active site. As a result of the reaction proceeding exponentially, free monomers are consumed quickly, shown in Figure 5.

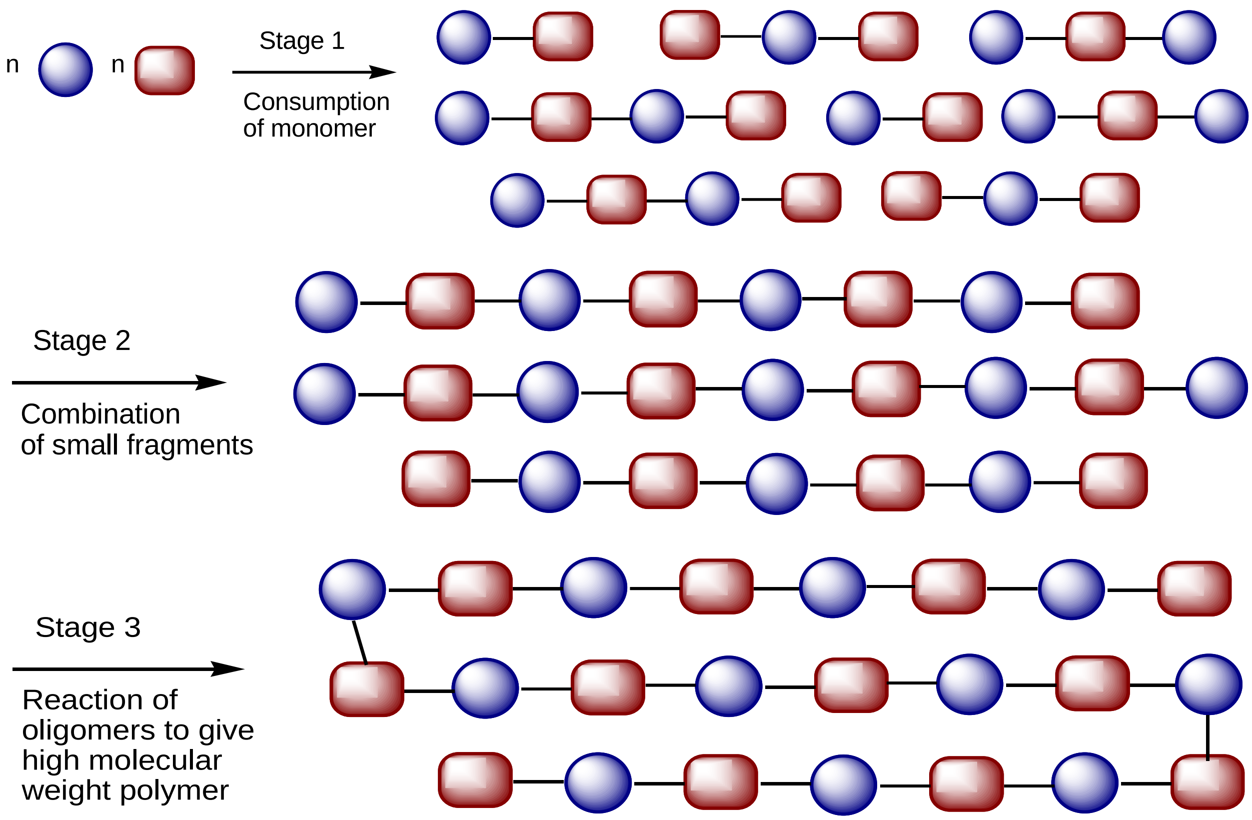


Figure 5. Step-growth Polymerization of a Copolymer (15)

Molecules can combine with themselves or other polymers of various lengths to obtain high molecular weights at the end of the reaction.

NANUQ® Competitors

Polyetheretherketone (PEEK) is a semi-crystalline thermoplastic that is used in the wire insulation industry because of its chemical resistance, high temperature performance, good electrical properties, and mechanical integrity (16). The step growth polymerization of PEEK is shown in Figure 6. Although it is well suited for high temperature environments, PEEK is a very costly

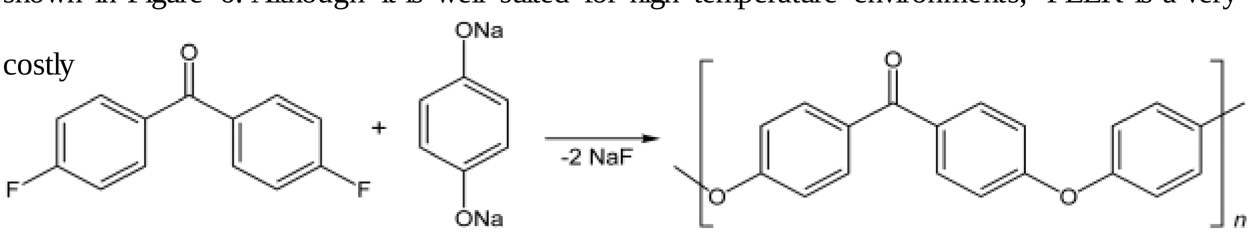


Figure 6: Step-growth of PEEK (62)

material and is usually only considered in applications where price is not a limitation (17). Therefore a cheaper alternative would be advantageous in the high temperature wire insulation market.

A second polymer used in high temperature conditions is ethylene propylene diene monomer (EPDM) in Figure 7. EPDM is a chemically cross-linked elastomer rubber that exhibits flexibility, good insulation resistance, dielectric strength, abrasion resistance and mechanical properties (18). Research has also shown that EPDM cable insulations are inherently resistant to treeing (19). Treeing is the tendency for electrical potential to cause the penetration of water, forming weakened patterns in the insulation (20). EPDM's resistance to degradation and reduced hydrophobicity inhibits water condensation and the subsequent oxidation that causes water trees (21). One of the main disadvantages to using EPDM, however, is decreased long-term service life.

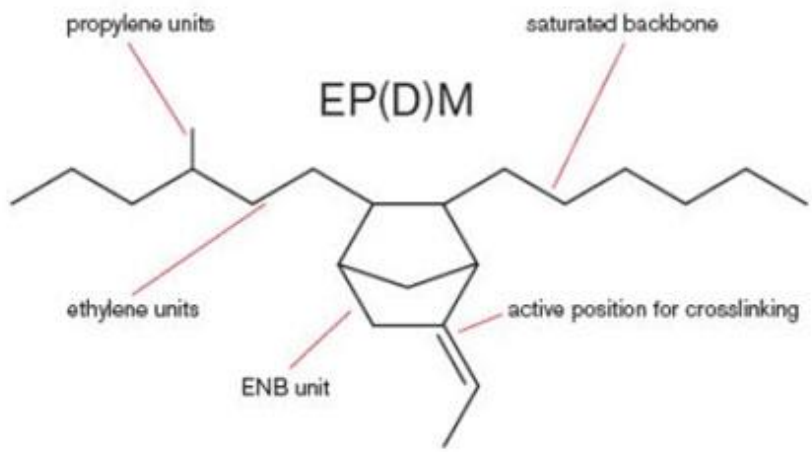


Figure 7: EPDM Structure (67)

Because the current insulation technologies are inadequate, the development of NANUQ® wire has the potential for many varied and profitable applications.

IV. Safety, Environmental, and Health Considerations

The production of NANUQ® high temperature wire insulation via the previously outlined process will require several safety and environmental considerations. Health and environmental considerations will be primarily focused on the safety of process operators and the surrounding environment. Specifically, mechanical machinery and toxicity of chemicals and materials used in the process will be assessed for the safety of process operators. In addition, the materials used and generated in this process will be assessed to ensure proper disposal of any hazardous waste for environmental safety.

Mechanical and Machinery Considerations

The process of producing NANUQ® high temperature wire poses some safety risks to operators because of its moving parts and its high temperature curing system. There are several moving parts that are expected to be rotating at high speeds during their operation. Moving process parts include: let off spool, take up spool, rotating winding head, and a resin mixing extruder. The spools are expected to be operating at 1800 RPM and the rotating winding head rotates at a faster rate. The screw of the extruder will also have significant power while it is turning, and body parts should not be fed into the extruder or hopper. During startup as well, the extruder should be operated at a low screw speed until resin is flowing freely from the die, at which point the speed can be increased. Simple casing or guards will prevent accidental injury to operators.

In addition to moving parts, the high temperature curing system also presents a safety concern to process operators. An induction curing system is operating at temperatures between 150-175 °C and these high temperatures are a safety concern to prevent accidental burns and injury to process operators. Accidents may be prevented by installing guards around hot machinery.

Material Considerations

CTD-1202 Resin

Due to trade secrets, the chemical composition of CTD-1202 resin is not be disclosed. However, in the case of an emergency, the composition will be revealed to a health professional. Though the composition of this resin is not known, there are several known safety considerations that will be assessed to ensure safety of operators. A sample MSDS of a similar product was provided by CTD from which all following information was determined (22). The primary route of entry for this resin is dermal and will cause damage to the skin or eyes. Therefore, contact with this material must be avoided. Inhalation of CTD-1202 is also considered a risk to health of operators, thus the material must be handled in a well-ventilated area with mechanical ventilation and local exhaust.

CTD-1202 and similar resins need to be stored at 0°C (or below) in a sealed and dry area. The resin will also need to be warmed before use and requires sealed containers. In the event of a spill or accidental release, all ignition sources must be eliminated first to avoid a potential fire. Once ignition sources are eliminated, the resin can be picked up with and absorbent such as sand. The absorbent can be scooped up and stored in a sealed container. Since the resin is considered an RCRA hazardous material by federal, state, and local authorities, it must be properly disposed of according to regulations on all levels. Characteristic properties, health, and environmental concerns related to CTD-1202 are summarized in Table 2. Additional information can be obtained by contacting Composite Technology Development, Inc.

Table 2 CTD-1202 Safety Information

CTD-1202							
Physical/Chemical Properties	**Form**	**Appearance**	**Odor**	**Boiling Point**	**H_2O solubility**	**Density**	**Decomposition T**
	liquid	clear	mild	>100°C	insoluble	~1g/cm^3	N/A
Health	**Oral LD_{50}**	**Dermal LD_{50}**	**Carcinogen**	**Ventilation**	**Eyes**	**Skin**	**Inhalation**
	N.D	N.D	No	local exhaust/ mechanical vent.	Chemical Goggles	Lab Coat, impervious rubber gloves	NIOSH approved respirator
Fire	**Flash Point**	**Extinguishing Media**	**Fire Procedure**	**Hazards**			
	>110°C	water spray; CO_2; dry chemical; foam	Self-contained breathing apparatus	Irritating fumes and acidic vapors at elevated T			
Reactivity	**Storage**	**Alkalis**	**Metal Salts**	**Precious Metals**	**Oxidizers**	**Hydridosilanes**	**Polymerization**
	sealed, dry container with inert atmosphere	yes	yes	yes	yes	yes	<150°C
Regulatory	**OSHA**	**RCRA**	**SARA/Title III**	**CERLA**	**Section 311 HazardClass**		
	Hazardous	Hazardous	No toxic chemicals under SEC 313	Not Listed	Immediate. Fire		

S-Glass Fiber

S-Glass fiber (all MSDS information from (23)) and other similar glass fibers do not pose any known long term or chronic health concerns to process personnel or operators. However, glass fibers are considered to have acute (short-term) risks to process operators. Fiberglass continuous filaments are a mechanical irritant. Contact with dust fibers will cause itching and short-term irritation to the skin. Eye contact with dust fibers may also cause short-term mechanical irritation. Ingestion may also cause short-term mechanical irritation of the stomach and intestines. Long-term breathing or skin conditions may also be aggravated and worsen with exposure to this product.

In order to maintain exposure of fibrous dust below regulatory limits, standard dilution ventilation and local exhaust ventilation will be required. In the event that fibrous dusts exceeds

OSHA regulatory limits, respiratory protection will be used in accordance with local regulation and OSHA regulations under 29 CFR 1910.134.

S-Glass is considered to be a RCRA non- hazardous material so there is no additional safety concern for process operators. In addition, there are no special requirements for storage. There is also no hazardous threat to the environment or special disposal requirements for this product. Physical and safety information for S-Glass are summarized in Table 3.

Table 3 S-Glass Safety Information

S-Glass							
Physical/Chemical Properties	**Form**	**Appearance**	**Odor**	**Boiling Point**	**H_2O solubility**	**S.G**	**Decomposition T**
	Solid	white	none	Not applicable	insoluble	2.6	Not applicable
Health	**Oral LD_{50}**	**Dermal LD_{50}**	**Carcinogen (OSHA)**	**Ventilation**	**Eyes**	**Skin**	**Inhalation**
	N/A	N/A	No	Dilution Vent./ Local exhaust	Chemical Goggles	Lab Coat, impervious rubber gloves	NIOSH approved respirator
Fire	**Flash Point**	**Extinguishing Media**	**Fire Procedure**	**Hazards**	**Combustion products**		
	None	water spray; CO_2; dry chemical	Self-contained breathing apparatus	None Known	CO, CO_2, H_2O		
Reactivity	**Storage**	**Stability**	**Incompatible Materials**	**Hazardous Polymerization**			
	No requirement	Stable	None	None			
Regulatory	**OSHA**	**RCRA**	**SARA/Title III**				
	Non-Hazardous	Non-Hazardous	No toxic chemicals under SEC 313				

12 AWG Copper Wire

12 AWG copper (all MSDS information from (24)) does not present any major health concerns to process operators. Though concerns are minimal, there are some safety considerations when handling and working with copper wire. For normal operation of the process, operators will be required to cut wire during the start-up and shut-down of the process. Cutting copper wire may cause jagged and sharp edges at the terminus; therefore, operators cutting wire should wear

heavy duty work gloves to prevent accidental injury. Process operators should also wear safety glasses when cutting wire to prevent copper shards from injuring their eyes.

Though the copper wire is not expected to generate any fine dust or fumes during this process, operators should be aware of the dangers that dust and fumes may have on their health. Fine copper powders, granules, and fumes generated from welding or abrasive operations pose a major health hazard. Soldered or brazed copper may give off fumes that cause eye and respiratory irritation. Adequate local exhaust is required to maintain fumes below OSHA ceiling limits if any of these operations are to take place. Short-term exposure to dust and fumes may include: irritation to the eyes, nose, and throat. Common symptoms of short-term exposure to copper dust and fumes are metallic taste in mouth, fever, cough, fatigue, and nausea. Long term exposure to copper dust and fumes are severe and may include: watering of the eyes, headaches, difficulty breathing, coughing, severe chest pains, and in acute cases, lung disease, lung fibrosis, pneumoconiosis, or neurological damage.

Due to the high price of copper, scrap pieces have a considerable reclamation value. However, when salvage of scrap material is not practical (pilot scale), it may be disposed of in accordance with local, state, and federal regulations. In solid form, copper wire has no special regulations. In fine powder form, cleanup should be conducted to minimize air-borne particles. In addition, fine copper particles should not be allowed to contaminate water that will reach city sewage or drainage. Physical and safety information regarding copper wire are summarized in Table 4.

Table 4: 12 AWG Copper Wire Safety Information

12 AWG Copper Wire							
Physical/Chemical Properties	Form	Appearance	Odor	Boiling Point	H_2O solubility	S.G	Decomposition T
	Solid	Lustrous orange-red	none	Not applicable	insoluble	8.89	Not applicable
Health	Oral LD_{50}	Dermal LD_{50}	Carcinogen (OSHA)	Ventilation	Eyes	Skin	Inhalation
	N/A	N/A	No	Local exhaust (if dust or fumes present)	Safety Glasses	Work Gloves	NIOSH approved respirator
Fire	Flash Point	Extinguishing Media	Fire Procedure	Hazards	Combustion products		
	None	water spray; CO_2; dry chemical	Self-contained breathing apparatus	None	None		
Reactivity	Storage	Stability	Incompatible Materials	Hazardous Polymerization			
	No requirement	Stable	None	None			
Regulatory	OSHA	RCRA	SARA/Title III				
	Non-Hazardous	Non-Hazardous	No toxic chemicals under SEC 313				

Unit Operation Considerations

Table 5: Safety Considerations for Each Unit Operation

Operation	Concern	Safety Precautions
Concentric Taping Head	• Moving parts	• Mechanical guards
Resin Delivery System	• Moving parts	• Mechanical guards
Induction Heater	• High temperatures	• Mechanical guards
Cooling Water Bath	• High wire speed	• Mechanical guards

V. Project Premises

Wire Production

- CTD wishes to have their present lab scale insulation process scaled up to three various wire production capacities
  - Pilot plant scale: 50,000 linear ft. per year
  - Pre-production scale: 500,000 linear ft. per year
  - Full production scale: 1-25,000,000 linear ft. per year
- Batch Production
- 12 AWG annealed copper wire
  - Delivered in 700lb max spools
  - Assume average density of 556 lb/ft^3 (25)
  - Electrical conductor grade (EC) metal
- CTD-HTM High-viscosity, polymer-derived Elastomer resin
  - Two part system
  - Assume 10:1 mix ratio of component A and component B
  - Safety concerns similar to CTD-1202 (22)
  - Resin viscosity is specified at 20,000 to 40,000 cP
  - Thermal curing at 175 °C for 5 minutes (26)
  - The resin has a working time of 24 hours (26)
  - The resin will be applied immediately after the wrapping of glass fiber reinforcement
- CTD-GFR, Glass fiber reinforcement
  - S-glass required at 15,000 yards per pound
  - Less than 9 microns in thickness
  - 0.3-0.4% binder content (26)
  - Overall thickness of S-glass and insulation on 12 AWG wire of 0.006 in ± 0.001
  - High fiber wrapping angle of 73^o (26)
  - The high application angle enables significant wrapping overlap to occur, increasing the backbone strength of the insulation.

- Pilot Scale Parameters, calculated for the batch production of 5000 ft. of wire, summarized in Table 6

Table 6: Pilot Parameters for 5000ft of Wire (26)

Pilot Scale Parameters			
Wrap Speed	1800 RPM	Insulation Volume	0.018 in3/ft
Wrap Rate	136.8 in/min	Resin Volume	0.010 in3/ft
Insulation Thickness	0.0055 in	Resin Volume Fraction	0.55
Band Width	0.08 in	Total Resin for Total Length	49.2 in
Wrapping Overlap	5%	Oven Length	57 ft
Fiber Angle	73 deg	Time for Full Length	7 hrs
Wire Length	5000 ft	Cure Time	5 min

Economic Design

- The plant will be located in Atlanta, Georgia
- The plant operational startup will begin in 2013
- Plant lifetime is 20 years (26)
- No construction period but 1 year for design
- Utility values:
    - Electricity costs are $0.06 per kW-hr (27)
    - Cooling Water costs $0.019/m^3
- Material values:
    - The cost of resin is $66.75 per pound (26)
    - The cost of the S-Glass fiber is $20.00 per pound
    - Price of wire same as that of industrial copper: currently $4.3495 per pound (28)
- The depreciation method for economic analysis will be a 5 year MACR
- None of the equipment will be salvageable
- Statistical data from the Department of Labor for average industrial manufacturing facility
- Inflation is assumed to be 1.9% per year
- Cost of capital is assumed to be 4.5% for a large corporation that carries little risk
- Startup spare parts assumed to be 2.5% of investment

- The equipment contingency is assumed to be 15% of the direct permanent investment costs
- The state income corporate tax rate for Georgia is a flat 6% (29)

VI. Approach

Initial Material Balances

Calculations outlined in this section are elaborated upon in Appendix A.

The first step in beginning the scale up of wire production is to do material balances on the supplies for insulation production, which is summarized in Table 7. The copper wire lengths needed are equal to the required production scales. Because costing of copper wire was based on the current selling price of copper in tons, the volume of copper wire is calculated from the diameter and length of wire. The diameter of 12AWG wire is

$$D = 0.0808\ in$$

Using basic calculations for cylindrical volume

$$V = \frac{\pi D^2 L}{4}$$

and given the density of copper

$$\rho = 556\ lb/ft^3$$

the mass of copper can be determined. The copper requirements for each scale are in the second column of Table 7.

Table 7: Material Requirements per Year

Summary of Material Requirements			
Scale	Copper (tons)	Fiberglass (# spools)	Resin (cuft)
50,000 feet	0.5	0.2	1.7
500,000 feet	5.0	2	16.5
1 million feet	9.9	4	33.1
25 million feet	247.5	88	827.2

In order to calculate the fiberglass requirements, additional characteristics of the S-glass are required. The band width of the fiberglass is the width of the S-glass yarn as it is wrapped around the wire. There is also a wrapping overlap of 5%. In our process, the band width and fiber angle of:

$$BW = 0.08\ in$$

$$\theta = 73\ degrees$$

which can be combined to determine the length of wire advanced for every wrap of fiberglass using the equation:

$$l = \frac{BW}{sin\theta} * .95$$

This indicates that every full wrap or revolution around the wire, there is an advancement of 0.084 inches along the copper wire. Using that information and the circumference of the wire, the length of fiberglass can be found from:

$$Length = 2\pi D * \frac{1}{BW} * Scale$$

The available spools of S-glass come in 20 pound units, and the fiberglass is 15,000 yards per pound. These spool quantities are reflected in Table 7.

The final material balance required is on the resin. The final resin is a mixture of two viscous resins in a 10:1 ratio. Knowing the final thickness of the insulation,

$$Ins = 0.0055\ in$$

the resin volume fraction,

$$Frac = 0.55$$

and the diameter of the wire, the resin volume can be determined from:

$$ResinVol = \left(\frac{\pi(Ins + D)^2}{4} - \frac{\pi D^2}{4}\right) * Scale * Frac$$

The amount of resin that will have to be mixed on a daily basis depends on the length of time required for completion of each scale. Based on an 1800rpm fiberglass-wrapping rate, the time can be calculated using the length of wire wrapped per time using the equation:

$$t = RPM * l * Scale$$

The down time in machine operation is accounted for with start-up and shut down time, therefore the plant is assumed to be producing wire 75% of the time. So the adjusted time is:

$$t_{adj} = t * \frac{100}{75}$$

Using the calculation of total time required to produce each entire wire scale, the total amount of production days necessary can be determined based on either 8- or 24-hour days for one production line (Table 8).

Table 8: Time Requirements for Wire Production

Production Time			
Scale	Hours of Production	8-Hour Days Required	24-Hour Days Required
50,000 feet	93.2	12	4
500,000 feet	932.1	117	39
1 million feet	1864.1	234	78
25 million feet	46603.5	5826	1942
# Production Lines	N/A	16	6

Made evident from calculations, the largest 25 million foot scale cannot be completed in one year. To accommodate for the largest scale, multiple lines of equipment will be purchased: 16 if running 8-hour days and 6 if running 24-hour days.

Curing Kinetics of Epoxy Resin System

In order to provide an accurate estimate of the power required to cure the resin structure during the production of the high temperature wire, we must first characterize the reactions that are taking place throughout this process. Given we do not know the exact identity or composition of the resin, we will assume it is an epoxy resin based on conversations with CTD liaisons and will use equations developed in the literature to model the reaction kinetics of the process.

The kinetic parameters for the curing process are obtained from Isothermal Differential Scanning Calorimeter (DSC) measurements, collected between temperatures of 55-180 °C as provided by CTD. We selected several models that are widely used to show a cross-linking process over time, and using ordinary least squares (OLS) multiple regression methods selected the best one, based on calculating the maximum value of the coefficient of determination (R^2 value). For a detailed description of this process, consult Appendix B.

The models we explored ranged from the most simple, lacking any mechanistic information, to more complex models that incorporated mass and heat transfer phenomenon. The first model by Barrett (1967) is developed as follows (30). The first assumption made using DSC data is that the rate of reaction is proportional to the heat flow relative to the instrumental baseline as shown in the following equation:

$$r_p = \frac{1}{\Delta H_r}\left(\frac{dH}{dt}\right)_t$$

where ΔH_r is the heat of reaction (kJ g^{-1}), and dH/dt is the heat flow (J s^{-1} g^{-1}) as measured by the thermo-calorimetric characterization of the resin at time t. From this equation we can then calculate the degree of crosslinking (DOC) as partial fraction under the dH/dt curve versus the time (31).

$$DOC = \frac{1}{\Delta H_r} \int_0^t \left(\frac{dH}{dt} \right)_t dt$$

This DOC can then be used to calculate the rate of reaction, since the DOC can be normalized to equal the overall conversion of the reaction, α, or the degree of cure (32).

$$r_p = kf(DOC) = kf(\alpha)$$

$$r_p = \frac{d\alpha}{dt} = kf(\alpha)$$

where k is the reaction rate constant. The reaction time constant is assumed to follow the Arrhenius law given as follows:

$$k = A_r e^{-E_a/RT}$$

where A_r is the Arrhenius frequency factor (s^{-1}), E_a is the activation energy (kJ mol^{-1}), R is the universal gas constant (8.3144 J mol^{-1} K^{-1}), and T is the absolute temperature (K). The simplest model that takes the conversion into account is given by Chu et al. (32), which can be solved analytically using data from a single dynamic DSC experiment.

$$r_p = \frac{d\alpha}{dt} = k(1-\alpha)^n$$

$$\frac{(1-\alpha)^{(1-n)}}{(1-n)} = A_r e^{-E_a/RT}$$

The resulting equation can then be fitted using OLS regression techniques, and will subsequently be referred to as Model 1.

The next level of complexity can be added by including a second conversion term. This is known as the autocatalytic kinetic model of crosslinking where product of the reaction is a catalyst of the reaction (33) and also utilizes the Arrhenius law (34), (35).

$$r_p = \frac{d\alpha}{dt} = k\alpha^m(1-\alpha)^n$$

$$\frac{d\alpha}{dt} = A_r e^{-E_a/RT}\alpha^m(1-\alpha)^n$$

The resulting equation can be solved using multiple OLS regression techniques, first with a simple transformation as shown in Sun (2001), and will be subsequently referred to as Model 2. In order to take advantage of linear regression techniques, the natural log of both sides of the equation is taken as shown here (36):

$$ln\left(\frac{d\alpha}{dt}\right) = ln\left(A_r e^{-E_a/RT}\alpha^m(1-\alpha)^n\right)$$

$$ln\left(\frac{d\alpha}{dt}\right) = ln(A_r) + mln(\alpha) + nln(1-\alpha) - \frac{E_a}{R}\frac{1}{T}$$

Another empirical form of the autocatalytic model for thermoset curing was developed by Kamal and Sourour (1973), which takes into account a combination of resins in two- or three-component epoxy resin systems (37).

$$r_p = \frac{d\alpha}{dt} = (k_1 + k_2\alpha^m)(1-\alpha)^n$$

$$k_1 = A_{r,1}e^{-E_{a,1}/RT}$$

$$k_2 = A_{r,2}e^{-E_{a,2}/RT}$$

The resulting equation can be solved using nonlinear OLS techniques as developed by Brown (2001), by maximizing the R^2 value (38). These equations shall subsequently be referred to as Model 3. The full process is outlined in Appendix B. The final and most complicated model investigated utilizes the autocatalytic model with a diffusion control factor. As shown in Choe and Kim (2002), the following model is based on free-volume considerations, and helps to explain the retardation of the cure reaction in the last stages of the reaction due to the vitrification of the epoxy resin (39).

$$r_p = \frac{d\alpha}{dt} = \frac{(k_1 + k_2\alpha^m)(1-\alpha)^n}{1 + exp[C(\alpha - \alpha_c)]}$$

$$k_1 = A_{r,1}e^{-E_{a,1}/RT}$$

$$k_2 = A_{r,2}e^{-E_{a,2}/RT}$$

where C is a parameter of diffusion control, and α_c is the critical value of the cure conversion, which based on the data provided was assumed to be 98%. The starting value of the diffusion control factor, C, is chosen to approximate the values found in the literature (40). As α approaches the critical value of α_c, the extent of the reaction becomes controlled by diffusion. The resulting equation is fitted using the method outlined by Brown (2001), as shown in the previous equation and shall subsequently be referred to as Model 4. The models are all fitted using the methods outlined in the preceding section, and the resulting parameters that are calculated are given in Table 9. As previously stated, for detailed calculations consult Appendix B. For our later analysis of the resin curing time, we used Model 1.

Table 9: Calculated Parameters for Crosslinking Model Kinetics.

Model Number	n	m	$A_{r,1}$ (s^{-1})	$E_{a,1}$ (kJ mol^{-1})	$A_{r,2}$ (s^{-1})	$E_{a,2}$ (kJ mol^{-1})	C	α_c
1	2.53	-	3.11E08	82.91	-	-	-	-
2	2.76	0.48	5.36E08	82.91	-	-	-	-
3	2.52	0.44	7.40E08	82.80	3.00E08	82.91	-	-
4	2.63	0.87	1.17E08	82.80	4.78E08	82.91	6.14	0.98

VII. Process Flow with Material & Energy Balances

In order to produce NANUQ® wire at the desired scales, spools of copper wire are fed in a semi-batch process as fiberglass reinforcements are wrapped around the wire continuously. After the resin is deposited onto the wire at an assigned thickness, the resulting product is cured in an induction heater. Following the curing process, the wire is rapidly cooled in a water bath before being rolled onto a second spool of finished wire. Only a few pieces of equipment are required to complete this process: a let off spool, a rotating winding head to wrap the reinforcement, a screw extruder and die, an induction coil, a water bath, and a take up spool. These equipment prices were determined and scaled to multiple production lines to fulfill the production requirements.

Process Flow Sheet

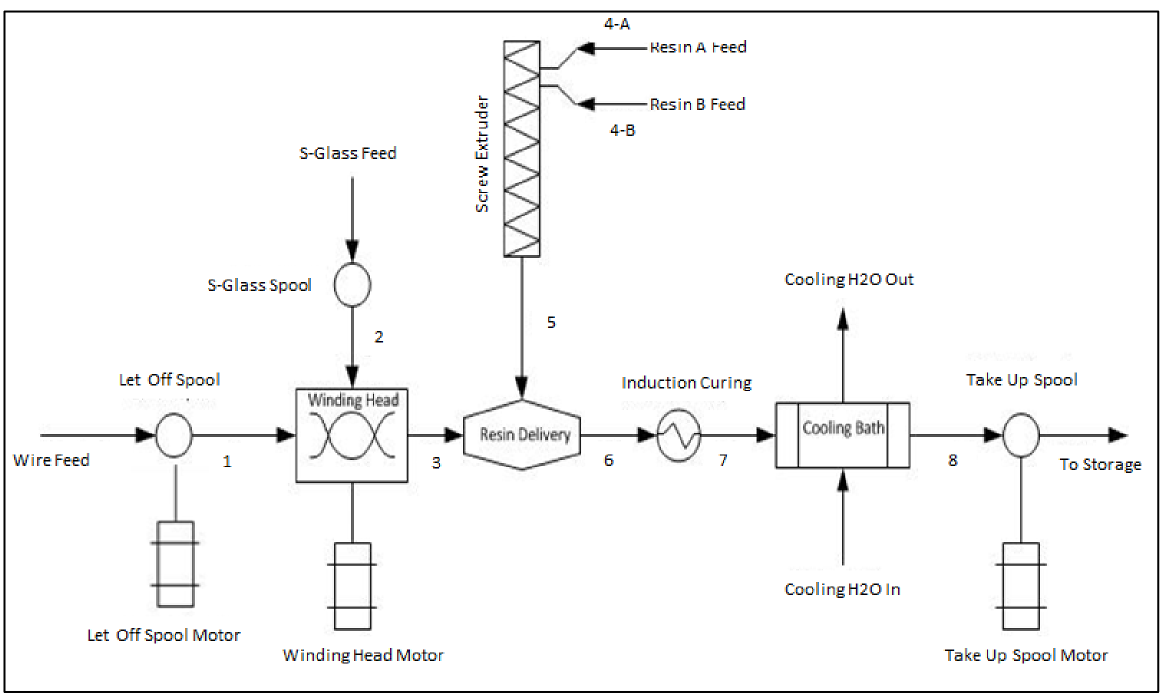


Figure 8: NANUQ® Wire Manufacturing Process Flow Diagram

Let Off Spool Unit Operation

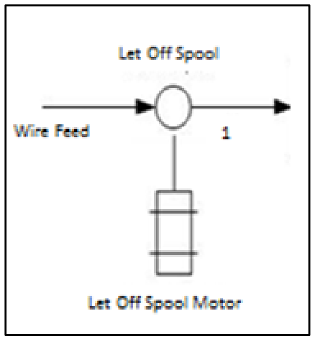


Figure 9: Let Off Spool Unit Operation

The first unit operation identified in the process flow diagram is a let off spool shown in Figure 9. The let off spool is a semi-batch operation and is loaded with 700 lb. spools of 12 AWG copper wire. Once loaded, the let off spool is powered by an AC electric motor to feed the copper into the winding head at 11.92 ft. /min. Since the let off spool operation is semi-batch, the let off spool will need to be re-loaded with a new 700 lb. copper spool after every 49 hours of continuous operation.

The let off spool is powered by an electric 0.25 HP motor. The power required to spin the let off spool is determined from its rpm and torque. With an rpm of 0.95 and a required torque of 1,400 ft-lb, the horsepower is determined from the following equation:

$$HP = \frac{rpm * torque}{5{,}252}$$

Where HP is the required horsepower and 5,252 is a constant. With a horsepower of 0.25, the let off spool requires 0.19 kW of electricity to feed copper into the process. A summary of material and energy balances associated with the let off spool is shown in Table 10.

Table 10: Let Off Spool Material and Energy Balances

Let Off Spool (Semi-Batch Process)							
Stream	Material	T (°C)	P (atm)	Initial Mass Load (lb)	Mass Flow Rate (lb/hr)	Mass Composition	Power (kW)
Wire Feed	Copper	25	1	700	-	1	-
1	Copper	25	1	-	14.3	1	-
Energy	Electricity	-	-	-	-	-	0.19

Winding Head Unit Operation

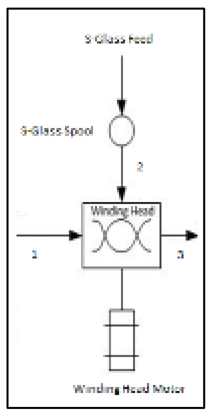


Figure 10: Winding Head Unit Operation

The second unit operation identified in the process flow diagram is a concentric winding head outlined in Figure 10. The winding head is a semi-batch operation where 20 lb. spools of S-glass fiber yarns are loaded onto the winding head. Once the fiberglass is loaded, the winding head rotates around the incoming copper wire at 1,800 rpm. In order to achieve 1,800 rpm with 13.3 ft-lb of torque, the winding head requires a 4.6 HP electric motor. Since the concentric winding head is a semi-batch operation, the winding head will need to be re-loaded with 20 lb. S-glass spools every 280 hours of continuous operation. The mass and energy balances associated with the winding head unit operation are summarized in Table 11.

Table 11: Winding Head Material and Energy Balances

Winding Head (Semi-Batch Process)							
Stream	Material	T (°C)	P (atm)	Initial Mass Load (lb)	Mass Flow Rate (lb/hr)	Mass Composition	Power (kW)
S-Glass Feed	S-Glass	25	1	20	-	1	-
1	copper	25	1	-	14.3	1	-
2	S-Glass	25	1	-	0.07	1	-
3	S-Glass	25	1	-	0.07	0.005	-
	Copper				14.3	0.995	
	Total				14.37	1	
Energy	Electricity	-	-	-	-	-	3.43

Resin Screw Extruder Operation

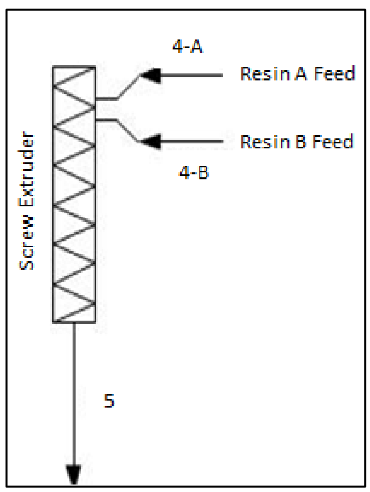


Figure 11: Resin Extrusion Operation

The third unit operation identified in the NANUQ® process flow diagram is a screw extrusion process outlined in Figure 11. The screw extruder provides the required blending of the two-part resin system. The resin identities are unknown by our team due to trade secrets; however, mass balances were based off densities and mix ratios provided by CTD. Like the previous unit operations, the screw extruder is a semi-batch operation. It is a semi-batch operation because a two-part reactive resin system must be loaded into to the extruder on a daily basis. No more than one day's worth of resin should be loaded into the holding reservoir to avoid unwanted reaction before it can be applied to the wire. Once the resins are loaded in the holding reservoir, they are blended continuously with a screw inside the extruder designed for mixing viscous polymers. The rotating screw is powered by a 5 HP electric motor. A summary of mass and energy balances for the screw extruder is outlined in Table 12.

Table 12: Screw Extruder Material and Energy Balances

Resin Srew Extrusion (Semi-Batch Process)							
Stream	**Material**	**T (°C)**	**P (atm)**	**8 hr Initial Mass Load (lb)**	**Mass Flow Rate (lb/hr)**	**Mass Composition**	**Power (kW)**
4-A	Resin A	25	1	9.03	1.129	1	-
4-B	Resin B	25	1	0.9	0.113	1	-
5	Resin A	25	1	-	1.129	0.91	-
	Resin B				0.113	0.09	-
	Total				1.242	1	-
Energy	Electricity	-	-	-	-	-	3.75

Resin Delivery System

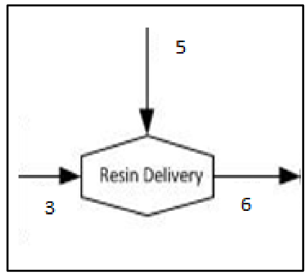


Figure 12: Resin Delivery System

After the two-part resin is mixed inside the screw extruder, the resulting resin is applied to the incoming wire. The system achieves a uniform coating around the fiberglass with a specialty die designed for viscous coating applications. The power required to inject the resin into the die is provided by the screw extruder motor and is accounted into the energy balance for the screw extruder. A summary of material and energy balances for the resin delivery die is outlined in Table 13.

Table 13: Resin Delivery Material and Energy Balances

Resin Delivery							
Stream	Material	T (°C)	P (atm)	Initial Mass Load (lb)	Mass Flow Rate (lb/hr)	Mass Composition	Power (kW)
3	Copper	25	1	-	14.3	0.995	-
	S-Glass				0.07	0.005	
	Total				14.37	1	
5	Resin A	25	1	-	1.129	0.91	-
	Resin B				0.113	0.09	
	Total				1.242	1	
6	Copper	25	1	-	14.3	0.916	-
	S-Glass				0.07	0.004	
	Resin A				1.129	0.072	
	Resin B				0.113	0.007	
	Total				15.612	1.000	
Energy	-	-	-	-	-	-	0

Induction Curing Operation

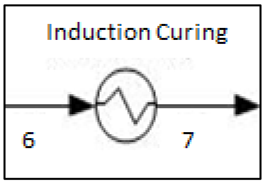


Figure 13: Induction Curing Operation

After the resin is applied to the fiberglass layer on the copper wire, the resulting product is cured continuously with an induction heating coil. The induction coil provides the power required to heat the copper wire internally to a curing temperature of 175°C. A summary of material and energy balances related to the induction coil is outlined in Table 14.

Table 14: Induction Curing Material and Energy Balances

Induction Curing							
Stream	**Material**	**T (°C)**	**P (atm)**	**Initial Mass Load (lb)**	**Mass Flow Rate (lb/hr)**	**Mass Composition**	**Power (kW)**
6	Copper	25	1	-	14.3	0.916	-
	S-Glass				0.07	0.004	
	Resin A				1.129	0.072	
	Resin B				0.113	0.007	
	Total				15.612	1	
7	Copper	175	1	-	14.3	0.916	-
	S-Glass				0.07	0.004	
	Resin A				1.129	0.072	
	Resin B				0.113	0.007	
	Total				15.612	1	
Energy	-	-	-	-	-	-	5.94

Cooling Bath Operation

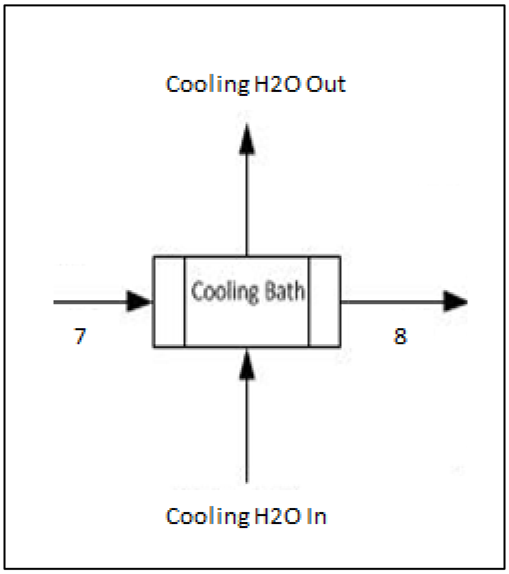


Figure 14: Cooling Bath Operation

After the wire is cured for 5 minutes at 175°C, it is cooled down to a temperature of 45°C for packaging. The cooling that takes place is provided by cooling water at an estimated temperature of 32°C. The temperature of the cooling water was estimated by heuristics in (41). The minimum temperature approach for the cooling water was also estimated by (41). A summary of the material and energy balances for the cooling bath is outlined in Table 15.

Table 15: Cooling Bath Material and Energy Balances

Cooling Bath							
Stream	Material	T (°C)	P (atm)	Initial Mass Load (lb)	Mass Flow Rate (lb/hr)	Mass Composition	Power (W)
7	Copper	175	1	-	14.3	0.916	-
	S-Glass				0.07	0.004	
	Resin A				1.129	0.072	
	Resin B				0.113	0.007	
	Total				15.612	1	
Cooling H2O In	Water	32	1	-	396.5	1	-
8	Copper	45	1	-	14.3	0.916	-
	S-Glass				0.07	0.004	
	Resin A				1.129	0.072	
	Resin B				0.113	0.007	
	Total				15.612	1	
Cooling H2O Out	Water	33	1	-	396.5	1	-
Energy	-	-	-	-	-	-	-210

Take Up Spool

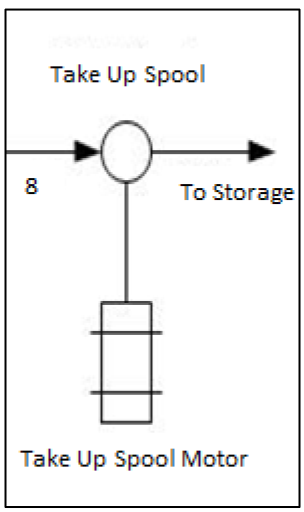


Figure 15: Take Up Spool Operation

Once the NANUQ® wire is cooled down to 45°C, the wire is ready to be packaged onto a spool where it can be stored in the warehouse. Like the let off spool, the take up spool is powered by a 0.25 HP motor and is a semi-batch operation. After 48 hours of continuous operation, a final spool of NANUQ® will be finished weighing approximately 750 lbs. A summary of material and energy balances for the take up spool is outlined in Table 16.

Table 16: Take Up Spool Material and Energy Balances

Take Up Spool (Semi-Batch)							
Stream	Material	T (°C)	P (atm)	Final Mass Load (lb)	Mass Flow Rate (lb/hr)	Mass Composition	Power (kW)
8	Copper	45	1		14.3	0.916	-
	S-Glass				0.07	0.004	
	Resin A				1.129	0.072	
	Resin B				0.113	0.007	
	Total				15.612	1	
To Storage (Spool)	Copper	45	1	750	14.3	0.916	-
	S-Glass				0.07	0.004	
	Resin A				1.129	0.072	
	Resin B				0.113	0.007	
	Total				15.612	1	
Energy	-	-	-	-	-	-	0.19

A mock- up production line created with Google Sketch-up which incorporates all of the unit operations is shown in Figure 16.

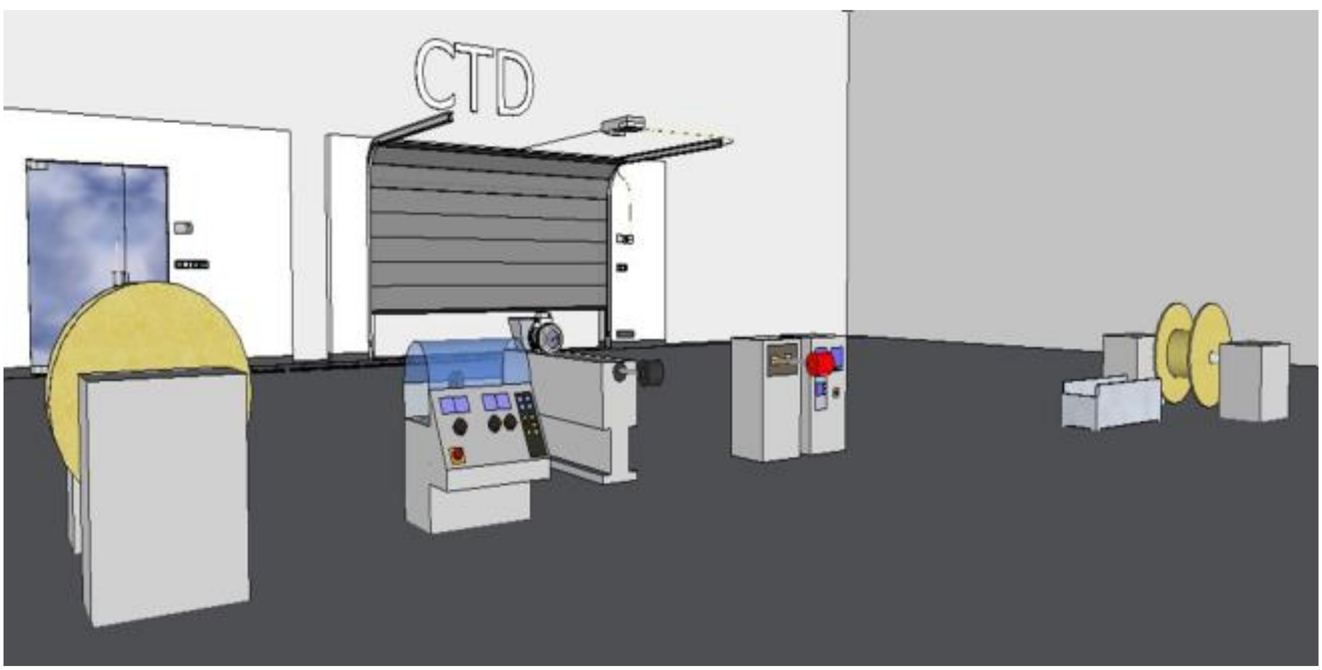


Figure 16: Mock-Up Production Line

VIII. Process Description & Equipment Specifications

In this section we provide an overview of each major piece of equipment used in the wire production process. Specifically, the unit operations are fully designed in order to estimate capital requirements for the plant's construction. The detailed calculations used to size and cost the equipment are found in Appendix C. The following sections summarize the results of these calculations.

Concentric Taping Head

From past case studies, Composite Technology Development has identified taping as the most feasible option for mass-producing NANUQ® high temperature wire. The taping process is a commonly used method in industry for producing high quality wire. Taping differs from other methods of wire insulating in that a tape or substrate is mechanically wrapped around the conductor needing insulation. Taping heads vary in configuration and style and must be selected appropriately depending on the application. The most common types of taping heads used in industry are concentric and eccentric style taping heads. In a concentric style taping head, the wire conductor is fed through a single tape pad while it spins. The head is called concentric because the tape pad is perpendicular to the direction of wire travel and spins in a concentric path relative to the wire. A model created with Google Sketch-up of a typical concentric tape pad is shown in Figure 17.

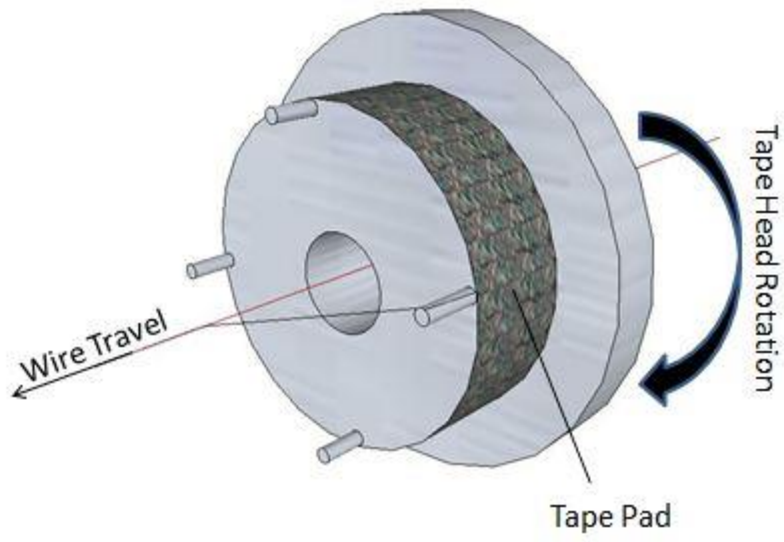


Figure 17: Concentric Tape Head Model

Eccentric models provide a slightly different configuration than concentric heads and have certain benefits depending on the application. Eccentric tape heads can bear multiple tape pads and rotate similar to a concentric tape head. However, the head is called eccentric because the pads travel around the wire in an eccentric path. A model created with Google Sketch-up of a typical eccentric taping head is shown in Figure 18.

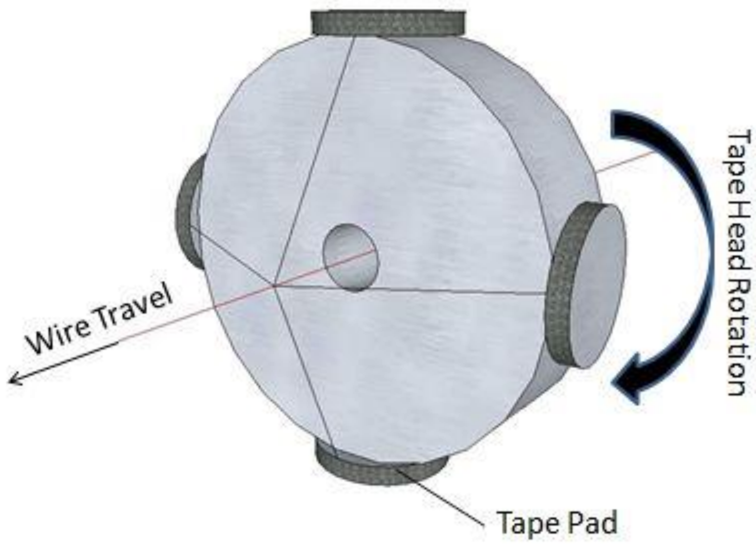


Figure 18: Eccentric Tape Head Model

In applications where more than one layer of insulation is needed, concentric tape heads are not as cost efficient as eccentric heads because each head bears only one tape pad. Therefore, one concentric head only produces one layer of insulation. To produce multiple layers of insulation using concentric heads, the tape heads must be configured in series to achieve the desired number of insulation layers. Producing multiple layers of insulation via concentric heads in series can be costly due to the upfront capital required to purchase several heads. In the scenario where multiple layers of insulation are needed, eccentric tapers are typically used because they can carry multiple tape pads and produce multiple layers with only one head. Though eccentric heads are beneficial for this scenario, there is a trade-off between line speed and layers of insulation. As a result of carrying multiple tape pads which can weigh a substantial amount, eccentric tape heads are limited by how quickly they can rotate. Concentric tape heads only carry one tape pad and can therefore achieve a significantly higher rotation speed which results in better line speeds and productivity. Therefore, the high cost of concentric tape heads in series may be advantageous and outweigh the benefits of an eccentric head if high line speeds are required.

Since the NANUQ® application only requires one layer of insulation to meet the product specification, a single concentric tape head was chosen for its ability to achieve higher line speeds and productivity at a comparable capital cost to an eccentric head. Concentric heads are designed around multiple factors including rotation rate, pad weight, and breaking tension of the tape. In the NANUQ® application, the tape used is a light fiberglass yarn and weighs only one pound per 45,000 feet. A 20 pound tape pad would correspond to about 1 million linear feet which could accomplish the largest production scale with only 72 fiberglass pads in one year. A 20 pound pad is considered a light load for a concentric tape head and is therefore not an influencing factor on the price of the head. The most important consideration for the NANUQ® application is the breaking strength of the fiberglass yarns which ultimately determines the maximum RPM of the tape head. CTD performed tensile strength experiments on the yarn and determined the breaking strength to be between 10 and 100 pounds. Considering the large deviation in breaking strengths, a maximum tension of 8 pounds was chosen as the critical operating tension to ensure the head will always operate under the breaking strength of the yarn.

In order to select a concentric head that could meet the application's specifications and design requirements; several commercial vendors were consulted for aid in machine selection and pricing. The cheapest vendor available for concentric heads was Wire and Plastic Machinery Corp. The mechanical engineer at Wire and Plastic Machinery Corp. suggested a Pourtier 16" concentric taping head which comes complete with let off spool, take-up spool, transmission, gear box, control station, and tension control. This machine is capable of operating between 5 and 200 pounds of tape tension and can control the tension via a multi-speed transmission within an error of one pound. Operating at 8 pounds of tension, however; limits the rotation of the winding head to 1800 RPM. At higher tensions the machine can achieve speeds of 5400 RPM.

The let off and take up spools which come stock with the winding head are capable of carrying loads up to 2,100 pounds. This maximum load works conveniently with the 700 pound spools of copper wire that will be used to manufacture the end product.

Resin Delivery System

Once the copper wire is wrapped with S-glass, the two part resin must be applied to the designated thickness. The initial design of the mixing and application system focused on a basic mixer system with pumps serving to transport the resin from tanks to the mixer and applicator. Calculations conducted to determine required flow rates of delivery were too low for pump usage (0.142 cc/s). A superior option for resin mixing and delivery is a crosshead extrusion process. In crosshead extrusion, the wire is pulled through a crosshead die at a constant rate where the high viscosity mixed resin is applied to the assigned thickness. Using an extruder system will also minimize the amount of solvent required to clean the apparatus once the resin has reached its 24-hour working time.

Wire coating is usually done with single screw extruders (42). Because the wire is being pre-wrapped with S-glass fiber, the standard preheating of the wire to aid in resin adhesion is unnecessary. Instead, required volumes of resin A and resin B can be added to the reservoir of a single screw extruder diagrammed in Figure 19.

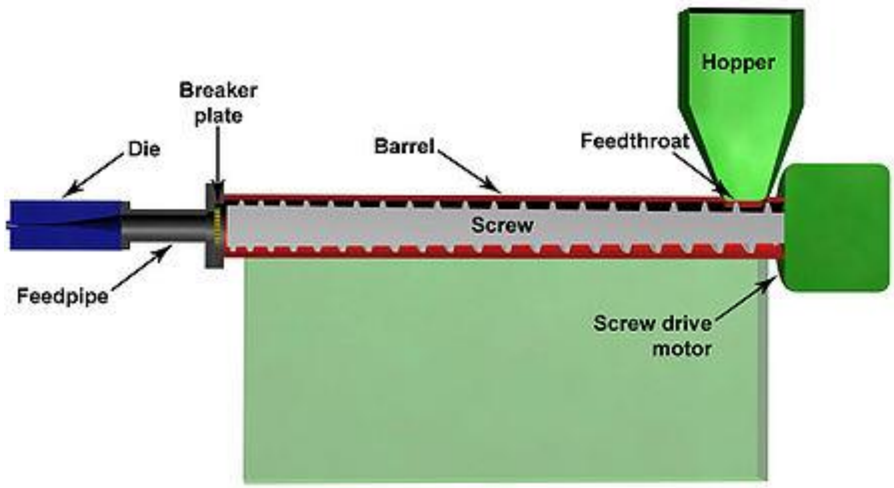


Figure 19: Cross-Section of Extruder (42)

Flood feeding which is reliant upon gravity is used here because the extruder mixed resin output rate is directly proportional to the speed of the screw. In this way, the feed rate will not be the determining factor for resin production.

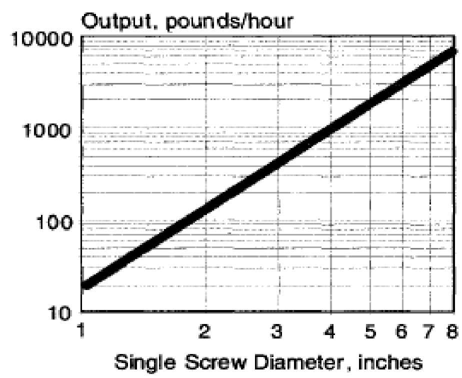


Figure 20: Extruder Throughput (10)

The process requires approximately 10.1lb/hr. of resin. By consulting Figure 20 we can see that only the smallest screw diameter of 1 inch is necessary. Additionally, a Saxton type screw will be used here because of its excellent ability to completely mix resin components (42).

Figure 21: Saxton Type Screw Head (10)

The drive motor required to turn the screw will allow for constant screw speed and constant resin production. Because our production levels are so low, only a small motor of 5-10hp is required.

The most crucial piece of equipment in resin application is the die, which applies the resin at the appropriate thickness to the wire. A pressure coating or tube coating die can be used to apply the resin. The type of die depends on the application. A pressure die is used in instances when good adhesion between the S-glass backbone and resin is required. The tube coating die is better for applications onto wires already insulated, i.e. adding additional layers of resin (43). Because we desire intimate contact between the resin and the fiberglass insulation, we are going to use a pressure die. The pressure die illustrated in Figure 22 shows the schematic for a basic pressure die.

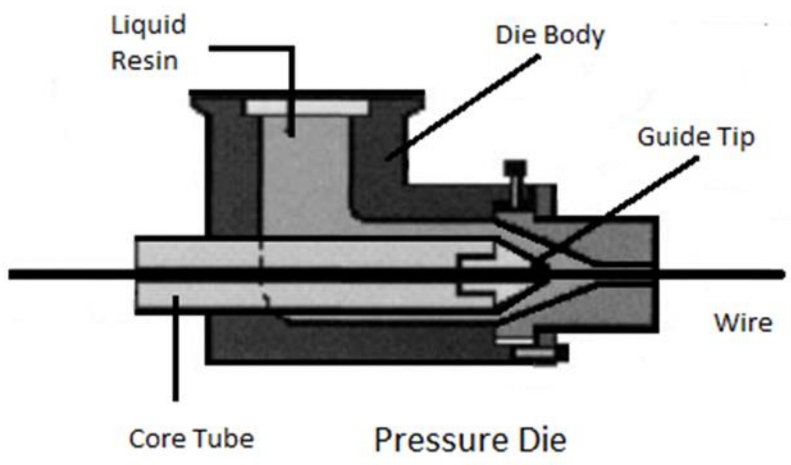


Figure 22: Pressure Die for Wire Coating (42)

The viscous resin enters through the top, while the wire enters perpendicular to the liquid resin flow. The core tube acts to guide the wire into the die and prevents resin backflow. The guide tip is where the resin comes into contact with the polymer. The diameter of the die opening is the required wire plus insulation diameter (42). In our application, the die opening diameter necessary to accommodate a 12AWG wire plus 0.0055in thick insulation is 0.086in.

Pricing of a single screw extruder was done using the economics sheet (44) provided by Dr. Alan Weimer utilizing the mass flow rate of the mixed resin. The cost using a CE of 500 is $ 144,816 and factoring in inflation and a CE of 556, the total purchase cost for a single screw extruder is $ 161,035.

Induction Heater

Following the resin delivery system, an induction coil heater is incorporated into the process to heat the product to 175°C. Heating the product to 175°C provides the energy to cure and harden the resin into its finished state. Composite Technology Development has determined the reaction kinetics through DLC experiments. Analysis of this data indicated a 5 minute cure time at 175°C which was used as the design point for curing equipment.

In the preliminary proposal, our group suggested a convection oven as the unit operation to complete the curing process. Though convection ovens have proven their ability to produce a quality product, they are vastly cost inefficient compared to induction heaters. Convection heaters are less efficient than induction heaters due to their high equivalent length and energy requirements to achieve the same degree of heating (45). Furthermore, once the conductor achieves its steady state curing temperature, the conductor maintains its temperature throughout the 5 minute curing time without any additional heating since it is effectively insulated by the cured resin and fiberglass.

The electromagnetic phenomenon of induction heating is fairly simple and applicable to a wide range of processes. An alternating voltage applied to an induction coil will result in an alternating current in the coil circuit. As a result, the alternating current in the coil will produce a time-variable magnetic field in its surroundings with the same frequency as the alternating current. The variable magnetic field produces eddy currents within the work piece (copper wire) located inside the coil. Induced eddy currents inside the work piece will have the same frequency in the opposite direction as the coil frequency. These eddy currents provide the heating energy by the joule effect (I^2R) (45). A diagram showing the basic induction process is depicted in Figure 23.

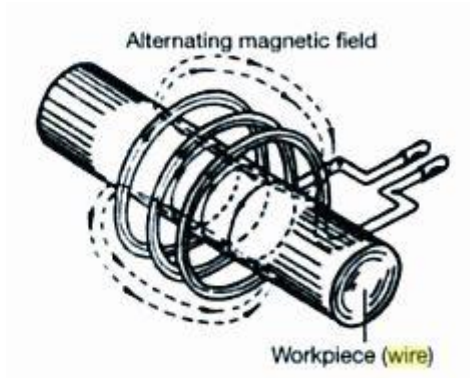


Figure 23: Induction Heating Diagram (46)

In order to achieve the desired heating, one must determine the frequency of the coil current and the required coil power. When a direct current flows through a conductor, the current density is uniform within the conductor's cross-section. However, when an alternating current flows through a conductor, the current distribution is not uniform. The current density will always be largest at the surface of the conductor and decreases towards the middle when an alternating current flows through it. The phenomenon of non-uniform current density through a conductor's cross section is known as the skin effect. The skin effect is of great practical importance for determining the frequency of the induction coil. As a result of the skin effect, approximately 86% of the current is concentrated towards the surface of the conductor (45). There will be a pronounced skin effect when the frequency of current oscillations is high or the radius of the work piece is large. The effective radial power density as a function of different coil frequencies is shown in Figure 24.

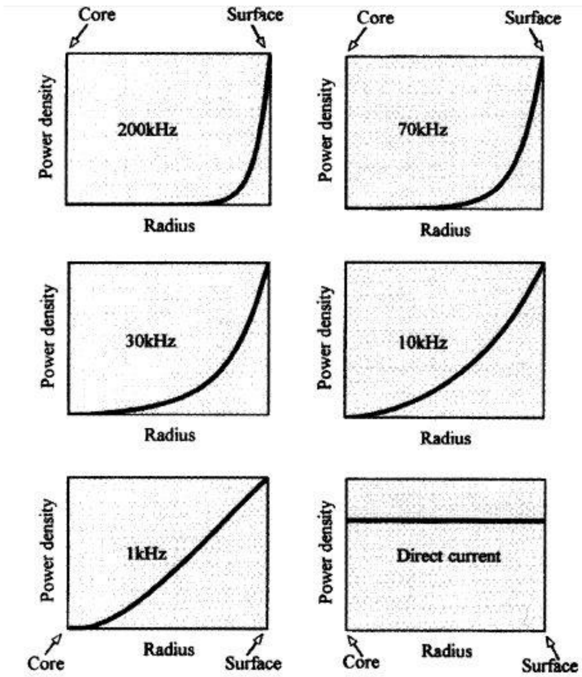


Figure 24: Power Density for Various Coil Frequencies (45)

For this application, uniform heating through the conductor's cross-section is desired. Uniform heating to the core of the conductor will result in higher efficiency when curing the resin (46). For this reason, a low frequency current is desired to achieve the heating (1-20kHz).

In addition to coil frequency, the coil power must be estimated in order to determine the cost of the induction heater. The theoretical power to the work piece (P_w) is estimated by the following equation:

$$P_w = mC_p dT/dt$$

where m is the mass of copper inside the coil at any instant, C_p is the heat capacity of copper, and dT/dt is the change in temperature with respect to time. The change in time was determined based on an estimate of the coil distance in the process line. Since the copper must be heated almost instantly to the resin's curing temperature, the coil distance in the process line was assumed to be approximately 0.5-1ft. With a copper flow rate of 11.92 ft/min, the process time within the coil was determined by the following equation:

$$dt = \frac{l_{coil}}{u_{copper}}$$

where U is the haul velocity of copper into the coil in ft/sec and l_{coil} is the linear length of the coil in the process line. The theoretical power to heat the copper wire from 25°C to 175°C was estimated to be 2.67 kW.

Once the theoretical power to the wire is estimated, the power to the coil is estimated based on thermal and electrical efficiencies. The theoretical coil power (P_c) is estimated by the following equation:

$$P_c = \frac{P_w}{\eta_{el}\eta_{th}}$$

where η_{el} and η_{th} are the electrical and thermal efficiencies, respectively. For this application the thermal efficiency is assumed to approach 100% since there is negligible heat loss once the work piece reaches the resin's curing temperature. The heat loss from the work piece was estimated by a simple heat transfer analysis. The only mode of heat transfer from the work piece to the surroundings is conduction; therefore a conduction analysis was performed based on the radial geometry of the wire. A diagram showing the geometry of the conductor and insulation used for the conduction analysis is shown in Figure 25.

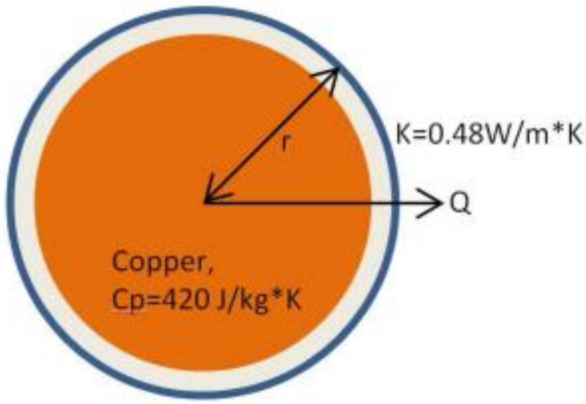


Figure 25: Geometry of Conductor and Insulation

The heat loss from the conductor to the surroundings was determined via the following equation:

$$Q_{loss} = kr_0(T_0 - T_{amb})$$

where k is the thermal conductivity of the resin, r_0 is the thickness of the insulation and T_0-T_{amb} is the difference between the copper temperature and the ambient temperature surrounding the insulation. The heat loss from the work piece to the surroundings was estimated to be 0.01W which is less than 0.002% of the work piece's energy at the curing temperature.

The electrical efficiency (η_{el}) is estimated from the relative geometry of the induction coil and the work piece. With induction coil geometries known, the electrical efficiency can be estimated by the following equation:

$$\eta_{el} = \frac{1}{1 + \frac{D_1}{D_2}\sqrt{\frac{\rho_1}{\rho_2 \mu_r}}}$$

where D_1 is the inside diameter of the coil, D_2 is the outside diameter of work piece, ρ_1 is the density of the induction coil material, ρ_2 is the density of the work piece material and μ_r is the relative magnetic permeability of the work piece. In the electrical efficiency equation, the square root term in the denominator approaches one since the relative magnetic permeability of copper is essentially one and both the coil and work piece will be made of copper. Therefore the work piece and the coil will have the same densities. The most electrically efficient coil will be when the inside diameter of the coil is approximately equal to the outside diameter of the work piece which will reduce the D1/D2 term to one. However, since a ratio of one will physically mean the coil and the work piece are in contact, D1 will assumed to be slightly larger than D2. Since coils are custom made and designed to achieve maximum efficiency, the electrical efficiency was assumed to approach the maximum electrical efficiency where D1/D2 approaches 1.2, resulting in an electrical efficiency of 45%. Literature estimates that the electrical efficiency of most induction coils for wire processing are between 0.35 and 0.45 (45). Therefore, 0.45 was assumed to be the maximum electrical efficiency that could be obtained for the induction heating process. The sensitivity of required coil power on electrical efficiency for this particular curing process is shown in Figure 26.

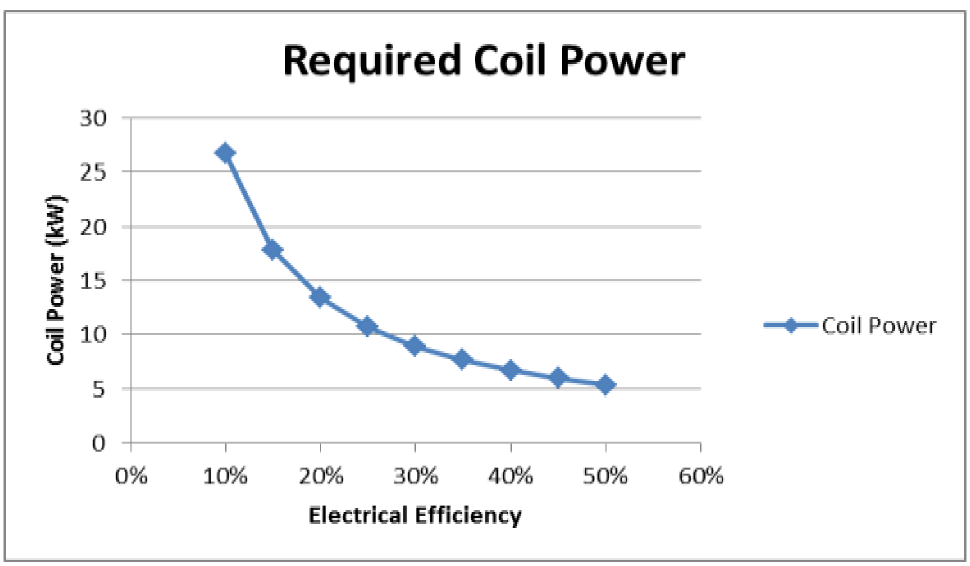


Figure 26: Sensitivity of Coil Power on Electrical Coil Efficiency

Incorporating an electrical efficiency of 45%, the theoretical coil power needed to heat the copper to a curing temperature of 175°C was estimated to be 6.5kW.

With an estimated frequency and coil power, industrial vendors of induction heating equipment were contacted for price quotes. Superior Induction Company of Pasadena, CA provided an estimate of $24,875 for an induction heater that can operate between 1-20 kHz and up to 10kW of power. A picture showing the quoted induction equipment is shown in Figure 27.

Figure 27: Superior Induction Company Equipment (47)

Water Bath

After the product finishes curing, it is rapidly cooled in a water bath to bring it to a suitable temperature for packaging. In order to determine the dimensions of the water bath, heat transfer principles were applied to the geometry of a wire being pulled through a water bath. The heat transfer process in this scenario is unsteady and the cooling rate is determined by conduction and convection modes of heat transfer. Rao et. al (1998) have determined heat transfer coefficients for several different cooling media and estimated the heat transfer coefficient (α) of a water bath with epoxy composites to be 25 W/m^2*K (48). Since the resin is a trade secret and the composition is unknown, CTD suggested we could assume the properties were similar to an epoxy and fiberglass composite. The thermal conductivity of the insulation layer was estimated by CTD to be 0.48 W/m*K. Furthermore, the thermo physical properties of pure copper and epoxy-fiberglass composites were taken from (49).

In the transient heat transfer analysis of the water bath, the Biot number was calculated first to characterize the temperature gradients within the NANUQ® wire. The Biot number (Bi) is a dimensionless number used in transient heat transfer analyses which gives a simple index ratio of the heat transfer resistance inside the wire to the heat transfer resistance at the water-surface interface. This simple index ratio will determine if the thermal gradients inside the wire will vary significantly in space while being cooled by the water bath. The Biot number is calculated via the following equation:

$$Bi = \frac{\alpha R}{k}$$

where α is the convection heat transfer coefficient, R is the radius of NANUQ® wire, and k is the thermal conductivity of the insulation layer. The Biot number for this transient cooling process was estimated to be 0.057, showing that the temperature gradients will not vary significantly in space from the water-insulation interface to the core of the wire. Therefore, the lumped capacitance model is a valid assumption for estimating the required length of the water bath. Following the Biot number calculation, a temperature ratio (θ_{TB}) is calculated based on the center-line temperature via the following equation:

$$\theta_{TB} = \frac{T_b - T_w}{T_a - T_w}$$

where T_b is the desired centerline temperature after cooling, T_w is the temperature of cooling water, and T_a is the temperature of the hot wire leaving the curing process. T_w was assumed to be

32°C from cooling water heuristics, T_b was estimated to be 45°C from minimum temperature approach heuristics, and T_a was assumed to be 175°C which is the curing temperature of the resin. The centerline temperature ratio is a function of the Biot number and the Fourier number. Therefore, the centerline temperature ratio is used to estimate the Fourier number. The Fourier number (Fo) is another dimensionless parameter that characterizes heat conduction. Conceptually, Fo is the ratio of heat conduction rate to the rate of thermal energy storage within the solid space and is determined via the following equation:

$$Fo = \frac{\ln(\theta_{TB})}{-Bi}$$

Fo was determined to be 41.4 which is representative of values found in literature for cooling an insulated wire in a water bath (48). Once the Fo number is calculated, the required length of the cooling bath can be estimated from the time to cool the wire to 45°C. The time to cool the product from 175°C to 45°C is estimated based on the following equation:

$$t = \frac{FoR^2}{a}$$

where a is the thermal diffusivity of the wire. The resulting cooling time (26.3 seconds) is multiplied by the wire haul rate to estimate the required length of the bath. The required length of the water bath to cool the cured wire to 45 °C is approximately 5.5 feet. A plot showing the length of cooling bath required to cool the wire to various temperatures is shown in Figure 28.

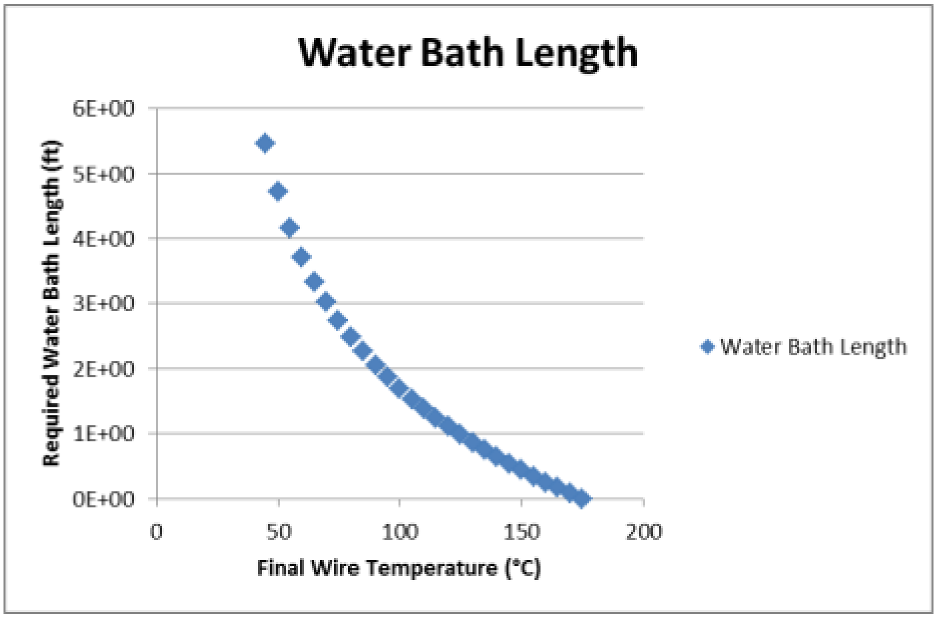


Figure 28: Cooling Bath Length vs. Final Wire Temp.

Water Bath Pricing

After the water bath was designed around its required length, the cost of the bath was estimated based on its overall dimensions. The bath was assumed to be made out of ¼" stainless steel 316 plates. The width and height of the water bath were assumed to be 6" and 6", respectively. A model of the water bath is shown in Figure 29.

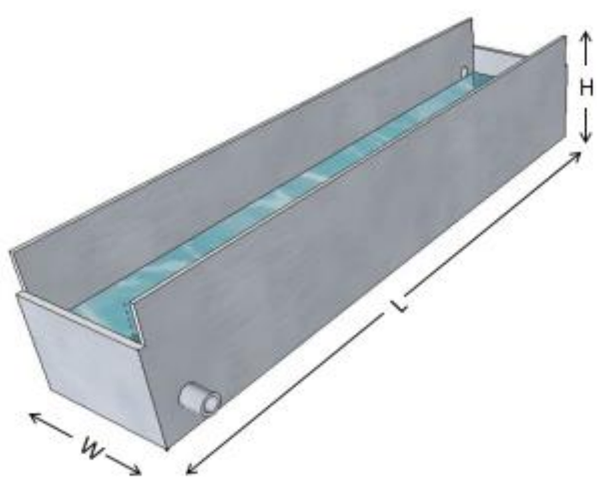


Figure 29: Model of Water Bath

With the estimated dimensions of the water bath, the total volume of stainless required to fabricate the bath was estimated. After the total volume of stainless steel was estimated, the volume was multiplied by the density of stainless steel to characterize its overall weight. The resulting weight was then multiplied by the market's current SS 316 value. At a price of $0.90/lb., the total material costs for a 5.5 ft. bath is estimated to be $100.00. In addition to material costs, the price of fabricating the bath was estimated by required welding labor. Each bath was assumed to require 8 hours of fabrication by a professional welder. At $100.00 per hour of welding time, each bath is estimated to cost $900.00. A plot showing the sensitivity of overall bath cost on the fabrication time is shown in Figure 30.

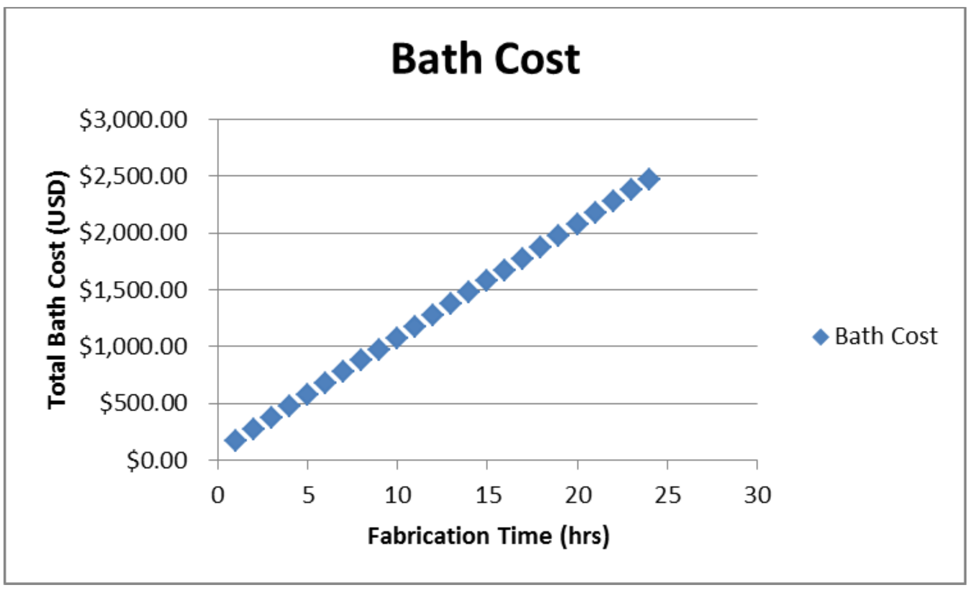


Figure 30: Bath Cost Sensitivity on Fabrication Time

IX. Utility Summary

The utilities required to operate the NANUQ wire manufacturing process are electricity and cooling water which are assumed to be available at \$0.06/kW-hr and \$0.019/m^3 respectively. In the NANUQ wire manufacturing process, electricity is required to power the let-off spool motor, concentric taping head motor, screw extruder motor, induction coil, and take-up spool motor. Cooling water utilities are required to cool the cured wire down to a proper packaging temperature in the water bath.

Electrical utilities are estimated based off of the net electrical duty required to power the electrical motors and induction coil. A summary of the net duties required to power all electrical equipment in a single production line is show in Table 17.

Table 17: Summary of Electrical Equipment Duties for a Single Production Line

Equipment	Required Duty (kW)
Let-Off Motor	0.20
Take-Up Motor	0.20
Taping Head Motor	3.43
Extrusion Motor	3.75
Induction Coil	6.50
Total	**14.07**

Water utilities required to operate the water bath are estimated based on an overall energy balance on the bath. All of the energy lost by the wire when it is cooled down to a packaging temperature must be gained by the surrounding water. In order to calculate the amount of energy lost by the wire during cooling, the wire was analyzed for mass composition. Based off of the geometry and mass of wire components, NANUQ® wire was determined to have a copper mass composition of 99%. Therefore, the wire was assumed to have the heat capacity of copper. Based off the mass flow rate of NANUQ® wire into the water bath, the heat loss from the wire was calculated via the following equation:

$$Q_{loss} = mC_p(T_{cure} - T_{package})$$

where m is the mass flow rate of wire, C_p is the heat capacity of copper, T_{cure} is the curing temperature, and $T_{package}$ is the necessary packaging temperature. The heat lost from the wire in the cooling process was estimated to be 210 W. To determine the required flow rate of water in the bath, the heat loss from the wire was set equal to the heat gained by the cooling water.

$$Q_{loss} = mC_P(H_2O)(T_{hot} - T_{cold})$$

The mass flow rate of cooling water into the cooling bath was estimated by process heuristics for the temperature of cooling water and a 1°C temperature increase of water in the bath. The cooling water flow rate was estimated to be 0.05 kg/s.

Once the duties for all required utilities were determined, they were priced according to their current market prices. A sample calculation for determining the annual electrical utility cost for the 24 hour production of NANUQ wire is shown below.

$$70.3kW \frac{8{,}000hr}{year} \frac{\$0.06}{kW - hr} = \$30{,}369$$

A summary of utilities and their annual costs is outlined in Table 18.

Table 18: Summary of Net Utilities for NANUQ Production

Production	Utility	Units	Annual Duty	Utility Cost/Unit	AnnualCost	Utility Unit/ft wire	Cost/ft wire
8 Hour Production	Electricity	kW-hr	492662.4	$0.06	$29,559.74	0.0197	$0.001
	Cooling Water	kg	6382886.4	$0.00	$121.27	0.2547	$0.000
24 Hour Production	Electricity	kW-hr	506154.9	$0.06	$30,369.30	0.0197	$0.001
	Cooling Water	kg	6557694.4	$0.00	$124.60	0.2547	$0.000

The current price of cooling water ($0.000019/kg) is significantly cheaper than electricity and is a negligible price compared to the annual price of electricity because the required flow rates are so low. Figure 31 shows the sensitivity of the annual utility costs based on the market selling price of electrical and cooling water utilities. Since the cost of cooling water is negligible compared to the annual requirements of electricity, this plot reflects the sensitivity of electrical utilities on market price.

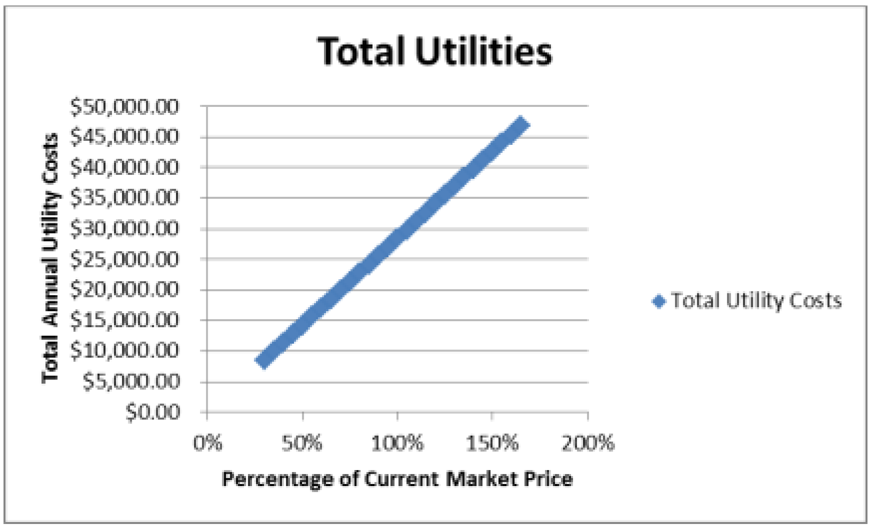


Figure 31: Sensitivity of Annual Utility Costs on Market Price

X. Estimation of Capital Investment & Total Production Cost

The total capital investment (TCI) of a chemical production plant is a total summation of all of the costs associated with creating a plant to the required specifications. All of the one-time costs associated with the design, construction, and startup of the plant are included in the TCI. These costs also include equipment costs, site preparation/conversion, contingencies, contractor's fees and working capital. Alternately, the total production cost is the sum of total costs required to manufacture the product to include materials, utilities, labor, maintenance, overhead and general expenses (50). For a comparison, an 8-hour workday (2920 total hours per year) is compared to a 24-hour workday (8000 total hours per year). The 8-hour scenario produces wire 8 hours per day, 365 days per year. The 24-hour scenario produces wire 24 hours per day, 333 days per year. To accommodate less working hours per year, additional production lines of equipment are necessary. The 24-hour case uses only 6 lines, while the 8-hour case uses 16. An economic analysis comparing the tradeoff between less operating hours versus more equipment is shown in is elaborated upon in Appendix D.

Table 19: Economic Summary of Wire Production

Economic Summary	8-Hour Days	24-Hour Days
Equipment - Direct Installed Costs	$2,889K	$1,081K
Total Permanent Investment	$3,600K	$1,400K
Working Capital	$299K	$244K
Variable Costs (per year)	$2,545K	$2,545K
Fixed Costs (per year)	$1,883K	$2.088K

Capital Investment

Total Permanent Investment

Total permanent investment (TPI), also known as the fixed capital investment, is defined as the sum of the installed equipment cost, contractor fees, contingencies, cost of land, royalties, technology, and other costs related to the plant start-up (41). As outlined in Section V. Project Premises, we assume there are no royalties, construction, or land purchased since the equipment will be incorporated into an existing facility.

Pricing of the equipment necessary in the wire production line is completed for the four major pieces of equipment. For each production line, a taping head including take up and let off spools, a screw extruder, an induction heater, and a water bath are required. Only the screw extruder was priced according to an equipment costs worksheet. The water bath was designed and priced according to raw material and construction labor requirements. The other two pieces of equipment were priced with quotes provided by industrial vendors. Details of equipment pricing are detailed further in their respective equipment design sections; however, costing is highlighted in Table 20. The costs of sixteen versus six lines of equipment are also shown in Table 20.

Table 20: Equipment Costs

	Cost/One Line	Cost/16 Lines	Cost/6 Lines
Taping Heads	$ 14,500.00	$ 232,000.00	$ 87,000.00
Screw Extruder	$ 58,328.19	$ 933,251.02	$ 349,969.13
Induction Heating Coils	$ 24,875.00	$ 398,000.00	$ 149,250.00
Water Baths	$ 900.00	$ 14,400.00	$ 5,400.00

The NANUQ® insulation production plant will be built in an existing warehouse in Atlanta, Georgia. The site factor associated with the US Southeast is 0.95, which accommodates differences in production locations. This is the factor that the total venture guidance appraisal values are multiplied against. Because it is an existing site, there are only a few costs associated with the site preparation. Miscellaneous equipment totals 10% of engineered equipment and combined with the actual equipment costs amounts to the subtotal for purchased equipment. Instruments and electrical charges are 7% and 9% of purchased equipment, respectively. There is a 40:60 split of labor and materials, with freight as 12% of the material. In addition, contract labor is estimated as 44% of labor. Additional indirect costs associated with engineering are 15% of the subsequent total. Two percent for dismantling and rearranging of the site, and 2% for power and services are also applied to the total equipment cost. All of these costs plus a 15% contingency fund and 1.9% inflation rate comprise the total permanent investment (TPI).

Working Capital

The raw materials required for start-up are priced and make up the working capital. For our purposes, we would like to have a one month's supply of the materials on hand at start up. That translates to nearly 400lb of resin, 41,000lb of copper, and 150lb of fiberglass on the basis of 25million feet of insulated wire per year. Additionally, there will be a start-up spare parts fund of 2.5% of the investment to cover incidentals that arise during start up.

Operating Costs

Variable

Utilities and raw materials make up the variable portion of operating costs. To determine these rates, the units of ingredient needed per unit of finished product are calculated. This ratio is multiplied against the cost per unit to result in the cost per foot. The only materials needed are resin, copper wire, and S-glass while the only utilities needed are cooling water and electricity. These costs combine to be the total variable cost, which does not depend on the different operating hours of the plant.

Fixed

The total fixed operating costs include labor, overhead, insurance and local taxes. When calculating labor requirements, the operators required depend on the total hours of production per year. For further economic analysis, a comparison of a 24-hour workday and an 8-hour workday was done. A 24-hour workday means an 8000-hour work year to accommodate vacations, down time, and days off. An 8-hour workday translates to 2920 work hours per year working 8 hours a day and 7 days a week. Doing a calculation of required operators means taking into account 1 operator per production line, which we believe would be adequate to monitor fiberglass wrapping, resin delivery, and take up of finished product. To compensate for shorter manufacturing hours, more production lines are necessary. Sixteen lines of equipment are required when working 8-hour days while six lines of equipment are required for 24-hour days. Additionally, eight hours per day and seven days a week result in 56 shifts that need to be covered per line for a total of 896 shifts. When each operator works five shifts per week, 23 total operators are needed. A similar calculation for 24-hour days results in 26 operators on six lines of machinery. Based on average wages of manufacturing line operators in Georgia, each operator receives $30,000 annually (51). To accommodate additional employee benefits such as health care, 40% of wages are allotted. Finally, local insurance taxes are applied to the TPI, which are estimated at 1.5%.

Profitability Analysis

An Excel file provided by Dr. Weimer enables us to evaluate the economics of wire production, and to compare the 8-hour and 24-hour production schedules. The NANUQ wire production plant has a lifetime of 20 years. The first operational year in 2012 is for planning and design. The second year in the 8-hour a day plant is assigned to construction and production of the two smallest production scales, 50,000 feet and 500,000 feet. The third production scale, 1 million feet, is earmarked for the third year of plant operations. Finally in 2015, we will transition to full-scale production of 25 million feet of wire per year. When operating in the 24-hour production day, we are able to complete all three of the smallest scales of production in the second year of operation, scaling up to full production in 2014. From that point on, the full capacity of the plant (25M feet/year) will be manufactured.

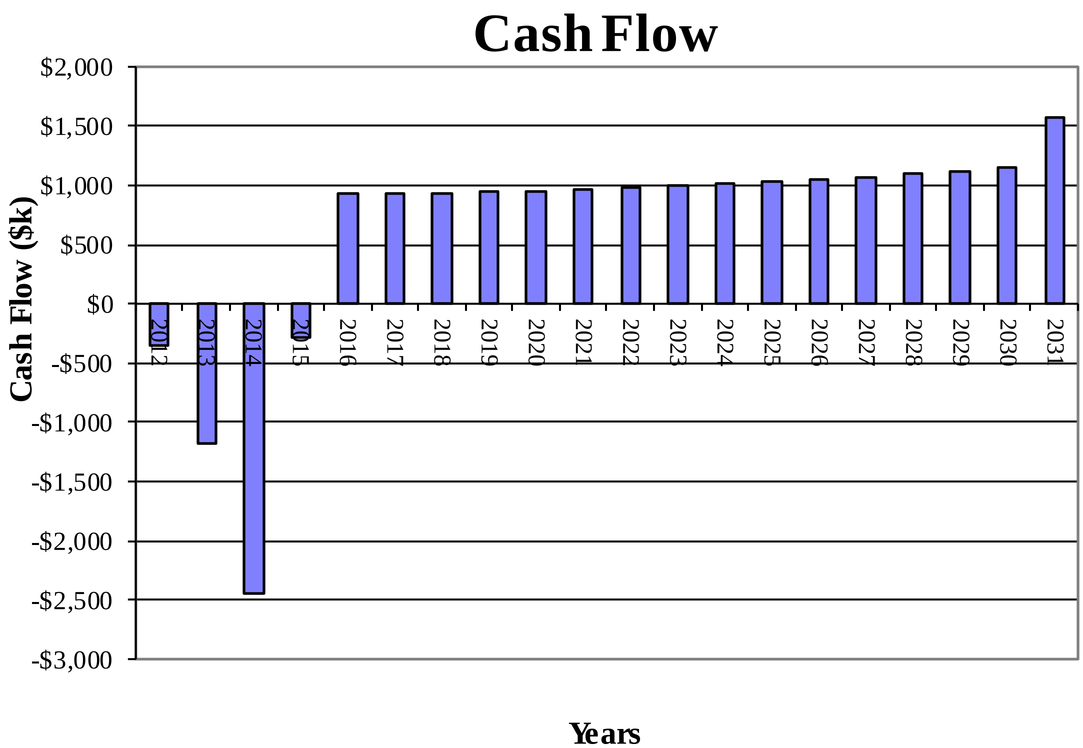


Figure 32: Production Economics: 8-hrs per day

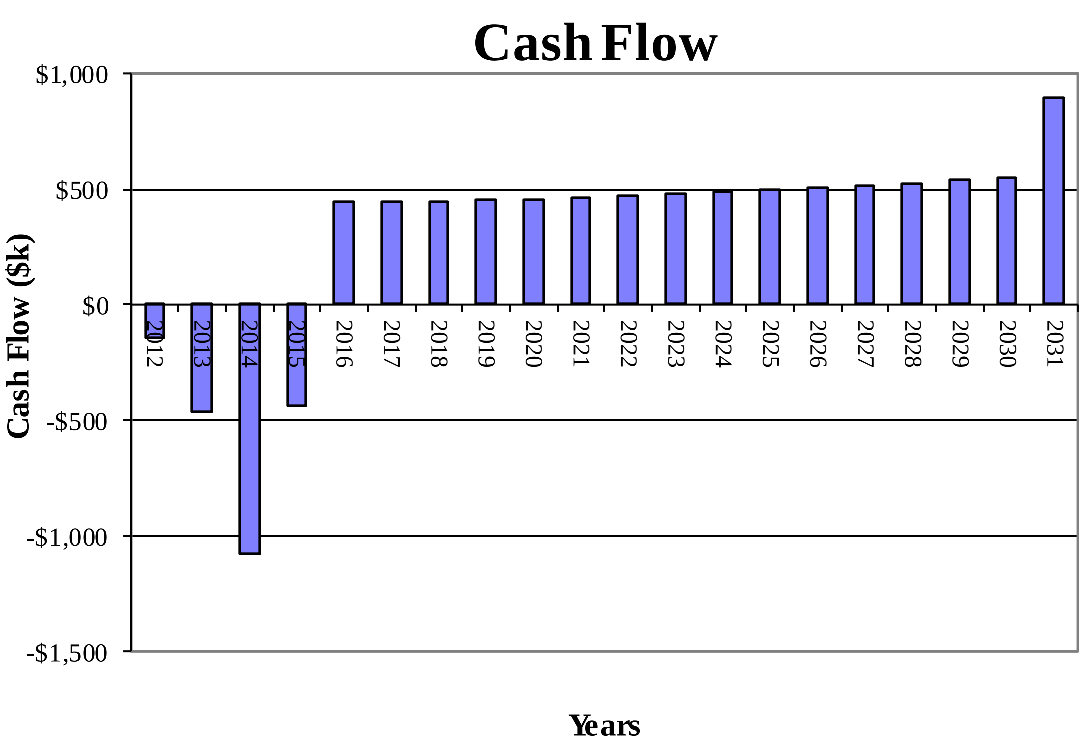


Figure 33: Production Economics: 24-hrs per day

Examining the cash flow charts (Figure 32, Figure 33), the sharp negative cash flow associated with the tremendous start-up capital costs can be seen in the first four years of plant operation. After that point, the venture capital loans are paid back and income from the wire plant leads to strictly positive cash flow. The cash flow is calculated using a default five-year modified accelerated cost recovery system (MACRS). Using MACRS enables a corporation to decrease its income tax liability by treating depreciation as a cost of wire production. Rather than use straight-line depreciation, MACRS uses rapid depreciation of investments at the beginning of the plant lifetime, and then switches back to straight line when it is economically advantageous (50). This explains the minimal cash flow in the first years of operation.

Table 21: Profitability Summary.

Profitability Summary	8-Hour Days	24-Hour Days
Selling Price (per foot)	$0.22	$0.20
Return on Investment	19.80%	19.40%
Payback Period	5.0 years	5.2 years
Net Present Value (end of period)	$4,657K	$2,187K
Net Present Value (start of period)	$4,857K	$2,286K
Investor's Rate of Return	16%	16%
Total Net Income	$12,426K	$6,019K

The profitability values for both 8-hour and 24-hour days are highlighted in Table 21. The cash flow calculations are based on a selling price of NANUQ® wire at $0.22 per foot ($0.20/foot when running 24-hour days) calculated by the economics spreadsheet macro provided. From that selling price, the return on an investment and payback period can be calculated. Determining an operation's return on investment (ROI) is also a method of evaluating profitability that is easier to understand, although less exact. The annual interest that is garnered on the profits of the initial investment is the ROI.

$$ROI = \frac{net\ earnings}{total\ capital\ investment}$$

The ROI for this plant with an investor's rate of return (IRR) of 16% is 19.8% (or 19.4% when on a 24-hour schedule). A venture capital investor could stand to earn nearly 20 percent on his investment, which is quite lucrative.

Beyond the ROI it is possible to calculate a payback period, PBP, or the time required for the annual profits to equal the capital that was initially invested. The shorter the time period, the more advantageous a prospect is to investors.

$$PBP = \frac{total\ depreciable\ capital}{cash\ flow}$$

For this specific plant with an IRR of 16%, the initial depreciable capital invested would be recouped in just over five years.

The wire plant's net present value (NPV) is calculated by reducing the expected cash flow for all of the years of operation by an assigned interest rate, then totaling those discounted cash flows based on a 16% IRR. When the NPV of a manufacturing process equals zero, the corresponding interest rate is the IRR. Larger IRR values are advantageous to a manufacturing process and the investors that are looking to contribute startup venture capital. Here in the wire production process, there is a much higher NPV when the IRR is set at 16% for the 8-hour workday than for the 24-hour workday.

Besides the fixed and variable operating costs, additional funds are deducted from the gross profit of the wire sales. Accounts receivable at 45 days and corporate income tax at 6% in Georgia (52) are also deducted from cash flows.

Because of the many benefits from working an 8-hour day production schedule including higher return on investment, shorter payback period, and greater total net income, the plant should be run on an 8-hour not 24-hour a day schedule.

Sensitivity Analysis

A multitude of factors affect the cost of production and can influence the profitability of the entire project. As part of the profitability analysis that was requested by CTD, a sensitivity analysis on the most important variables affecting the profitability was completed.

Key variables are chosen because they are either a significant portion of the total project costs, vary due to macroeconomic conditions, occur early in the life of the project, or are essential to the project design (53). The extent to which these factors impact the overall profitability is expressed via the investor's rate of return (IRR) and the return on investment (ROI).

The sensitivity analysis was performed on the following variables:

- Total permanent investment (TPI)
- Raw material costs
- Product selling price
- Operator salary

Total Permanent Investment

The sensitivity analysis for a 50% change in TPI was completed for both 8- and 24- hour production day scenarios. The results can be seen in Figure 34 and Figure 35, respectively. The relationship seen between ROI/IRR and TPI is inversely proportional. However, the non-linear decay tells us that an increase in the TPI has less of an effect on ROI and IRR as the TPI increases.

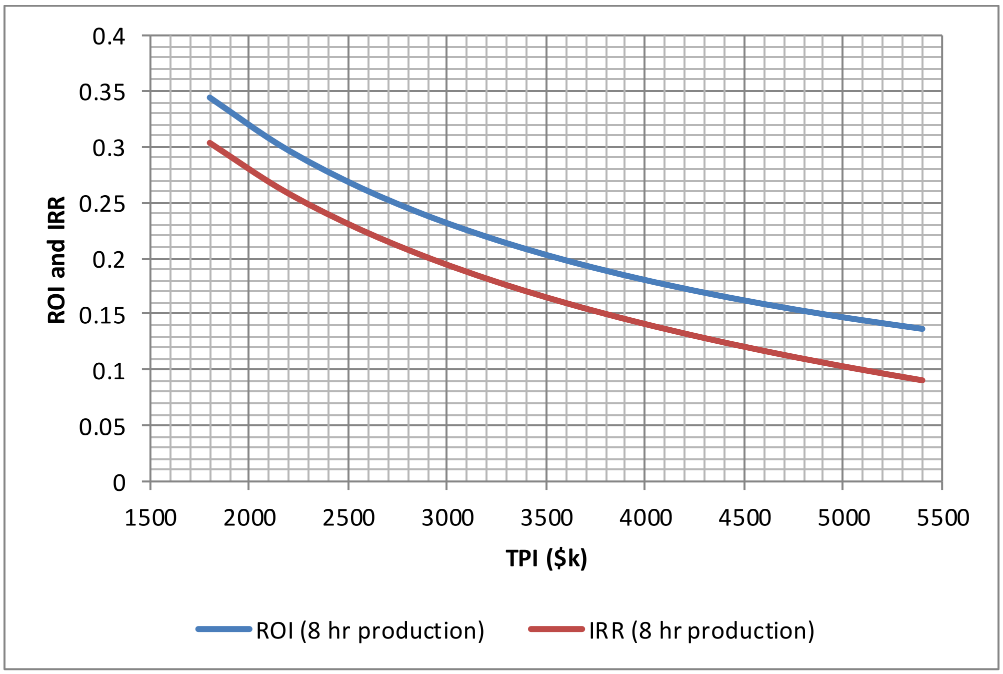


Figure 34: ROI and IRR vs. TPI (8 hour Production 50% Sensitivity)

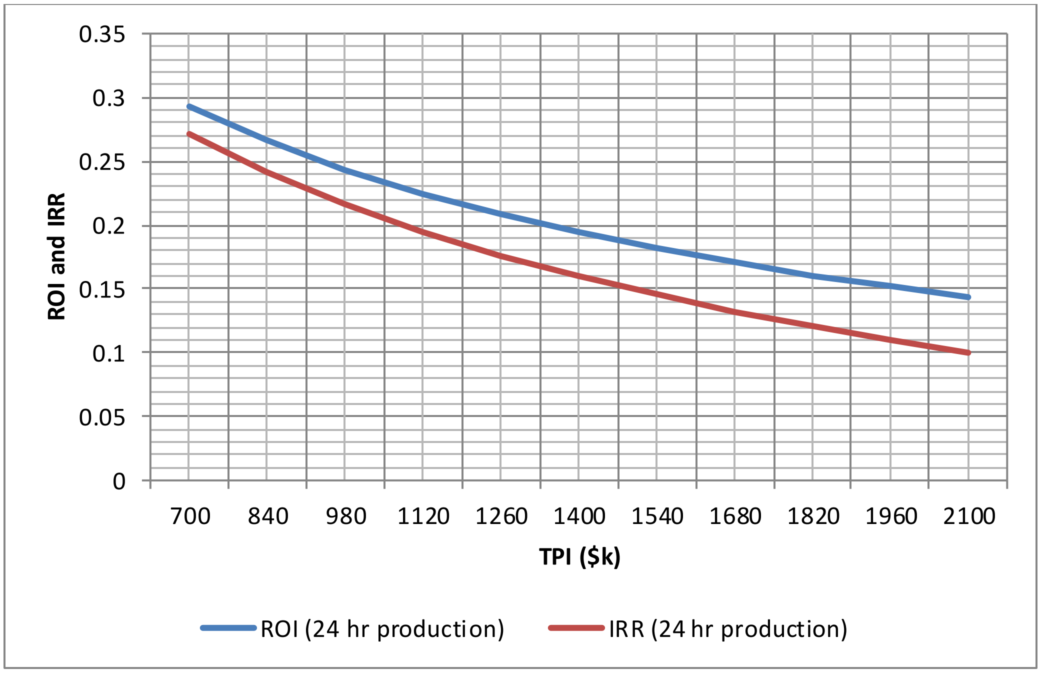


Figure 35: ROI and IRR vs. TPI (24 hour Production 50% Sensitivity)

Raw Materials

The final selling cost of the product depends on the cost of raw materials. As discussed in Section VII, the three materials used in producing the high-temperature application wire are copper wire, S-glass fiber reinforcement, and resin. Following the sensitivity analysis, we will report the current market outlook for copper in the future.

To see how the ROI and IRR are impacted by a change in raw material cost, we conducted a sensitivity analysis for a 50% change in the cost of the raw materials as seen in Figure 36 and Figure 37, respectively. In both scenarios, an increase in the material cost decreases the ROI and IRR in a linear fashion.

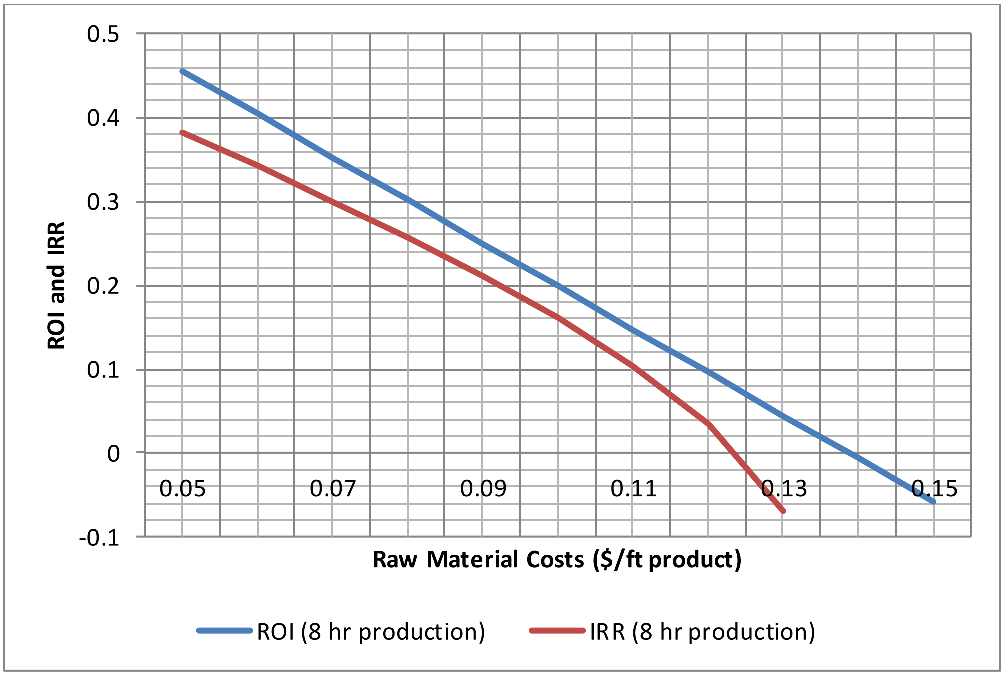


Figure 36: ROI and IRR vs. Raw Material Cost (8 hour Production 50% Sensitivity)

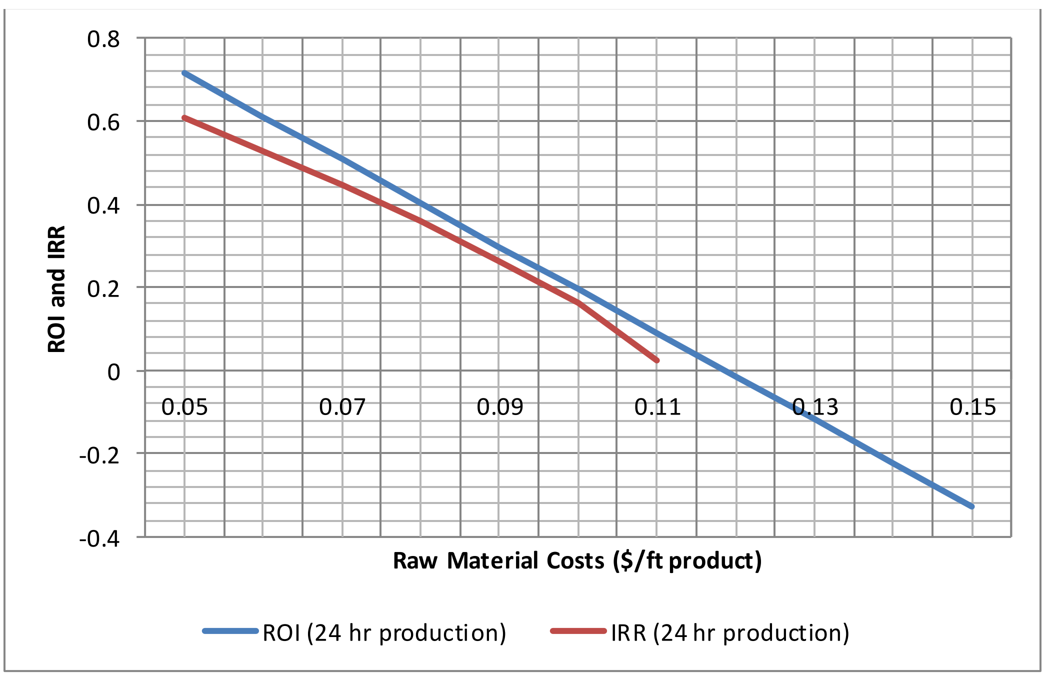


Figure 37: ROI and IRR vs. Raw Material Cost (24 hour Production 50% Sensitivity)

As outlined in Section V, the price of copper wire is assumed to be the market price of industrial copper and the price of fiber is estimated from industrial vendors. However, these prices are subject to the supply and demand determined by various economic and political factors. At the time of this report, most industrialized and developed countries are still in a recession (54). However, as the economy recovers there will be increased demand for all raw materials. As developing countries expand their internal markets, the strain on raw materials will cause an increase in price (55), (54). The following section will provide a brief overview of market projections by industry forecasters and commodity analysts.

The price of copper is expected to increase, as China has a sustained demand for the metal (56). Reserves of the commodity continue to decrease and in 2011 the price of copper is expected to increase by 20% before the price begins to stabilize (57). The price of copper over the next year, along with the predictions of industry experts are given in Figure 38. The long-term changes are hard to predict given the volatility of metal prices as additional copper reserves are found and as demand responds to economic conditions.

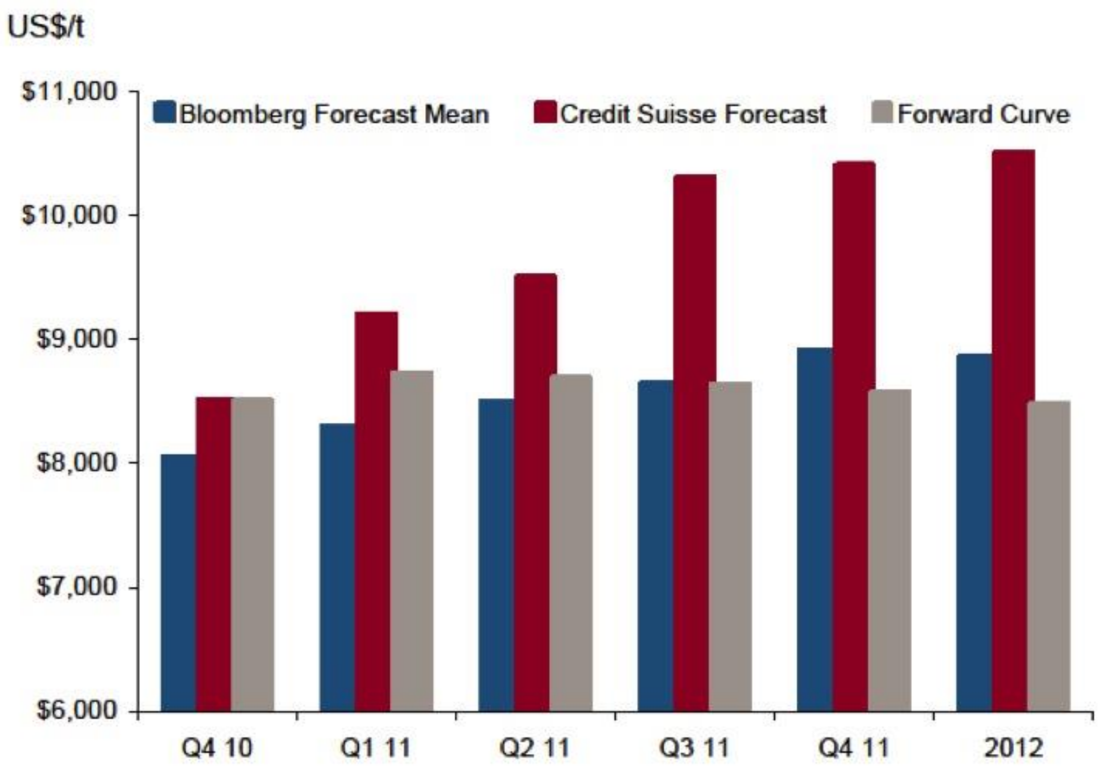


Figure 38: Price of copper Credit Suisse forecast vs. the industry consensus (57)

In the immediate future, as countries such as China increase production of certain raw materials, we may see the price of the S-glass fiber fall. In 2007, the total fiber glass produced in China represented 38.1% of total output worldwide (58).The trends being reported are a huge increase in production and a decrease in cost of production, as a result of expansion and technology developments in China. The prices of fiberglass are expected to fall over the next decade (59).

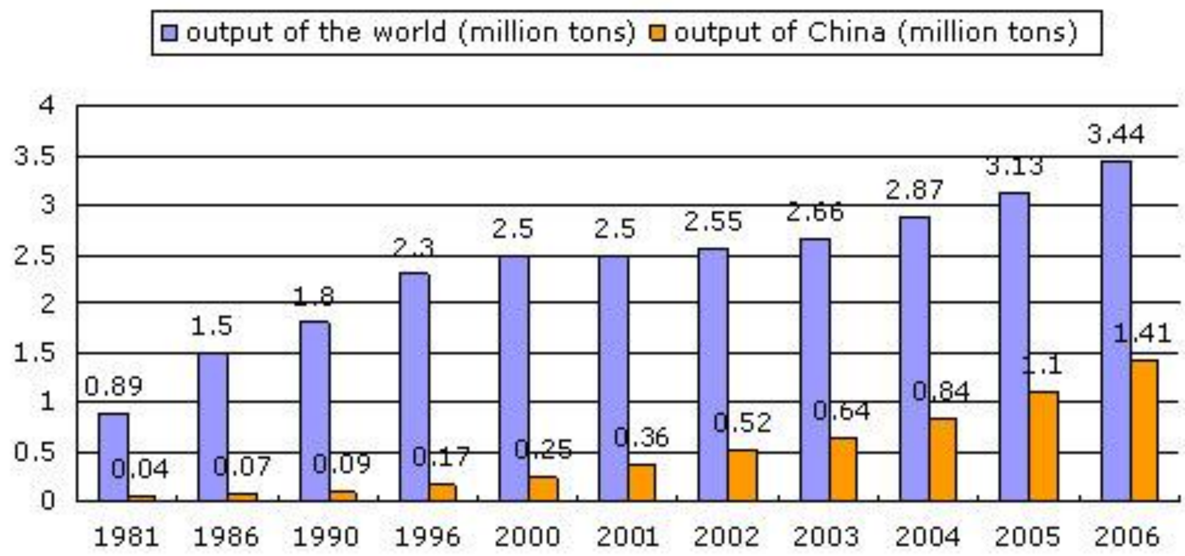


Figure 39: Worldwide vs. China's Fiberglass Production, 1981-2006 (59)

Since the chemical composition of the resin is unknown, we will assume that the costs will mirror other polymer-derived elastomer resins. Though market analysis reveals that the recession negatively affected demand for most raw materials, the market for elastomer resins has remained constant (60). As the economy continues to recover, however, the cost of resin is expected to increase.

Product Selling Price

One of the greatest sources of uncertainty in any profitability analysis is calculating the market selling price of a product. This is due to the nature of the markets themselves. In our case they dictate not only the interest rates, the cost of labor and capital, and the cost of raw materials, but also the demand for the product itself. Therefore, analysis needs to be done on how the profitability of the process changes as the cost per unit increases or decreases. As shown in Figure 40, the cost of the process and subsequently the selling prices of the products, change in an iterative manner. The goal is to calculate the costs and profitability of the process to guarantee the final design is economically feasible.

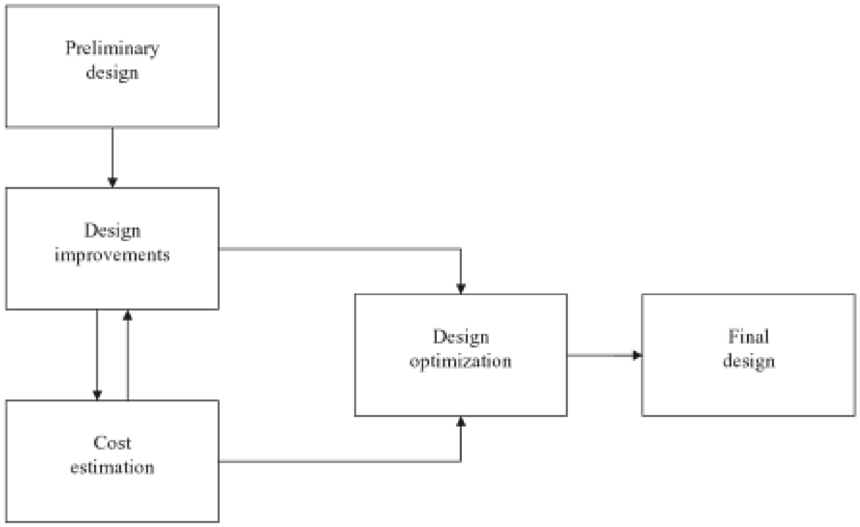


Figure 40: Role of Cost Estimation in Design Optimization (61)

In order to examine how a change in product price affects the profitability of this process, a 50% sensitivity analysis on wire selling price was completed for both the 8- and 24-hour production day scenarios in terms of the ROI, seen in Figure 41. For a given change in the selling price, the ROI of the 24-hour production changes to a greater extent than that of the 8-hour production scenario. This translates to a higher ROI for the 24-hour production at any selling price where returns on investment are positive.

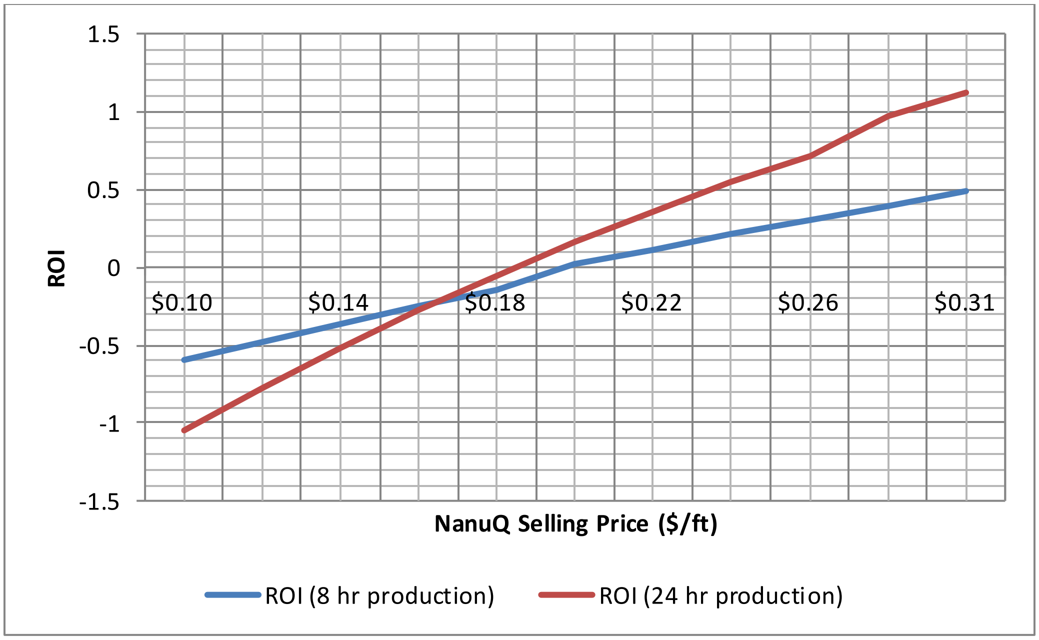


Figure 41: ROI vs. Product Selling Price (50% Sensitivity)

Operator Salary

As dictated by the project premises, the production facility will be located in Atlanta, GA. In order to see how the cost of labor affects the profitability of the process we utilized data from the U.S. Department of Labor to estimate operator salaries. From government estimates, operators in the American Southeast tend to earn approximately 5% less than the rest of the US (51). Therefore, building a production facility in this region is economically favorable. Shown in Table 22 are the current wage estimates of plant operators. The yearly salaries can vary by approximately $10,000 per operator per year. Due to the variability in salary, a sensitivity analysis is essential to understand the overall effect of fixed costs on profitability.

Table 22: May 2009 State Occupational Employment and Wage Estimates: Georgia (62)

Occupation		Wage Estimates			
Occupation Code	Occupation Title	Median Hourly	Mean Hourly	Mean Annual[1]	Mean RSE[2]
51-4011	Computer-Controlled Machine Tool Operators, Metal and Plastic	$15.87	$16.25	$33,800	2.00%
51-4021	Extruding and Drawing Machine Setters, Operators, and Tenders, Metal and Plastic	$14.24	$14.53	$23,220	2.20%
51-6091	Extruding and Forming Machine Setters, Operators, and Tenders, Synthetic and Glass Fibers	$15.58	$16.55	$24,430	3.30%
51-8091	Chemical Plant and System Operators	$22.18	$22.52	$46,850	2.90%
51-9041	Extruding, Forming, Pressing, and Compacting Machine Setters, Operators, and Tenders	$16.39	$16.33	$33,960	2.50%

The sensitivity analysis for a 50% change in the operator salary was done for both the 8-and 24-hour production day scenarios in terms of the ROI, as seen in Figure 42. From the graph, if running on an 8-hour schedule, a greater ROI is achieved if operators are paid more than $30K per year compared to a 24-hour schedule. The opposite is true if the operators are paid less than $30K per year.

[1] Annual wages have been calculated by multiplying the hourly mean wage by a "year-round, full-time" hours figure of 2,080 hours; for those occupations where there is not an hourly mean wage published, the annual wage has been directly calculated from the reported survey data (52)
[2] The relative standard error (RSE) is a measure of the reliability of a survey statistic. The smaller the relative standard error, the more precise the estimate (52)

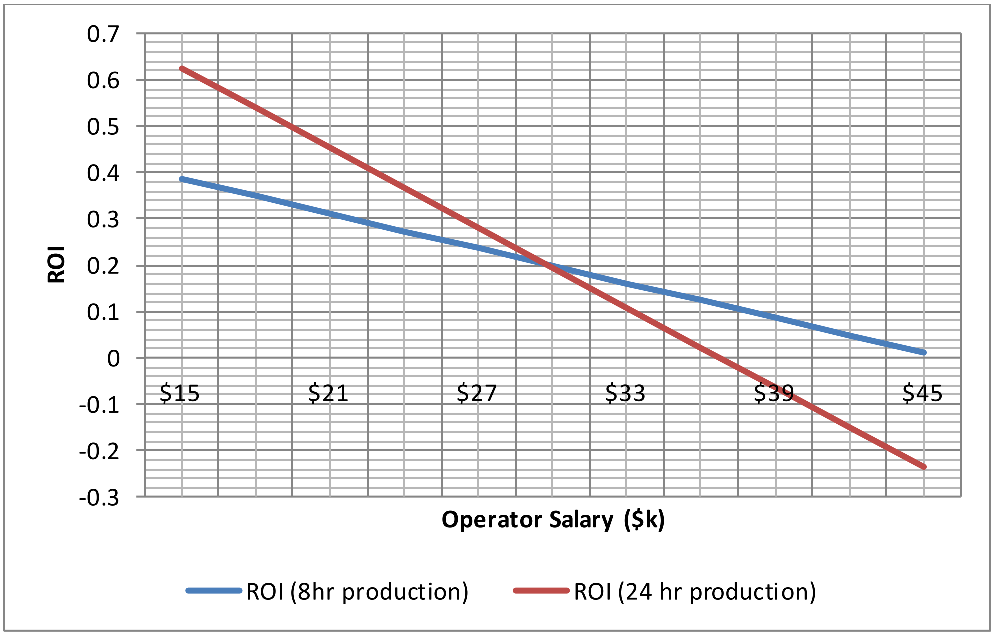


Figure 42: ROI vs. Operator Salary (50% Sensitivity)

XII. Works Cited

1. **Allied Electronics, Inc.** Belden 37112 010500. *Allied Electronics.* [Online] 2011. [Cited: April 20, 2011.] www.alliedelec.com/search/productdetail.aspx?SKU=2142000.

2. **Hazelton, Craig.** Manufacturing Design and Fabrication Cost Analysis forProduction of NANUQ® High Temperature Wire. *Design Project Proposal.* Lafayette : s.n., 2011.

3. **Cicerone, Ralph J.** Climate Change: Evidence and Future Projections. *Before the Subcommittee on Oversight and Investigations Committee on Energy and Commerce, US House of Representatives.* Washington DC : s.n., 27 July 2006. Speech.

4. **Weimer, Alan.** Process Design Lecture. Boulder : University of Colorado, 2010. Vol. Lecture.

5. **US Department of Energy.** Geothermal Technologies Program. *Energy Efficienty and Renewable Energy.* [Online] 2010. [Cited: January 29, 2011.] http://www1.eere.energy.gov/geothermal/pdfs/egs_basics.pdf.

6. *High-Temperature Electrical Insulations for EGS Downhole Equipment.* **Hooker, M.W., et al., et al.** Lafayette : Thirty-Fifth Workshop on Geothermal Reservoir Engineering, Stanford University, 2010.

7. *Wrappable Ceramic Insulation for Superconducting Magnets.* **Rice, J.A., Fabian, P.E. and Hazelton, C.S.** 200, s.l. : Advances in Cryogenic Engineering, Vol. 46.

8. **Rice, J.A., Hazelton, C.S. and Fabian, P.E.** *Ceramic Electrical Insulation for Electrical Coils, Transformers, and Magnets. 6,407,339* US, June 18, 2002.

9. *High Performance Downhole Heater Cables.* **Hooker, M.W., et al., et al.** Lafayette : Rocky Mountain Section of the American Association of Petroleum Geologists, 2006, Vol. June.

10. **Giles, H.F., Wagner, J.R., & E.M. Mount.** *Etrusion - The Definitive Processing Guide and Handbook.* Norwich : William Andrew Publishing, 2005.

11. Polymer Structure. *Nondestructive Testing (NDT) Resource Center.* [Online] [Cited: March 25, 2011.] http://www.ndt-ed.org/EducationResources/CommunityCollege/Materials/Structure/polymer.htm.

12. **Kricheldorf, H.R., Nuyken, O., and G. Swift.** *Handbook of polymer synthesis.* s.l. : CRC Press, 2005.

13. **Wicks, Z.W., Jones, F.N., and S.P. Pappas.** *Organic Coatings: Science and Technology.* New York : Wiley & Sons, 1999.

14. **Strong, A.B.** *Plastics: Materials and Processing.* Upper Saddle River : Prentice Hall, Inc., 2005.

15. Chemistry of industrial polymers. *Encyclopædia Britannica.* [Online] [Cited: March 4, 2011.] http://www.britannica.com/EBchecked/topic/468716/chemistry-of-industrial-polymers/76392/Step-growth-polymerization?anchor=ref608598.

16. **Victrex.** High Performance PEEK Polymers. *Craftech Industries, Inc.* [Online] [Cited: April 15, 2011.] http://www.craftechind.com/Materials%20PDF%27s/PEEKHigh_Temperature%20Victrex.pdf.

17. **Robello, Dr. Douglas R.** Aromatic Addition-Elimination Polymerization. *Chem 421: Introduction to Polymer Chemistry.* [Online] December 18, 2002. [Cited: April 15, 2011.] http://chem.chem.rochester.edu/~chem421/aromaddnelim.htm.

18. **Calvert.** Typical Characteristics of Insulation and Jacket Compounds. *Calvert Wire and Cable.* [Online] 2011. [Cited: April 15, 2011.] http://www.calvert-wire.com/compound_characteristics.php.

19. *Water treeing - filled versus unfilled cable insulation.* **Boggs, S. and Xu, J.** 1, s.l. : Elec. Insul. Magazine IEEE, 2001, Vol. 17.

20. **Ito, Akira and Kamohara, Hiroaki.** *Method and apparatus for measuring deterioration of power cable insulation . 5,469,066* US, November 21, 1995 .

21. **Easter, Mark.** Rubber Insulated Power Cables. *Indianapolis Compounds.* [Online] April 2005. [Cited: April 15, 2011.] http://www.indianapoliscompounds.com/downloads/EPR_cables_final%20version_4.04.05.PDF.

22. **Composite Technology Development, Inc.** *Material Safety Data Sheet CTD-1202.* Lafayette : CTD Inc., 2010.

23. **Owens Corning TM.** *Material Safety Data Sheet: Woven Unidirectional Fiberglass Fabric.* Toledo : s.n., 1997.

24. **MWS Wire Industries.** *MSDS 027 - Bare Copper.* Westlake Village : s.n., 2010.

25. **Green, D.W., and R.H. Perry.** *Perry's Chemical Engineers' Handbook.* 8th Edition. New York : McGraw-Hill, 2008.

26. **Hazelton, Craig, Walsh, Jennifer and Hooker, Matthew.** *NANUQ (R) Commercial Wire Insulation Production.* Lafayette : Composite Technology Development, Inc., 2011.

27. **Seider, Warren D., et al., et al.** *Product and Process Design Principles.* 3rd Ed. Hoboken : Wiley & Sons, 2009.

28. **New York Times.** *Commodities Market Summary.* New York, NY, USA : s.n., January 1, 2011.

29. **The Tax Foundation.** State Corporate Income Tax Rates, 2000-2010. *Tax Foundation.* [Online] March 29, 2010. [Cited: January 30, 2011.] http://www.taxfoundation.org/taxdata/show/230.html.

30. *Determination of rates of thermal decomposition of polymerization initiators with a differential scanning calorimeter.* **Barrett, K.E.J.** 9, s.l. : John Wiley & Sons, 1967, Journal of Applied Polymer Science, Vol. 11.

31. *Crosslinking of an unsaturated polymer resin in the mould: Modelling and heat transfer studies.* **Kosar, V., & Z. Gomzi.** 1586-1596, 2010, Applied Mathematical Modelling, Vol. 34.

32. *Curing Kinetics of an Acrylic Resin/Epoxy Resin System Using Dynamic Scanning Calorimetry.* **Chu, F., McKenna, T., and S. Lu.** 6, s.l. : Elsevier Science Ltd., 1997, European Polymer Journal, Vol. 33.

33. **McNaught, A.D., and A. Wilkinson.** *IUPAC. Compendium of Chemical Terminology.* 2nd. Oxford : Blackwell Scientific Publications, 1997.

34. *A new method to modeling the cure kinetics of epoxy/amine thermosetting resins. 1. Mathematical development.* **Cole, K.C.** 11, 1991, Macromolecules, Vol. 24.

35. *Kinetics Analysis of the Curing Reaction of Fast Cure Epoxy Prepregs.* **Yang, L.F., Yao, K.D., and W. Koh.** s.l. : John Wiley & Sons, Inc., 1999, Journal of Applied Polymer Science, Vol. 73, pp. 151-1508.

36. *Thermal Rheological Analysis of Cure Process of Epoxy Prepreg.* **Sun, L.** Baton Rouge : s.n., 2001, Diss. Louisiana State University.

37. *Kinetics and Thermal Characterization of Thermoset Cure.* **Kamal, M.R., and S. Sourour.** 1973, Polymer Engineering & Science, Vol. 13, pp. 59-64.

38. *A step-by-step guide to non-linear regression analysis of experimental data using a Microsoft Excel spreadsheet.* **Brown, A.M.** s.l. : Elselview, 2001, Computer Methods and Programs in Biomedicine, Vol. 65, pp. 191-200.

39. *Cure Reactions of Epoxy/Anhydride/(Polyamide Copolymer) Blends.* **Choe, Y. and K. Wonho.** 5, 2002, Macromolecular Research, Vol. 10, pp. 259-265.

40. *Estimating Diffusion-Controlled Reaction Parameters in Photoinitiated Polymerization of Dimethylacrylate Macromonomers.* **Choe, Y.** 5, s.l. : Springer, 2003, Macromolecular Research, Vol. 11, pp. 311-316.

41. **Seider, Seader, Lewin, Widago.** *Product and Process Design Principles Synthesis, Analysis, and Evaluation.* Hoboken : John Wiley and Sons, 2009.

42. **Giles, Harold F., Wagner, J.R., Mount, E.M.** *Extrusion - The Definitive Processing Guide and Handbook.* Norwich : William Andrew Publishing/Plastics Design Library, 2005.

43. **Michaeli, Walter.** *Extrusion Dies for Plastics and Rubber, 3rd Ed.* Munich : Carl Hanser Verlag, 2003.

44. **Weimer, Alan.** Formatted Cost Equation Spreadsheet. 2010.

45. **Rudnev, V., Loveless, D., Cook,R., and M. Black.** *Handbook of Induction Heating.* New York : Marcel Dekker, 2003.

46. **Goldshmidt, Streitberger.** *BASF Handbook on Basics of Coating Technology.* Hannover : Munster, 2003.

47. **HelloTrade.com.** Superior Induction Company. *HelloTrade.com.* [Online] [Cited: April 19, 2011 .] http://www.hellotrade.com/superior-induction-company/product.html.

48. **Rao, O'Brien.** *Design Data for Plastics Engineers.* Munich : Carl Hanser Verlag, 1998.

49. **Incropera, Dewitt.** *Fundamentals of Heat and Mass Transfer.* NY : Wiley, 2007.

50. **Seider, W.D., Seader, J.D., Lewin, D.R., Widagdo, S.** *Product and Process Design Principles, 3rd Ed.* Hoboken : Wiley & Sons, 2009.

51. **US Department of Labor: Bureau of Labor Statistics.** May 2009 State Occupational Employment and Wage Estimates: Georgia. *Occupational Employment Statistics.* [Online] May 2009. [Cited: April 10, 2011.] http://www.bls.gov/oes/2009/may/oes_ga.htm.

52. **Federation of Tax Administrators.** State Corporate Income Tax Rates. *Federation of Tax Administrators.* [Online] January 1, 2011. [Cited: April 3, 2011.] www.taxadmin.org/fta/rate/corp_inc.pdf .

53. **Athukorala, S.L.** *Handbook for the Economic Analysis of Water Supply Projects.* Manila : Economics and Development Resource Center, 1999.

54. **The World Bank.** *Global Economic Prospects January 2011: Navigating strong currents.* Washington D.C. : The International Bank for Reconstruction and Development / The World Bank, 2011.

55. *Placing the Recent Commodity Boom into Perspective.* **Baffes, J., and T. Haniotis.** s.l. : Center of Economic and Policy Research. World Bank., 2010, Food Prices and Rural Poverty, pp. 40-70.

56. **Burns, S.** Copper Outlook 2011. *AG Metal Miner.* [Online] January 3, 2011. [Cited: March 21, 2011.] http://agmetalminer.com/2011/01/03/copper-outlook-for-2011/.

57. **Credit Suisse Group AG.** *2011 Commodity Outlook.* Fixed Income Research. London : Credit Suisse Securities Limited, 2010.

58. **Hinton Information Services.** *China Fiberglass Industry Report, 2008.* Taipei City : Hinton Information Services, 2008.

59. **Research In China.** *China Fibreglass Industry Report, 2006-2010.* Beijing : Beijing Waterwood Technologies CO., Ltd, 2007.

60. **Schlechter, M.** *Polypropylene Resins and Elastomers.* Wellesley : BCC Research, 2010.

61. **Mital, A., Desai, A., and A. Subramanian.** *Product development: a structured approach to consumer product development, design, and manufacture.* Burlington : Butterworth-Heinemann, 2007.

62. **U.S. Bureau of Labor Statistics.** May 2009 State Occupational Employment and Wage Estimates: Georgia. *U.S. Bureau of Labor Statistics.* [Online] April 6, 2010. [Cited: March 21, 2011.] http://www.bls.gov/oes/current/oes_ga.htm#(2).

63. American Wire Gauge (AWG) Sizes. *RBE Electronics.* [Online] http://www.rbeelectronics.com/wtable.htm.

64. **Department of the Treasury.** 2010 Instructions for Form 1120. *US Corporate Income Tax Return.* 2009.

65. **Hoa, S.V.** *Principles of the Manufacturing of Composite Materials.* Lancaster : DEStech Publications, Inc., 2009.

66. **Temenoff, J.S., and A.G. Mikos.** *Biomaterials: The Intersection of Biologicy and Materials Science.* Upper Saddle River : Pearson Education, Inc., 2008.

67. **KetonePro, Inc.** Products of KetonePro. *KetonePro.* [Online] 2011. [Cited: April 15, 2011.] http://ketonepro.com/products.html.

68. Lanxess. *What is ethylene-propylene rubber?* [Online] 2011. [Cited: April 15, 2011.] http://www.buna-ep.de/buna/en/about_buna/overall_product_description/ethylene_propylene_rubber/.

Appendix A. Approach Calculations

American Wire Gauge (AWG) Diameters

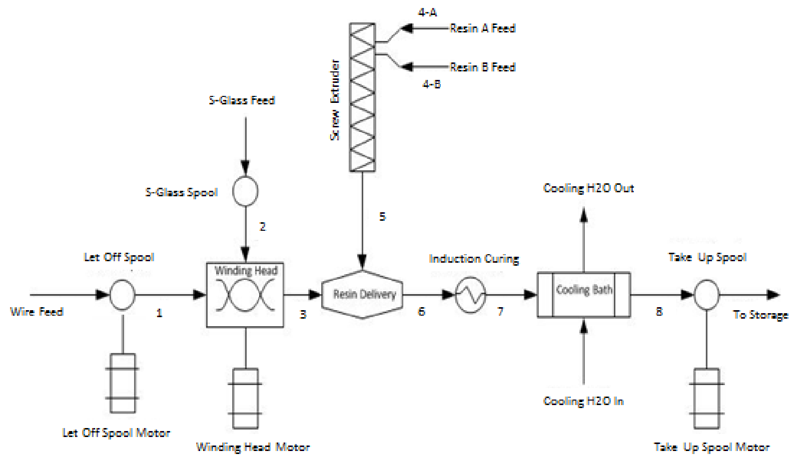
American Wire Gauge (AWG) sizes may be determined by measuring the diameter of the conductor (the bare wire) with the insulation removed. Refer to the Wire gauge Diameter Table for dimensions. When choosing wire gauge, the distance the wire must run and the amperage it will be expected to carry must be determined first. Refer to the Wire gauge Selection Table. Note that you can always use thicker wire (lower gauge number) than is recommended.

Table 23. WIRE GAUGE DIAMETER TABLE (63)

American Wire Gauge	Wire Diameter (in.)
20	0.03196118
18	0.040303
16	0.0508214
14	0.064084
12	0.0808081
10	0.10189
8	0.128496
6	0.16202
5	0.18194
4	0.20431
3	0.22942
2	0.25763
1	0.2893
0	0.32486
00	0.3648

Material and Energy Balances

Process Flow Diagram: Material and Energy Balances



Let Off Spool (Semi-Batch Process)							
Stream	Material	T (°C)	P (atm)	Initial Mass Load (lb)	Mass Flow Rate (lb/hr)	Mass Composition	Power (kW)
Wire Feed	Copper	25	1	700	-	1	-
1	Copper	25	1	-	14.3	1	-
Energy	Electricity	-	-	-	-	-	0.19

Winding Head (Semi-Batch Process)							
Stream	Material	T (°C)	P (atm)	Initial Mass Load (lb)	Mass Flow Rate (lb/hr)	Mass Composition	Power (kW)
S-Glass Feed	S-Glass	25	1	20	-	1	-
1	copper	25	1	-	14.3	1	-
2	S-Glass	25	1	-	0.07	1	-
3	S-Glass	25	1	-	0.07	0.005	-
	Copper				14.3	0.995	
	Total				14.37	1	
Energy	Electricity	-	-	-	-	-	3.43

Resin Srew Extrusion (Semi-Batch Process)							
Stream	Material	T (°C)	P (atm)	8 hr Initial Mass Load (lb)	Mass Flow Rate (lb/hr)	Mass Composition	Power (kW)
4-A	Resin A	25	1	9.03	1.129	1	-
4-B	Resin B	25	1	0.9	0.113	1	-
5	Resin A	25	1	-	1.129	0.91	-
	Resin B				0.113	0.09	-
	Total				1.242	1	-
Energy	Electricity	-	-	-	-	-	3.75

Resin Delivery							
Stream	Material	T (°C)	P (atm)	Initial Mass Load (lb)	Mass Flow Rate (lb/hr)	Mass Composition	Power (kW)
3	Copper	25	1	-	14.3	0.995	-
	S-Glass				0.07	0.005	
	Total				14.37	1	
5	Resin A	25	1	-	1.129	0.91	-
	Resin B				0.113	0.09	
	Total				1.242	1	
6	Copper	25	1	-	14.3	0.916	-
	S-Glass				0.07	0.004	
	Resin A				1.129	0.072	
	Resin B				0.113	0.007	
	Total				15.612	1.000	
Energy	-	-	-	-	-	-	0

Induction Curing							
Stream	Material	T (°C)	P (atm)	Initial Mass Load (lb)	Mass Flow Rate (lb/hr)	Mass Composition	Power (kW)
6	Copper	25	1	-	14.3	0.916	-
	S-Glass				0.07	0.004	
	Resin A				1.129	0.072	
	Resin B				0.113	0.007	
	Total				15.612	1	
7	Copper	175	1	-	14.3	0.916	-
	S-Glass				0.07	0.004	
	Resin A				1.129	0.072	
	Resin B				0.113	0.007	
	Total				15.612	1	
Energy	-	-	-	-	-	-	5.94

Cooling Bath							
Stream	Material	T (°C)	P (atm)	Initial Mass Load (lb)	Mass Flow Rate (lb/hr)	Mass Composition	Power (W)
7	Copper	175	1	-	14.3	0.916	-
	S-Glass				0.07	0.004	
	Resin A				1.129	0.072	
	Resin B				0.113	0.007	
	Total				15.612	1	
Cooling H2O In	Water	32	1	-	396.5	1	-
8	Copper	45	1	-	14.3	0.916	-
	S-Glass				0.07	0.004	
	Resin A				1.129	0.072	
	Resin B				0.113	0.007	
	Total				15.612	1	
Cooling H2O Out	Water	33	1	-	396.5	1	-
Energy	-	-	-	-	-	-	-210

Take Up Spool (Semi-Batch)							
Stream	Material	T (°C)	P (atm)	Final Mass Load (lb)	Mass Flow Rate (lb/hr)	Mass Composition	Power (kW)
8	Copper	45	1		14.3	0.916	-
	S-Glass				0.07	0.004	
	Resin A				1.129	0.072	
	Resin B				0.113	0.007	
	Total				15.612	1	
To Storage (Spool)	Copper	45	1	750	14.3	0.916	-
	S-Glass				0.07	0.004	
	Resin A				1.129	0.072	
	Resin B				0.113	0.007	
	Total				15.612	1	
Energy	-	-	-	-	-	-	0.19

Summary of Material Requirements			
Scale	Copper (tons)	Fiberglass (# spools)	Resin (cuft)
50,000 feet	0.5	0.2	1.7
500,000 feet	5.0	2	16.5
1 million feet	9.9	4	33.1
25 million feet	247.5	88	827.2

Production Time			
Scale	Hours of Production	8-Hour Days Required	24-Hour Days Required
50,000 feet	93.2	12	4
500,000 feet	932.1	117	39
1 million feet	1864.1	234	78
25 million feet	46603.5	5826	1942
# Production Lines	N/A	16	6

Copper Balance

Level of production	Value	Unit	Description
Pilot Scale	50000	ft/yr	Linear ft produced per year
Pre-Production Scale	500000	ft/yr	
Production Scale	1000000	ft/yr	
	25000000	ft/yr	
ρ	556	lb/ft^3	Average Density

Gauge	Diameter		Cross-sectional Area		Volume needed per year (ft^3/yr)			
	in	ft	ft^2		Pilot Scale	Pre-Production Scale	Production Scale	
18	0.040303	0.003359	8.85936E-06		0.442967785	4.429677846	8.859355691	221.4838923
16	0.0508214	0.004235	1.40871E-05		0.704353445	7.043534445	14.08706889	352.1767223
14	0.064084	0.00534	2.23989E-05		1.119944799	11.19944799	22.39889597	559.9723993
12	0.0808081	0.006734	3.56153E-05		1.780767351	17.80767351	35.61534703	890.3836757
10	0.10189	0.008491	5.66227E-05		2.831134604	28.31134604	56.62269209	1415.567302
8	0.128496	0.010708	9.00547E-05		4.502737308	45.02737308	90.05474616	2251.368654
6	0.16202	0.013502	0.000143174		7.158708019	71.58708019	143.1741604	3579.354009

Gauge	Mass of copper needed per year (lb/yr)				Mass of copper needed per year (tons/yr)			
	Pilot Scale	Pre-Produ	Production Scale		Pilot Scale	Pre-Production Scale	Production Scale	
18	246.2900882	2462.901	4925.801764	123145	0.123145044	1.231450441	2.462900882	61.57252205
16	391.6205151	3916.205	7832.410303	195810.3	0.195810258	1.958102576	3.916205151	97.90512879
14	622.689308	6226.893	12453.78616	311344.7	0.311344654	3.11344654	6.22689308	155.672327
12	990.1066473	9901.066	19802.13295	495053.3	0.495053324	4.950533237	9.901066473	247.5266618
10	1574.11084	15741.11	31482.2168	787055.4	0.78705542	7.8705542	15.7411084	393.52771
8	2503.521943	25035.22	50070.43886	1251761	1.251760972	12.51760972	25.03521943	625.8804858
6	3980.241659	39802.42	79604.83317	1990121	1.990120829	19.90120829	39.80241659	995.0604146

Resin Balance

S-Glass Balance

Wrapping Speed	1800	rpm

Wire Gauge	Diameter		Circumference = 1 rev		RPM	Length of copper wrapped		Time to Make Production Scales (min)			
	in	ft	in	ft		in/min	ft/min	50000	500000	1000000	25000000
18	0.04030	0.00336	0.12662	0.01055	3609	286.82	23.90	2091.91	20919.15	41838.29	1045957.29
16	0.05082	0.00424	0.15966	0.01331	2862	227.46	18.95	2637.87	26378.69	52757.38	1318934.42
14	0.06408	0.00534	0.20133	0.01678	2270	180.38	15.03	3326.26	33262.60	66525.20	1663129.97
12	0.08081	0.00673	0.25387	0.02116	1800	143.05	11.92	4194.32	41943.19	83886.38	2097159.55
10	0.10189	0.00849	0.32010	0.02667	1428	113.45	9.45	5288.57	52885.69	105771.37	2644284.26
8	0.12850	0.01071	0.40368	0.03364	1132	89.96	7.50	6669.54	66695.45	133390.89	3334772.30
6	0.16202	0.01350	0.50900	0.04242	898	71.35	5.95	8409.60	84095.97	168191.95	4204798.66

Wire Gauge	Time to Make Production Scales (hr)				Accounting for 75% Efficiency			Time(hr)
	50000	500000	1000000	25000000	50000	500000	1000000	25000000
18	34.9	348.7	697.3	17432.6	46.5	464.9	929.7	23243.5
16	44.0	439.6	879.3	21982.2	58.6	586.2	1172.4	29309.7
14	55.4	554.4	1108.8	27718.8	73.9	739.2	1478.3	36958.4
12	69.9	699.1	1398.1	34952.7	93.2	932.1	1864.1	46603.5
10	88.1	881.4	1762.9	44071.4	117.5	1175.2	2350.5	58761.9
8	111.2	1111.6	2223.2	55579.5	148.2	1482.1	2964.2	74106.1
6	140.2	1401.6	2803.2	70080.0	186.9	1868.8	3737.6	93440.0

Band width	0.08	
Length advanced	0.083655341	

Wire Gauge	8 Hour Days				#Lines
18	5.8	58.1	116.2	2905.4	8
16	7.3	73.3	146.5	3663.7	11
14	9.2	92.4	184.8	4619.8	13
12	11.7	116.5	233.0	5825.4	16
10	14.7	146.9	293.8	7345.2	21
8	18.5	185.3	370.5	9263.3	26
6	23.4	233.6	467.2	11680.0	32

Wire Gauge	24 Hour Days				# lines
18	1.9	19.4	38.7	968.5	3
16	2.4	24.4	48.8	1221.2	4
14	3.1	30.8	61.6	1539.9	5
12	3.9	38.8	77.7	1941.8	6
10	4.9	49.0	97.9	2448.4	8
8	6.2	61.8	123.5	3087.7	10
6	7.8	77.9	155.7	3893.3	12

Wire Gauge	# years If running 8000 hr/yr				# years If running 2920 hr/yr			
	50000	500000	1000000	25000000	50000	500000	1000000	25000000
18	0.0058	0.0581	0.1162	2.9054	0.0159	0.1592	0.3184	7.9601
16	0.0073	0.0733	0.1465	3.6637	0.0201	0.2008	0.4015	10.0376
14	0.0092	0.0924	0.1848	4.6198	0.0253	0.2531	0.5063	12.6570
12	0.0117	0.1165	0.2330	5.8254	0.0319	0.3192	0.6384	15.9601
10	0.0147	0.1469	0.2938	7.3452	0.0402	0.4025	0.8050	20.1239
8	0.0185	0.1853	0.3705	9.2633	0.0508	0.5076	1.0152	25.3788
6	0.0234	0.2336	0.4672	11.6800	0.0640	0.6400	1.2800	32.0000

Fiberglass Requirements

Wire Gauge	Circumference = 1 rev		RPM	Sglass		Total S Glass required (ft)			
	in	ft		in per ft	ft per foot	50000	500000	1000000	25000000
18	0.12661561	0.010551301	3609	18.9923	1.5827	79134.8	791347.6	1582695.1	39567377.7
16	0.15966014	0.013305011	2862	23.9490	1.9958	99787.6	997875.9	1995751.7	49893792.8
14	0.20132582	0.016777152	2270	30.1989	2.5166	125828.6	1258286.4	2516572.8	62914319.9
12	0.25386613	0.021155511	1800	38.0799	3.1733	158666.3	1586663.3	3173326.7	79333166.7
10	0.32009688	0.02667474	1428	48.0145	4.0012	200060.5	2000605.5	4001210.9	100030273.6
8	0.40368209	0.033640174	1132	60.5523	5.0460	252301.3	2523013.1	5046026.1	126150653.0
6	0.50900084	0.042416737	898	76.3501	6.3625	318125.5	3181255.3	6362510.5	159062763.0

Wire Gauge	Spools S Glass required, 15000yd/pound				20 Lb Spools S Glass			
	50000	500000	1000000	25000000	50000	500000	1000000	25000000
18	1.76	17.59	35.17	879.28	0.09	0.88	1.76	43.96
16	2.22	22.18	44.35	1108.75	0.11	1.11	2.22	55.44
14	2.80	27.96	55.92	1398.10	0.14	1.40	2.80	69.90
12	3.53	35.26	70.52	1762.96	0.18	1.76	3.53	88.15
10	4.45	44.46	88.92	2222.89	0.22	2.22	4.45	111.14
8	5.61	56.07	112.13	2803.35	0.28	2.80	5.61	140.17
6	7.07	70.69	141.39	3534.73	0.35	3.53	7.07	176.74

Appendix B. Process Modeling/Simulation

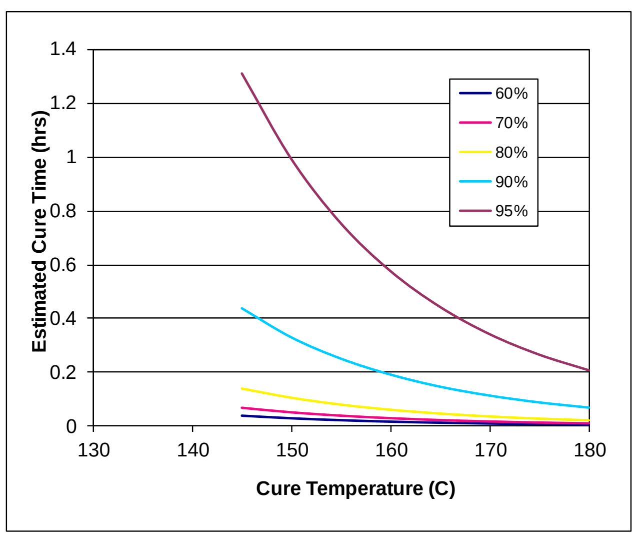
DSC Cure Analysis of CTD-1202X: Raw Data

Method Green resin analysis
Comment CTD-1202X uncured resin
Exotherm Up

Temperature	Conversion Time				
°C	60%	70%	80%	90%	95%
55	27.3	47.6	97.2	303	911
60	17.3	30.2	61.6	192	577
65	11.1	19.4	39.6	123	371
70	7.23	12.6	25.7	80.3	241
75	4.76	8.31	17	52.9	159
80	3.17	5.54	11.3	35.3	106
85	2.14	3.73	7.62	23.8	71.4
90	1.46	2.54	5.19	16.2	48.7
95	1	1.75	3.58	11.2	33.5
100	0.699	1.22	2.49	7.77	23.3
105	0.491	0.856	1.75	5.45	16.4
110	0.348	0.607	1.24	3.87	11.6
115	0.249	0.434	0.886	2.77	8.31
120	0.179	0.313	0.639	1.99	5.99
125	0.13	0.228	0.465	1.45	4.36
130	0.0956	0.167	0.341	1.06	3.19
135	0.0706	0.123	0.252	0.785	2.36
140	0.0526	0.0917	0.187	0.584	1.75
145	0.0394	0.0687	0.14	0.438	1.31
150	0.0297	0.0518	0.106	0.33	0.992
155	0.0226	0.0394	0.0804	0.251	0.753
160	0.0172	0.0301	0.0614	0.192	0.576
165	0.0133	0.0231	0.0472	0.147	0.443
170	0.0103	0.0179	0.0365	0.114	0.342
175	0.00798	0.0139	0.0284	0.0887	0.266
180	0.00624	0.0109	0.0222	0.0694	0.208

*Completed 01/26/05

Note: predicted cure times are typically over estimated by 15-20% by this model



Model 1

SUMMARY OUTPUT						
Regression Statistics						
Multiple R	0.999530191					
R Square	0.999060603					
Adjusted R Square	0.99904581					
Standard Error	0.097752182					
Observations	130					
ANOVA						
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	2	1290.623137	645.3115687	67533.07616	5.9692E-193	
Residual	127	1.213547107	0.009555489			
Total	129	1291.836685				
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	19.55640389	0.090259101	216.6696058	5.2535E-165	19.37779742	19.73501036
ln(1-α)	2.533672005	0.011336903	223.4888926	1.0369E-166	2.511238319	2.556105691
1/T	-9972.810988	34.18256674	-291.7513791	2.2044E-181	-10040.45212	-9905.169857
A	3.11E+08	1/s				
m	2.533672005					
R	8.314	J/mol*K				
Ea	82913.95055	J/mol				
	82.91395055	kJ/mol				
ρ	610.4976157	kg/m3				
Ar	2249.810441					

Model 2

SUMMARY OUTPUT						
Regression Statistics						
Multiple R	0.999928144					
R Square	0.999856293					
Adjusted R Square	0.999852872					
Standard Error	0.038384587					
Observations	130					
ANOVA						
	df	*SS*	*MS*	*F*	*Significance F*	
Regression	3	1291.651039	430.5503464	292220.1693	7.511E-242	
Residual	126	0.185645446	0.001473377			
Total	129	1291.836685				
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	20.09974007	0.040979371	490.4843487	1.3844E-208	20.0186431	20.18083704
ln(α)	0.483247971	0.018295789	26.41307148	3.29517E-53	0.447041143	0.519454799
ln(1-α)	2.763261844	0.009765925	282.9493247	1.6453E-178	2.743935366	2.782588322
1/T	-9972.810988	13.4225518	-742.9891974	2.6561E-231	-9999.373823	-9946.248152
A	5.36E+08	1/s				
	32163066534	1/min				
m	0.483247971					
n	2.763261844					
R	8.314	J/mol*K				
Ea	82913.95055	J/mol				
	82.91395055	kJ/mol				
ρ	610.4976157	kg/m3				
Ar	3.27E+11	kg/m3*s				

Model 3

A_two	3.00E+08
Ea_two	82913.95
A_one	7.40E+07
Ea_one	82000
m	0.437551097
n	2.524203203
Mean_of_y	0.001364318
df	124
SE_of_y	4.71026E-05
RSQ	0.999878429
Critical_t	1.979280117
CI	9.32292E-05

Model 4

A_two	4.78E+08
Ea_two	82913.95
A_one	1.17E+08
Ea_one	82800
m	0.870409824
n	2.639797313
C	6.139776139
alpha_c	0.98
Mean_of_y	0.001364318
df	124
SE_of_y	9.59064E-06
RSQ	0.99999496
Critical_t	1.979280117
CI	1.89826E-05

Appendix C. Equipment Design and Costing

Motor Requirements

Let-Off Motor (x2 for Take-UP)		
Weight of Spool	700	lb
Diameter of Spool	4	ft
Circum	12.56637	ft
wire haul rate	11.92	ft/min
Steady State RPM (ω)	0.948563	min^{-1}
Torque (T)	1400	lb-ft

$$HP = \frac{rpmxT}{5252}$$

HP	0.252854	
	0.18964	kW/spool motor
Total	0.379281	kW

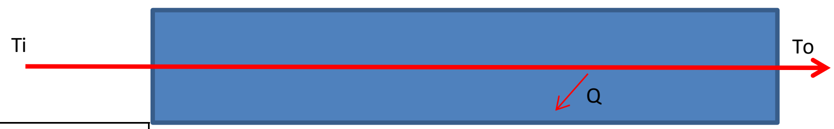
Taping Head Motor		
Spool Weight	20	lb
Head Diameter	16	inch
	1.333333	ft
RPM	1800	
T	13.33333	ft-lb
HP	4.569688	
	3.427266	kW

Extruder Motor		
HP	5	
	3.75	kW

Total Motor Power	7.56	kW

Water Bath

Heat Transfer Analysis and Design



Resin Properties	
T (C)	K (W/m*K)
200	0.48
27	0.4

Temperature Parameters		
Ti	To	Twater
175	45	32

Thermophysical properties of selected materials (Incropera et. al)		
Material	Cp(J/Kg*K)	K(W/m*K)
Copper	420	401
Epoxy composite	337	

Mass components of NanuQ wire	characteristic weight		weight/ft		Mass Frac	
Copper Mass	0.0198	lb/ft	0.009	kg/ft	0.990462533	
Resin	0.004764475	in^3/ft	0.086663753	g/ft	0.009537467	0.514497
			8.66638E-05	kg/ft		
Total			0.009086664	kg/ft		

Total weight	0.018537467	kg/ft	(99% Cu 1% resin)
m	0.003846524	kg/sec	
Total Cp	419.17	J/kg*K	
Q	209.6051886	W	

Wire haul velocity		
u	12.45 ft/min	3.79476 m/min
	0.2075 ft/sec	0.063246 m/sec

$$Re = \frac{uD}{\nu}$$

Reynold's # calcs		
D	0.0863081 in	0.007192342 ft
v	1.21E-05 ft^2/sec	
RE	1.23E+02 <	2300 (laminar flow)
SA	0.022595408 ft^2	0.002130747 m^2

EstimateHeat Transfer Coefficient (Rao et. Al, Design Data for Plastics Engineers, section 7.17 extrudate cooling)		
α	25.36579937 W/m^2*K	For water bath cooling
k	0.48 W/m*K	
R	0.001096113 m	

Biot Number	
$Bi = \frac{\alpha R}{K}$	
Bi	0.05792454

Fourrier Number	
$\theta = \frac{T - Tinfinity}{Ti - Tinfinity}$ = exp(-Bi*Fo)	
θ	0.090909091
Fo	41.3968808

Cooling Time and Length of Bath	
$t = \frac{FoLc^2}{a}$	
a	1.89E-06 m^2/s
t	2.63E+01 s
Length of bath	5.46E+00 ft

Cost Considerations for Cooling Bath

Dimensions of cooling bath		
L	5.46 ft	65.52 in
W	0.5 ft	6 in
H	0.5 ft	6 in

Material	S.S 316 plate with 1/4" thickness	
price S.S 316	$0.90	per lb
ρ	0.29	lb/in^3
Welding Cost	$100.00	per hr
Front Panel	(x2)	
V	18	in^3
Bottom/Side Panel	(x3)	
V	294.84	in^3
Total Volume S.S	312.84	in^3
Total Weight S.S	90.7236	lb
Total Metal Cost	$81.65	
Total labor	8	hrs
Total labor cost	$800.00	
Approximate Bath Cost	$881.65	

Utilities for Cooling Bath

Q	209.6052	W	
	0.209605	kW	
Estimate Cooling Rate			

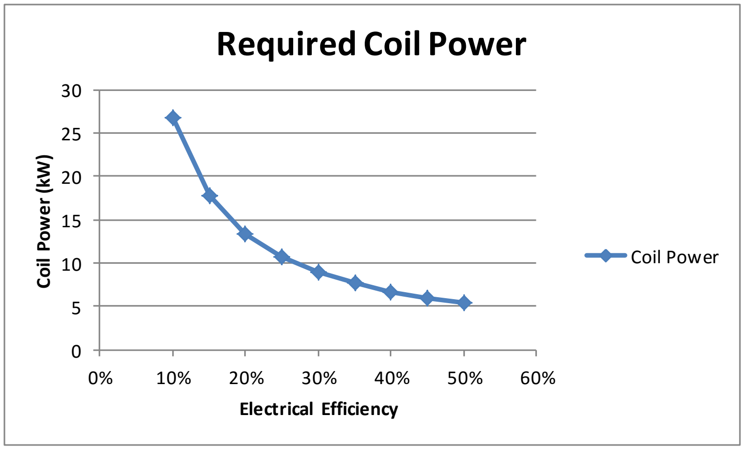
$$Q = mCpdT/dt$$

Tin	32	C	
Tout	33	C	(Estimated from minimum T approach heuristics)
P	1	atm	
Cost	$0.02	per kg	(cooling water)
Properties of Water (Elliot et. Al, Introductory Chemical Engineering Thermodynamics)			
Cp	4.187	kJ/kg*K	
	0.004187	J/Kg*K	
m	0.05006	kg/s	
cost	$0.00095	per sec	
	$3.42	per hour	
	$27.39	per day	

Induction Heating Coil

Induction Heating Coil Design

Theoretical Power Work Piece Power (Pw)		
Copper Work Piece		
Tin	25	C
Tout	175	C
weight copper	0.009	kg/ft
wire haul rate	11.9	ft/min
m	0.1071	kg/min
	0.001785	kg/sec
Coil Line distance	0.5	ft
Heating time	0.042017	min
Cp(copper)	420	J/kg*K
Pw= $mC_p dT/\mathrm{dt}$		
Pw	2676.429	W
	2.676429	kW



Theoretical Coil Power (Pc)		
Copper Induction Coil		
Calculate Electrical Efficiency		
$\eta_{el} = \dfrac{1}{1 + \dfrac{D1}{D2}\sqrt{\dfrac{\rho_1}{\rho_2 \mu_r}}}$		
μ_r	0.999994	
η_el	0.45	
η_th	1	
$P_c = \dfrac{P_w}{\eta_{th}\eta_{el}}$		
Pc	5.94762	kW

Heat Losses		
Conduction		
Tamb	25	C
Tmetal	175	C
K	0.48	W/m*K
Thickness	0.0055	in
	0.00014	m
Qloss	0.010058	W
Time	5	min
	300	Sec
Tfinal	174.9866	C

Screw Extruder

Screw Extruder	y	x	lo	hi	CE
y =584827.100409835*x+ 52369.3647540982000	Purchased Cost, $	Solids flow rate, kg/s	0.00	0.10	500
Vol Flow Rate	1.29E-01	cc/s			
Density	1.11	g/cc			
Mass Flow Rate	1.44E-04	kg/s			
Cost	$ 52,453.41				
Adjusted Cost	$ 58,328.19				
8 Hour Operation	$ 933,251.02	16	Lines		
24 Hour Operation	$ 349,969.13	6	Lines		

Pricing Quotes

SUPERIOR INDUCTION COMPANY

Induction Heating that is AFFORDABLE - PORTABLE - RELIABLE

QUOTATION

CUSTOMER:	COMPOSITE TECHNOLOGY DEVELOPMENT	DATE:	APRIL 12, 2011
LOCATION:	2600 CAMPUS DRIVE, SUITE D, LAFAYETTE, CO 80026	TOTAL PAGES:	2
CONTACT:	MARC LEBEL	FROM:	GARY REDKE
PHONE NO:	303-664-0394		PH: (818)244-4540
FAX NO:			FX: (866)332-3268
EMAIL:	MARC.LEBEL99@GMAIL.COM		EMAIL: SALES@SUPERIORINDUCTION.COM
REP:		QUOTATION NUMBER:	2011-0404

The technical or pricing information contained herein is proprietary to Superior Induction Co. Please do not disclose this information to any other party for any reason other than its original intent. Thank you for helping us protect our proprietary information.

Thank you for giving Superior Induction this opportunity to bid on your Induction equipment requirements. We are pleased to submit the following quotation for your review and consideration.

Item #	Part Number	Qty	Unit Price USD	Ship Date
1	Model SI-40KWLF	1	$24,875.00	3 weeks
Description:				

***Custom delivery options available.**

Superior Induction standard terms and conditions apply.

Warranty is one year parts and labor

Sales tax of 9.75% will be added to all orders inside California.

FOB is Pasadena, California.

Payment Options: 50% down when order is placed-50% balance due upon delivery, leasing arrangement, credit card, or wire transfer. Payment terms will be discussed with customer when order is placed.

Quotation Validity is 90 days on pricing and 30 days on delivery. STOCK QUOTATIONS VALID FOR 2 BUSINESS DAYS.

Our commitment to you:

- Provide the best customer support possible
- Provide the highest quality products and deliver on time!
- Call you within 24 hours of shipment to notify you that your order is on its way
- Drop Ship orders to other locations at no additional cost
- Provide prompt and reliable engineering and field application support when needed
- Provide fast turnaround on all warranty or non-warranty services, including a detailed Failure Analysis Report

We hope this quotation meets with your approval. If you have any questions or require additional information, please let us know. Thank you again for this opportunity.

Regards,

Superior Induction Company
557 Douglas St., Pasadena, CA 91104
TEL (818)244-4540 Fax (866)332-3268
Website: www.superiorinduction.com
Email: sales@superiorinduction.com

Item 1 - TPR267.1

10" Entwistle Concentric Taper,
3" ID with reeves drive & gear box.

Condition: As Is
Price Ex-Works Bristol, Connecticut..................................$7,500.00

Images:

Image 1 Image 2

Item 2 - TPR255

12" US Machinery Single Head Concentric Taper
Model LST1500, Serial Number: 64026
18" dual wheel capstan (1 flat).
Shaft is 13/16" od and 16" long
The motor control is in the taping/capstan controls.
30" Take up

Condition: As Is
Price Ex-Works Bonham, Texas..$18,500.00

Images:

Image 1 Image 2 Image 3

Item 3 - TPR149

Pourtier 16" Concentric Taping Head
Suitable for tape pads of up to 16" outside diameter
Line shaft driven
Transmission
Change gear box
Spare tape pad magazine
Full machine enclosure
Inspection window
Left to right direction of wire travel

Condition: As Is
Price Ex-Works New Haven, Connecticut...........................$14,500.00

Images:

Image 1 Image 2 Image 3

Unit Cost Summary and Scaling

Unit Costs	Cost/One Line	Cost/16 Lines	Cost/6 Lines
Taping Heads	$ 14,500.00	$ 232,000.00	$ 87,000.00
Screw Extruder	$ 58,328.19	$ 933,251.02	$ 349,969.13
Induction Heating Coils	$ 24,875.00	$ 398,000.00	$ 149,250.00
Water Baths	$ 900.00	$ 14,400.00	$ 5,400.00

Appendix D. Economic Analysis

Operators

8 Hours	
16	lines
1	operator per line
7	days per week
1	shift per day
5	shifts per operator per week
22.4	
24 Hours	
6	lines
1	operator per line
7	days per week
3	shifts er day
5	shifts per operator per week
25.2	

Economic and Profitability Summary

Economic Summary	8-Hour Days	24-Hour Days
Equipment - Direct Installed Costs	$2,889K	$1,081K
Total Permanent Investment	$3,600K	$1,400K
Working Capital	$299K	$244K
Variable Costs (per year)	$2,545K	$2,545K
Fixed Costs (per year)	$1,883K	$2.088K

Profitability Summary	8-Hour Days	24-Hour Days
Selling Price (per foot)	$0.22	$0.20
Return on Investment	19.80%	19.40%
Payback Period	5.0 years	5.2 years
Net Present Value (end of period)	$4,657K	$2,187K
Net Present Value (start of period)	$4,857K	$2,286K
Investor's Rate of Return	16%	16%
Total Net Income	$12,426K	$6,019K

Economic Analysis 8 Hour Base

Venture Guidance Appraisal: 8-Hr

	=User Input		=Calc by Computer		
Title:	NanuQ Economic Feasiblity Study		Date:	4/26/11	
Product	NanuQ Wire				
Units of Capacity		Component			
Operating Hours per Year		2,920			
Capacity:	25,000,000	Component per Year	Site:	US Southeast	
Capacity:	8,562	Component per Hour			

Enter cost of Land into cell B22 on Cash Flow sheet.

				Item Cost ($k)	Subtotal ($k)
Bare Module Cost (BMC)/Direct Installed Cost (DIC)					
Engineered Equipment/Purchased					
	Taping Heads			232	
	Screw Extruders			933	
	Induction Heating Coils			398	
	Water Baths			14	
Total Engineered Equipment/Purchased&Delivered				1,577	
Misc Equipment		10%		158	
	Subtotal/Purchased Equipment&Delivered				1,735
Field Mtl/Labor/Insulation					
Field Erected Equipment					
Equip Fdns,Sppts, Platforms					
	Installed Equipment				1,735
Factored Piping					
Factored Instruments		9%		156	
Factored Electrical		7%		121	
Identified Piping					
Identified Instruments					
Identified Electrical					
	Subtotal/Direct Installed Cost				2,013
Labor/Material Split		40%	L 60% M		
Freight, Quality Assurance, Sales Taxes		12%	of Matl	145	
Contractor Labor Distributives		44%	of Labor	354	
	Subtotal (Direct Installed Cost + Indirect Freight, QA, Taxes, & Overhead)				2,512
Engg+Home Office (Additional Indirect)		15%	of Total	377	
	Subtotal (DIC Equipment Calculated from Bare Module using PE)				2,889

PE with FBM factors	PE	FBM		
Equipment at Bare Module Level	Cost	Factor		
Subtotal (DIC from Total Bare Module Cost w/FBM Factors)				
Misc. Equipment	10%			
Subtotal (DIC Equipment from Bare Module Costs)				2,889
Subtotal (DIC Equipment Costs)..				2,889
Buildings, Structure				
Subtotal				2,889
Power, General, & Services (PG&S)	2%		58	
Dismantling & Rearranging (D&R)	2%		58	
Site Development				
Subtotal (DPI)				3,004
Contingency	15%		451	
Subtotal				3,455
Working Conditions		of Labor		
Net Total				3,455
Minor Changes				
Direct total				3,455
Field Indirects		of Total		
Spares & Portables				
Total Equipment				3,455
				EQUIP
Total (Current $$, USGC)				3,455
Site Factor	100%	of USGC Total		3,455
Inflation	1.9%	for 2.0 yrs		3,588
Scope Growth				
Total Project-Level Cost				3,588
			SAY	3,600
GRAND TOTAL (TPI)			$	**3,600** k

Working Capital: 8-Hr

Start-up Raw Materials Inventory

	Quantity	Units	Price			
Resin	397	lb	66.75	/lb	$26	k
Copper	41,255	lb	4.35	/lb	$179	k
S-Glass	147	lb	20.00	/lb	$3	k
				/		k
				Total	$209	k

Start-up Spare Parts:	2.5%	of Investment	$90	k

TOTAL WORKING CAPITAL.. $299

Site factor table	
US Gulf Coast	1.00
US Southeast	0.95
US Northeast	1.10
US Midwest	1.15
US West Coast	1.25
Western Europe	1.20
Mexico	0.95
Japan	1.15
Pacific Rim	1.00
India	0.85

Operating Cost Estimate Variable Cost: 8-Hr

	=USER INPUT		=CALC BY COMPUTER			
PRODUCT:	NanuQ Wire					
ANNUAL CAPACITY:	25,000,000	ıponent per Year				
INGREDIENTS:	UNIT OF MEASURE	COST PER UNIT ($)	UNITS OF INGRED/ ıponent PRODUCT	COST PER Component of PRODUCT ($)		
Resin	lb	66.75	0.00019	0.013		
Copper	lb	4.35	0.02	0.086		
S-Glass	lb	20.00	0.0001	0.001		
SUBTOTAL INGREDIENTS					0.100	
UTILITIES:						
HP STEAM	lb					
LP STEAM	lb					
PROCESS WATER						
COOLING WATER	kg	0.000019	0.339	0.0000		
INERT GAS	CF					
ELECTRICITY	kWh	0.06	0.03	0.002		
COMPRESSED AIR	CF					
BOILER FEEDWATER	lb					
WASTE TREATMENT						
SUBTOTAL UTILITIES					0.002	
CATALYSTS & CHEMICALS						
CATALYST	mg					
CHEMICAL 1						
CHEMICAL 2						
CHEMICAL 3						
SUBTOTAL CATALYSTS & CHEMICALS						
PACKAGING MATERIALS						
PACKAGING LABOR						
BYPRODUCT CREDIT	MMBtu					
OTHER VARIABLE COSTS						
TOTAL VARIABLE COST					$0.102	per Component
					$2,545	k per Year

Operating Cost Estimate Fixed Cost: 8-Hr

	=USER INPUT	=CALC BY COMPUTER		
PRODUCT:				
ANNUAL AnnCap:	25,000,000	nponent per Year		
TOTAL INVESTMENT (TPI):	$3,600	k		
OPERATING LABOR & BENEFITS:			ANNUAL COST ($k/yr)	
NO. of OPERATORS:	23			
ANNUAL WAGES	$30	k PER OPERATOR	690	
EMPL. BENEFITS @	40.0%	of WAGES	276	
OPERATING SUPERVISION @		of WAGES		
SUBTOTAL OPERATING LABOR:				966
OPERATING SUPPLIES:		of WAGES		
MAINTENANCE:				
TOTAL MAINTENANCE @		OF INVESTMENT		
MAINTENANCE LABOR@		of TOTAL MAINT.		
MAINTENANCE MATERIAL @		of TOTAL MAINT.		
OVERHEAD:				
GEN. OH @	125.0%	of (OPR. WAGES + MAINT LABOR + OPR. SUPRV.)		863
LAB &TECHNICAL SUPPORT @		of INVESTMENT		
CORPORATE OVERHEAD:				
SALES & ADMINISTRATION		of INVESTMENT		
RESEARCH & DEVELOPMNT		of INVESTMENT		
SUBTOTAL CORPORATE OVERHEAD..				
INSURANCE & LOCAL TAXES:				
	1.5%	of INVESTMENT		54
ROYALTIES:		per annual Component of Capacity		
TOTAL FIXED COST (for cash flow calculations):			$	1,883 k per Year
				$0.08 per Component
DEPRECIATION:				
		of INVESTMENT		
Note: Do not include Depreciation if total Fixed Cost is to be used in Cash Flow Calc.				
TOTAL FIXED COST (for ROI calculations):			$	1,883 k per Year
				$0.08 per Com

Cash Flow Analysis: 8-Hr

USER INPUT
INCOME
OPERATING COST
CAPITAL COST
SOLVED BY MACRO / USER

ALL FIGURES ARE IN $k

Sensitivity Analysis can be performed by pressing the Sensitivity Analysis button. A dialog box allows the user to select various options. For the Sensitivity Analysis Macro, X variables should be cells set by the user (yellow or blue). Y variables should be chosen to be calculated values or values solved by the worksheet (aqua or blue). Selling Price can be an X variable or a Y variable.
The Set Selling Price macro will break down if an unfeasible target value is entered.

Sensitivity

Set Selling Price

Macros created by Jeremiah Zartman.
Modified 6/15/04

COST OF CAPITAL = 4.5%
TOTAL CAPITAL COST = $3,600 k
SELLING PRICE = $0.22 per Unit
SALVAGE PERCENT= 0%
SALVAGE VALUE= 0

INFLATION = 1.9% ANNUALLY (Applies to all costs)
INFLATION = 1.9% ANNUALLY(Applies to selling price of product)
INCOME IS +, EXPENSES ARE -

Total Replacement Cost Factor 0.0125 %
First year Replacement factor 0.03 %

	DESIGN	CONSTRUCTION		STARTUP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
% OF CAPACITY	0%	2%	4%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
INCOME		108	216	5395	5498	5602	5709	5817	5928	6040	6155	6272	6391	6513	6636	6762	6891	7022	7155	7291
SALVAGE VALUE																		0	0	0
VARIABLE COST		-51	-102	-2545	-2593	-2643	-2693	-2744	-2796	-2849	-2903	-2959	-3015	-3072	-3130	-3190	-3251	-3312	-3375	-3439
FIXED COST		-1883	-1883	-1883	-1918	-1955	-1992	-2030	-2068	-2108	-2148	-2188	-2230	-2272	-2316	-2360	-2404	-2450	-2497	-2544
DEPRECIATION		-720	-720	-720	-1174	-728	-476	-478	-232	-50	-48	-49	-50	-51	-52	-53	-54	-211	-215	-219
CAPITAL COST	-360	-1188	-2052	-108	-45	-46	-47	-48	-49	-49	-50	-51	-52	-53	-54	-55	-56	-57	-59	-60
LAND																				
WORKING CAPITAL			-299															0	0	412
ACTS RECEIVABLE	45			-729	-14	-14	-14	-15	-15	-15	-16	-16	-16	-16	-17	-17	-17	-18	-18	-18
STARTUP COST			-108	-432																
GROSS INCOME			-108	-184	-187	277	548	566	832	1033	1056	1076	1097	1118	1139	1160	1183	1048	1068	1089
INCOME TAX	6.0%		6	11	11	-17	-33	-34	-50	-62	-63	-65	-66	-67	-68	-70	-71	-63	-64	-65
DEPRECIATION				720	1174	728	476	478	232	50	48	49	50	51	52	53	54	211	215	219
NET CASH FLOW	-360	-1188	-2452	-290	939	928	930	947	950	957	975	993	1012	1031	1051	1071	1091	1121	1143	1576

NPV = $4,657 k (Cash flows at end of each period)
NPV = $4,867 k (Cash flows at beginning of each period)

GUESS = 16.0% NPV = 0 SET BY MACRO ($0.00)
AFTER - TAX REAL IRR = 16.0%
TARGET= 16.0%

DEPRECIATION RATES (HALF-YEAR CONVENTION)

YEAR1	20%
YEAR2	32%
YEAR3	19%
YEAR4	12%
YEAR5	12%
YEAR6	5%

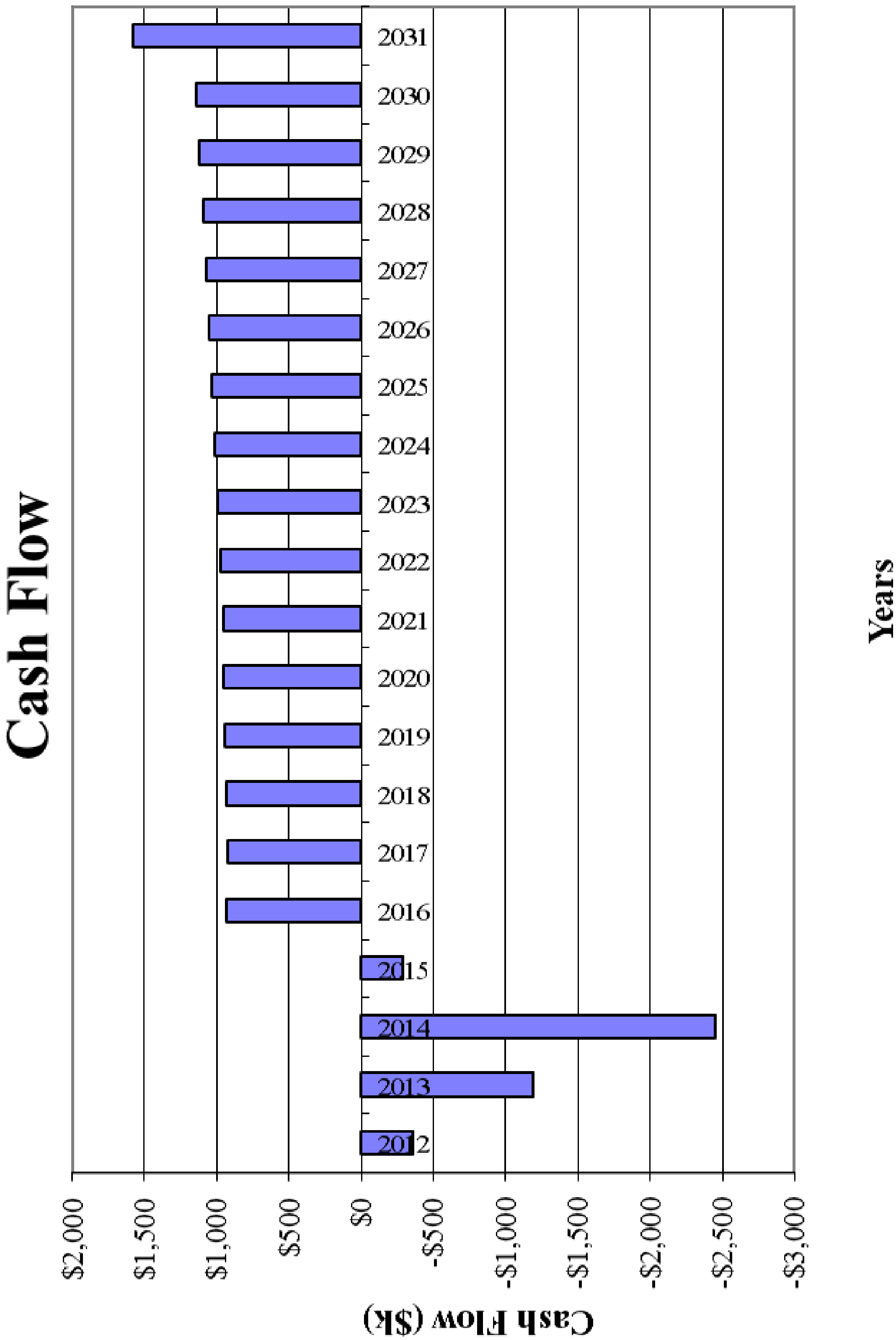
ROI CALCULATION

Third year income	5,602	$k/yr
Third year variable cost	-2,643	
Third year fixed cost	-1,955	
Gross income	1,005	
Income Tax	-60	
Net Income	945	
Capital Investment (incl. Working Cap.)	4,765	$k/yr

ROI = 19.8%

PAYBACK PERIOD = 5.0 Years

Cash Chart: 8-Hr



Economic Analysis 24 Hour Base

Venture Guidance Appraisal: 24-Hr

	(yellow) =User Input		(cyan) =Calc by Computer		
Title:	NanuQ Economic Feasiblity Study		Date:	4/26/11	
Product	NanuQ Wire				
Units of Capacity		Component			
Operating Hours per Year		8,000			
Capacity:	25,000,000	Component per Year	Site:	US Southeast	
Capacity:	3,125	Component per Hour			

Enter cost of Land into cell B22 on Cash Flow sheet.

			Item Cost ($k)	Subtotal ($k)
Bare Module Cost (BMC)/Direct Installed Cost (DIC)				
Engineered Equipment/Purchased				
	Taping Heads		87	
	Screw Extruders		349	
	Induction Heating Coils		149	
	Water Baths		5	
Total Engineered Equipment/Purchased&Delivered			590	
Misc Equipment		10%	59	
	Subtotal/Purchased Equipment&Delivered			649
Field Mtl/Labor/Insulation				
Field Erected Equipment				
Equip Fdns,Sppts, Platforms				
	Installed Equipment			649
Factored Piping				
Factored Instruments		9%	58	
Factored Electrical		7%	45	
Identified Piping				
Identified Instruments				
Identified Electrical				
	Subtotal/Direct Installed Cost			753
Labor/Material Split		40% L, 60% M		
Freight, Quality Assurance, Sales Taxes		12% of Matl	54	
Contractor Labor Distributives		44% of Labor	133	
	Subtotal (Direct Installed Cost + Indirect Freight, QA, Taxes, & Overhead)			940
Engg+Home Office (Additional Indirect)		15% of Total	141	
	Subtotal (DIC Equipment Calculated from Bare Module using PE)			1,081

PE with FBM factors	PE	FBM		
Equipment at Bare Module Level	Cost	Factor		
Subtotal (DIC from Total Bare Module Cost w/FBM Factors)				
Misc. Equipment	10%			
Subtotal (DIC Equipment from Bare Module Costs)				1,081
Subtotal (DIC Equipment Costs)..				1,081
Buildings, Structure				
Subtotal				1,081
Power, General, & Services (PG&S)	2%		22	
Dismantling & Rearranging (D&R)	2%		22	
Site Development				
Subtotal (DPI)				1,124
Contingency	15%		169	
Subtotal				1,293
Working Conditions		of Labor		
Net Total				1,293
Minor Changes				
Direct total				1,293
Field Indirects		of Total		
Spares & Portables				
Total Equipment				1,293
				EQUIP
Total (Current $$, USGC)				1,293
Site Factor	100%	of USGC Total		1,293
Inflation	1.9%	for 2.0 yrs		1,343
Scope Growth				
Total Project-Level Cost				1,343
			SAY	1,400
GRAND TOTAL (TPI)				$ **1,400** k

Working Capital: 24-Hr

Start-up Raw Materials Inventory

	Quantity	Units	Price			
Resin	397	lb	66.75	/lb	$26	k
Copper	41,225	lb	4.35	/lb	$179	k
S-Glass	147	lb	20.00	/lb	$3	k
				/		k
				Total	$209	k

Start-up Spare Parts:	2.5%	of Investment	$35	k

TOTAL WORKING CAPITAL... $244

Site factor table	
US Gulf Coast	1.00
US Southeast	0.95
US Northeast	1.10
US Midwest	1.15
US West Coast	1.25
Western Europe	1.20
Mexico	0.95
Japan	1.15
Pacific Rim	1.00
India	0.85

Operating Cost Estimate Variable Cost: 24-Hr

	=USER INPUT	=CALC BY COMPUTER

PRODUCT: NanuQ Wire

ANNUAL CAPACITY: 25,000,000 ıponent per Year

INGREDIENTS:	UNIT OF MEASURE	COST PER UNIT ($)	UNITS OF INGRED/ ıponent PRODUCT	COST PER Component of PRODUCT ($)	
Resin	lb	66.75	0.00019	0.013	
Copper	lb	4.35	0.02	0.086	
S-Glass	lb	20.00	0.0001	0.001	
SUBTOTAL INGREDIENTS					0.100
UTILITIES:					
HP STEAM	lb				
LP STEAM	lb				
PROCESS WATER					
COOLING WATER	kg	0.000019	0.339	0.0000	
INERT GAS	CF				
ELECTRICITY	kWh	0.06	0.03	0.002	
COMPRESSED AIR	CF				
BOILER FEEDWATER	lb				
WASTE TREATMENT					
SUBTOTAL UTILITIES					0.002
CATALYSTS & CHEMICALS					
CATALYST	mg				
CHEMICAL 1					
CHEMICAL 2					
CHEMICAL 3					
SUBTOTAL CATALYSTS & CHEMICALS					
PACKAGING MATERIALS					
PACKAGING LABOR					
BYPRODUCT CREDIT	MMBtu				
OTHER VARIABLE COSTS					
TOTAL VARIABLE COST					$0.102 per Component
					$2,545 k per Year

Operating Cost Estimate Fixed Cost: 24-Hr

	[yellow] =USER INPUT	[cyan] =CALC BY COMPUTER		
PRODUCT:				
ANNUAL AnnCap:	25,000,000	nponent per Year		
TOTAL INVESTMENT (TPI):	$1,400	k		
OPERATING LABOR & BENEFITS:			ANNUAL COST ($k/yr)	
NO. of OPERATORS:	26			
ANNUAL WAGES	$30	k PER OPERATOR	780	
EMPL. BENEFITS @	40.0%	of WAGES	312	
OPERATING SUPERVISION @		of WAGES		
SUBTOTAL OPERATING LABOR:				1,092
OPERATING SUPPLIES:		of WAGES		
MAINTENANCE:				
TOTAL MAINTENANCE @		OF INVESTMENT		
MAINTENANCE LABOR@		of TOTAL MAINT.		
MAINTENANCE MATERIAL @		of TOTAL MAINT.		
OVERHEAD:				
GEN. OH @	125.0%	of (OPR. WAGES + MAINT LABOR + OPR. SUPRV.)		975
LAB &TECHNICAL SUPPORT @		of INVESTMENT		
CORPORATE OVERHEAD:				
SALES & ADMINISTRATION		of INVESTMENT		
RESEARCH & DEVELOPMNT		of INVESTMENT		
SUBTOTAL CORPORATE OVERHEAD..				
INSURANCE & LOCAL TAXES:				
	1.5%	of INVESTMENT		21
ROYALTIES:		per annual Component of Capacity		
TOTAL FIXED COST (for cash flow calculations):			$	2,088 k per Year
				$0.08 per Component
DEPRECIATION:				
		of INVESTMENT		
Note: Do not include Depreciation if total Fixed Cost is to be used in Cash Flow Calc.				
TOTAL FIXED COST (for ROI calculations):			$	2,088 k per Year
				$0.08 per Com

ALL FIGURES ARE IN $k

USER INPUT
INCOME
OPERATING COST
CAPITAL COST
SOLVED BY MACRO / USER

Sensitivity Analysis can be performed by pressing the Sensitivity Analysis button. A dialog box allows the user to select various options. For the Sensitivity Analysis Macro, X variables should be cells set by the user (yellow or blue). Y variables should be chosen to be calculated values or values solved by the worksheet (aqua or blue). Selling Price can be an X variable or a Y variable.
The Set Selling Price macro will break down if an unfeasible target value is entered.

Sensitivity

Set Selling Price

COST OF CAPITAL = 4.5%
TOTAL CAPITAL COST = $1,400 k
SELLING PRICE = $0.20 per Unit
SALVAGE PERCENT= 0%
SALVAGE VALUE= 0

INFLATION = 1.9% ANNUALLY (Applies to all costs)
INFLATION = 1.9% ANNUALLY(Applies to selling price of product)
INCOME IS +, EXPENSES ARE -

Macros created by Jeremiah Zartman.
Modified 6/15/04

Total Replacement Cost Factor 0.0125 %
First year Replacement factor 0.03 %

	DESIGN	CONSTRUCTION		STARTUP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
% OF CAPACITY	0%	6%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
INCOME		306	5100	5100	5197	5295	5396	5499	5603	5710	5818	5929	6041	6156	6273	6392	6514	6637	6763	6892
SALVAGE VALUE																		0	0	0
VARIABLE COST		-153	-2545	-2545	-2593	-2643	-2693	-2744	-2796	-2849	-2903	-2959	-3015	-3072	-3130	-3190	-3251	-3312	-3375	-3439
FIXED COST		-2088	-2088	-2088	-2128	-2168	-2209	-2251	-2294	-2338	-2382	-2427	-2473	-2520	-2568	-2617	-2667	-2717	-2769	-2822
DEPRECIATION		-280	-280	-280	-456	-283	-185	-186	-90	-19	-19	-19	-19	-20	-20	-20	-21	-82	-84	-85
CAPITAL COST	-140	-462	-798	-42	-18	-18	-18	-19	-19	-19	-20	-20	-20	-21	-21	-22	-22	-22	-23	-23
LAND																				
WORKING CAPITAL			-244															0	0	336
ACTS RECEIVABLE	45			-689	-13	-13	-14	-14	-14	-14	-15	-15	-15	-16	-16	-16	-16	-17	-17	-17
STARTUP COST			-42	-168																
GROSS INCOME			-42	19	19	202	309	318	423	503	514	524	534	544	554	565	575	525	535	546
INCOME TAX	6.0%		3	-1	-1	-12	-19	-19	-25	-30	-31	-31	-32	-33	-33	-34	-35	-32	-32	-33
DEPRECIATION				280	456	283	185	186	90	19	19	19	19	20	20	20	21	82	84	85
NET CASH FLOW	-140	-462	-1081	-433	444	441	444	452	455	459	467	476	485	495	504	514	523	537	547	893

NPV = $2,187 k (Cash flows at end of each period)
NPV = $2,286 k (Cash flows at beginning of each period)

GUESS = 16.0% NPV = 0 SET BY MACRO ($0.00)
AFTER - TAX REAL IRR = 16.0%
TARGET= 16.0%

DEPRECIATION RATES (HALF-YEAR CONVENTION)

YEAR1	20%
YEAR2	32%
YEAR3	19%
YEAR4	12%
YEAR5	12%
YEAR6	5%

ROI CALCULATION

Third year income	5,295	$k/yr
Third year variable cost	-2,643	
Third year fixed cost	-2,168	
Gross income	485	
Income Tax	-29	
Net Income	456	
Capital Investment (incl. Working Cap.)	2,347	$k/yr

ROI = 19.4%

PAYBACK PERIOD = 5.2 Years

Cash Chart: 24-Hr

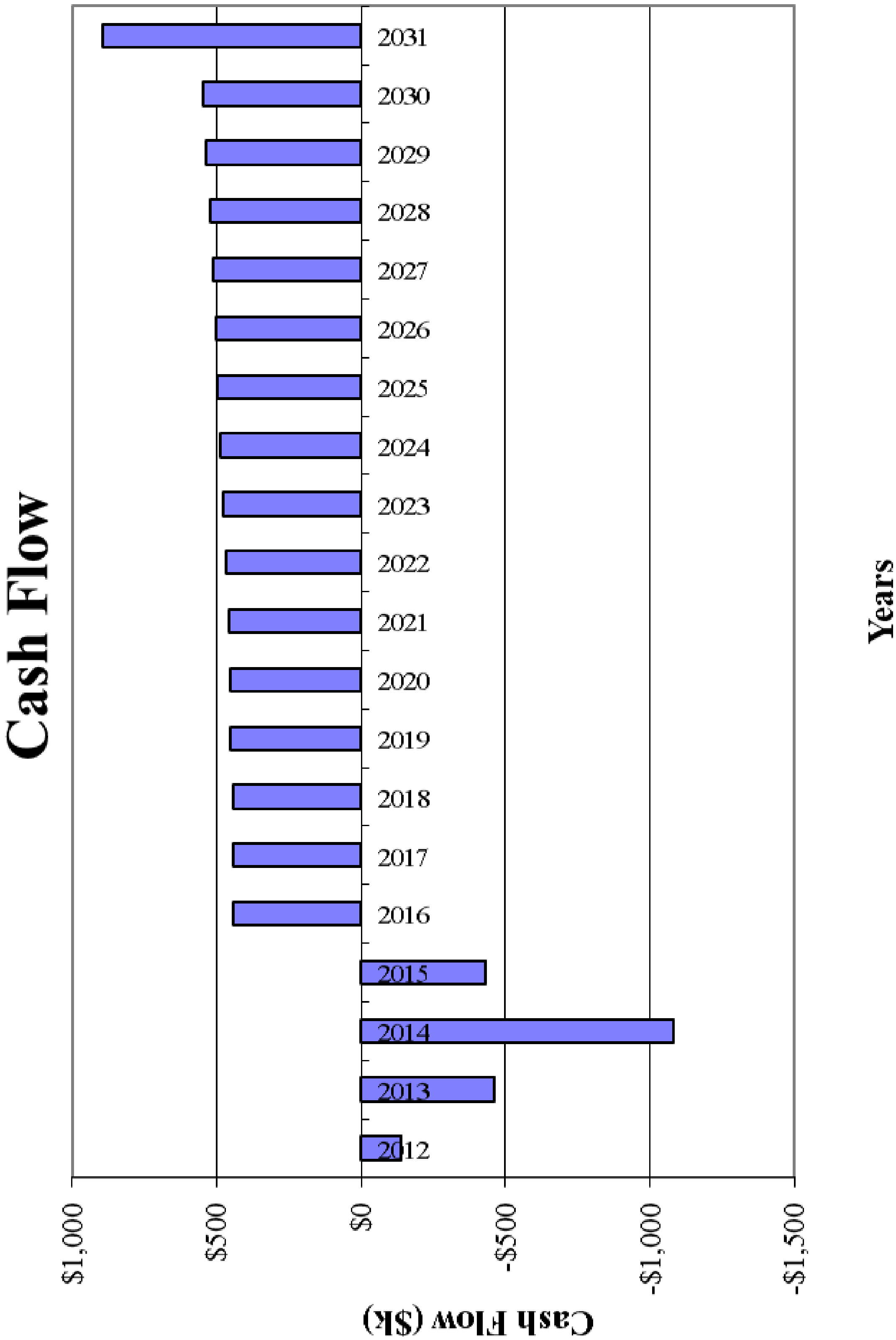


Table of Cost Definitions Utilized in Producing Economic Analysis (61)

Capital cost	The cost of obtaining capital expressed as an interest rate.
Depreciated cost	A noncash tax expense deduction for recovery of fixed capital from investments whose economic value is gradually consumed in the business operation.
Detailed cost	The value of the detailed estimate obtained with almost complete disclosure of engineering design data using various methods of estimating.
Direct cost	Cost traceable to a unit of output, such as direct labor costs or direct materials costs.
Direct labor cost	The labor cost of actually producing goods or services.
Direct materials cost	The cost of raw or semifinished materials that can be traced directly to an operation, product, project, or system design.
Engineering cost	The total of all costs incurred in a design to produce complete drawings and specifications or reports; included are the costs, salaries, and overhead for engineering administration, drafting, reproductions, cost engineering, purchasing and construction, costs of prototype, and design costs.
Estimated costs	Predetermined value of cost using rational methods.
Fixed cost	Costs that are independent of output.
Future cost	Costs to be incurred at a future date.
Historical cost	A tabulated cost of actual cash payments consistently recorded.
Indirect cost	That cost not clearly traceable to a unit of output or segment of a business operation, such as indirect labor costs and indirect materials costs.
Joint cost	Exists whenever, from a single source, material, or process, there are produced units of goods having varying unit values.
Manufacturing overhead cost	This includes all production costs, except direct labor and direct materials.
Marginal/incremental cost	The added cost of making one additional unit for an operation or product without additional fixed cost.
Measured cost	A cost based on time relationships to dollars using mathematical rules.
Operating cost	This comprises two distinct cost elements, direct labor and direct materials.
Operation cost	This includes labor, materials, asset value consumed, and appropriate overhead cost pursuant to the operation design.
Opportunity cost	The estimated dollar advantage foregone by undertaking one alternative instead of another.
Optimum cost	That operation, product, project, or system economic value for which a minimum (or maximum as appropriate) is uncovered for specified design variables using variational methods.
Period cost	Cost associated with a time period.
Policy cost	A cost based on the action of others; considered fixed for the purpose of estimating.
Preliminary cost	The value of a preliminary operation, product, project, or system design estimate; usually obtained quickly with a shortage of information.
Prime cost	The total of labor and materials directly traceable to a unit of output.
Product cost	Includes operation costs, purchase materials, overhead, general and administrative expenses, and appropriate design and selling costs.
Project cost	The investment or capital cost proposed for approval in a single evaluation of an engineered project.
Replacement cost	A present cost of the design equipment or facility intended to take the place of an existing design of equipment or facility.
Standard cost	Normal predetermined cost computed on the basis of past performance, estimates, or work measurement.
Sunk cost	The past or continuing cost related to past decisions that are unrecoverable by current or future decisions.
System cost	Usually a hypothetical cost for the evaluation of complex alternatives. It may include elements of operation, product, or project costs.
Unit cost	This implies, in manufacturing, the sum of total material, labor, and manufacturing overhead divided by the quantity produced; for an investment, it is the installed cost of the producing unit in convenient units of production.
Variable cost	The cost that varies in proportion to the rate of output.

Appendix E. Team Organization and Timeline

Table 24: Projected Tasks and Expected Completion Times

Organizational Gantt Chart													
#	**Task**	**February**				**March**				**April**			
1	**Pilot scale specs**												
1a	- number of spools of fiberglass required on winding head			X									
1b	- length of heater			X									
1c	- wrap rate			X									
1d	- volume of resin			X									
1e	- length of glass fiber			X									
2	**Pre-production scale specs**												
2a	- number of spools of fiberglass required on winding head				X								
2b	- length of heater				X								
2c	- wrap rate				X								
2d	- volume of resin				X								
2e	- length of glass fiber				X								
3	**Production scale specs**												
3a	- number of spools of fiberglass required on winding head					X							
3b	- length of heater					X							
3c	- wrap rate					X							
3d	- volume of resin					X							
3e	- length of glass fiber					X							
4	**Economics**												
4a	- Pricing of S-glass fiber per condition						X						
4b	- Pricing of resin per condition						X						
4c	- Heater temp vs cure time analysis							X					
4d	- Product cost for profitability								X				
5	**Presentation #1**												
5a	- Prepare powerpoint	X											
5b	- Practice and deliver		X										
6	**Presentation #2**												
6a	- Prepare powerpoint										X		
6b	- Practice and deliver											X	
7	**Write up report**												
7a	- Compile and write									X	X	X	
7b	- Edit and complete												X
7c	- Print and bind												X
7d	- Deliver April 29th, 5pm												X