N-Dimensional Engineering

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Shell Energy Proposal (2015)

Executive Summary

Over 25 trillion KWh of energy was consumed in the US in 2014 [U.S. Energy Information Administration / Monthly Energy Review July 2015], and over half of it was dissipated into waste heat [Smart Grid and Consumers, SBI Energy]. At $0.07 per KWh, the average for industrial consumers [US Department of Energy, eia], over $1 trillion of waste heat is lost each year in the US alone. Much of that heat is lost through industrial chimneys in refineries. A smoke stack that can convert the waste heat into electricity has great value, due to the savings over the period of operation. Heat that is given off as waste can be recovered and converted directly into electricity via thermoelectric materials, relying on the temperature difference between one side and the other to create a thermal voltage which drives a current in a device to produce power. Figure 1 shows a basic schematic of a thermoelectric generator (TEG). Until recently, thermoelectric efficiency has not been high enough to be commercially viable.

Earlier this year, however, we published calculations of a PbTe/SnTe (PST) nanoscaled superlattice (SL) which showed an efficiency higher than any yet achieved in a lab [2]. Figure 2 shows the efficiency of our material, in terms of percentage of heat which can be converted directly into electricity, over a range of temperatures. Since SLs are not practical for production of thermoelectric devices, we propose to use a sintered mixture of PbTe and SnTe nanoparticles of the correct size to achieve a three-dimensional analogue of the predicted high efficiency SL. Along with our thermoelectric ingots, we are developing heat capture and release technology. Modeling has shown that aluminum is not only much more cost effective but gives very near the heat conducting efficiency of copper.

Further modeling has shown that 250 thermoelectric generators (TEGs) can be incorporated within a 40 meter industrial chimney for a modest raw material cost of $60,000, generating approximately 12 million kWh of electricity per year. At 7 cents per kWh, a typical industrial price in steel refinery laden Pittsburg, this amount of energy equates to over $83 thousand per year. Selling each TEG for $640, 250 will sell for $160,000, saving the customer approximately $89,000 in the first three years. The three year maintenance schedule will include replacement of the PST at the end of the term, for reasonable fee, such that the customer continues to save money over the course of the TEG lifetime.

In order to commercialize the technology, we need funding to acquire the equipment necessary for research, development, and production. We require a phase one award of $400,000 for the first six months of operation, covering the cost of a spark plasma sintering system, mortar grinder, and metal smelting and molding equipment, along with general operating expenses. We will require a phase two

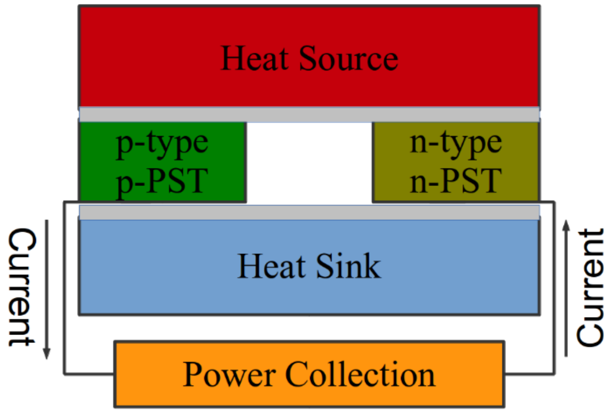

Figure 1. Schematic of a thermoelectric device. The voltage between the heat source and sink for the p-type side is opposite that of the n-type side, which drives a current through the wire for power generation. The grey regions represent electrically insulating thermally conducting regions of mica sheets.

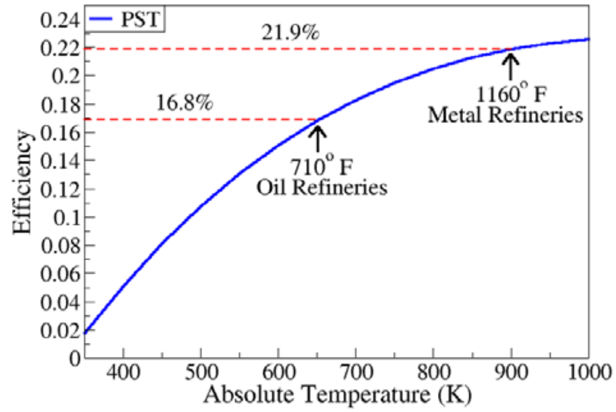

Figure 2. Theoretical efficiency of bulk n-type PST. For comparison, a modern combustion engine is limited to about 0.35. It is clear that PST has a wide range of applicable temperatures to create value for industrial consumers. The arrows indicate efficiencies of 16.8% and 21.9%, at 710 F and 1160 F, for exhaust systems at oil and metal refineries, respectively.

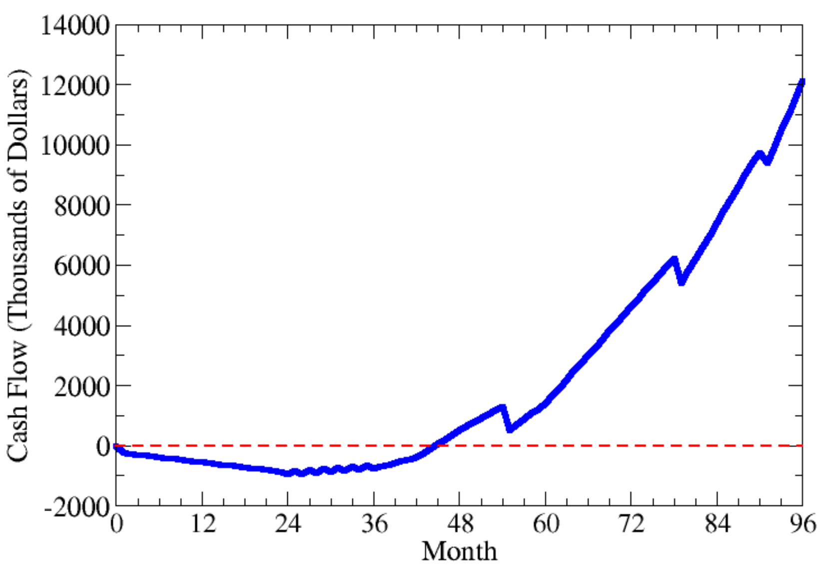

Figure 3. Eight year cash flow projections. We predict to become cash flow positive by the second half of the fourth year.

award of $750,000, so that we will become cash-flow sufficient in the middle of the fourth year. We estimate revenue exceeding $12 million in the eighth year of operation. For cash-flow estimates, see Figure 3.

Description and Status of the Technology

Efficiency of a bulk thermoelectric material is generally measured by the figure of merit, zT:

$$ZT = \frac{S^2\sigma}{\lambda_e + \lambda_l} T, \qquad (1)$$

where Z is a dimensionless constant, T is absolute temperature, S is the Seebeck coefficient, σ is electrical conductivity, λ_e is the electronic contribution to thermal conductivity, and λ_l is the lattice contribution to thermal conductivity. To increase ZT, one must either increase S, increase σ, or decrease the total thermal conductivity. With conventional materials, enhancing one parameter affects another, such that ZT is not significantly improved. However, successful recent approaches inhibit thermal conductivity by introducing anisotropy in the material. We will employ this strategy for the ingots used in our devices. The highest reported measured value of zT is 2.6 in 2014 [1]. Earlier this year, we published calculations showing a figure of merit of 3.0 for a PbTe/SnTe nanoscaled superlattice (SL) [2].

Even though zT is the standard method of measuring thermoelectric efficiency, a more practical measure of efficiency was developed recently:

$$\eta = \eta_{Carnot} \frac{(\int S(T)dT)^2 \int \sigma(T)dT}{\int \lambda(T)dT} \Delta T, \qquad (2)$$

where η is the thermodynamic efficiency, i.e., the percentage of heat energy which can be converted into electricity, η_{Carnot} is the Carnot limit to the thermodynamic efficiency, λ is the total thermal conductivity, and ΔT is the temperature difference between the hot and cool ends of the thermoelectric (Kim, Liu, et al., PNAS, 2015).

Our efficiency calculations can be seen in Figure 2, and the experimental method follows in the footsteps of one of the two best efficiencies achieved in a lab to date, adopting a nanoscale approach [6]. The highest figure of merit obtained relies on a structural phase transformation of SnSe at 750 K, which is not practical for an industrial product which requires durability [1]. The second best measured value was produced with a mortar grinder and a spark plasma sintering system creating PbTe-SrTe [6]. The latter method is much more practical for industrial application, so it is the method we will adopt for our PbTe-SnTe (PST). This nanomaterial composite, PST, has not yet been produced with appropriate nanoscale grain sizes.

PbTe is well-known to be the top contender for a commercially viable thermoelectric, yet no one has taken advantage of this production method. Furthermore, PbTe is known to be brittle, yet we have shown that it is possible to dope with iodine – an n-type dopant which produces an excellent efficiency – to make PbTe more ductile and durable. For industrial application, a structurally stable material is necessary for durability, and we have shown that both n and p-type dopants can provide the appropriate ductility [3]. With a calculated efficiency higher than that of any achieved in a lab and a more robust material, the potential market impact is unprecedented.

The efficiency of the device is not just dependent on the thermoelectric, however. The efficiency of the heat absorber and sink are both paramount to a successful device. For a traditional heat sink, [Machinery's Handbook, 29th Ed.]:

$$P_Q = N\lambda wt\sqrt{\frac{2\mathrm{h}}{\lambda t}}\Delta T\tanh\left(\sqrt{\frac{2\mathrm{h}}{\lambda t}}L\right), \qquad (3)$$

where P_Q is the heat power transferred, N is the number of fins, λ is the thermal conductivity, w is the fin width, t is the fin thickness, L is the fin length, and h is the convective heat transfer coefficient, found to be approximately 75 W/m^2K in a similar situation [7]. The thermal conductivity of aluminum and copper are 205 and 375 W/mK, respectively. With the heat power transferred being proportional to the square root of the thermal conductivity, it is found that aluminum is the more practical choice, due to the high price of copper. We have run simulations modeling the efficiency of the device, factoring in raw material cost for cost-benefit analysis. Coupling two instances of Equation 3 for the convection of the heat absorber and sink with three instances of the steady state heat flow equation,

$$q = -\lambda\,\nabla\mathrm{T}\,, \qquad (4)$$

for the two aluminum regions and the PST region, where q is the heat flux, we model TEGs in an industrial chimney with a steady heat flow. An initial guess efficiency is supplied to the routine computing the matrix equation involving Equations 3 and 4, solving for heat flow and boundary temperatures. The temperatures for either side of the PST ingot are fed into another routine which solves for efficiency via an extension of Equation 2, outlined by Kim, Liu, et al. Convergence is reached when the change in efficiency from the previous iteration is less than 10^{-6}. Heat energy is removed from the system after calculating the heat transfer through each TEG, and it is found that after a certain amount of heat is removed, it is no longer cost-effective to introduce additional TEGs to the

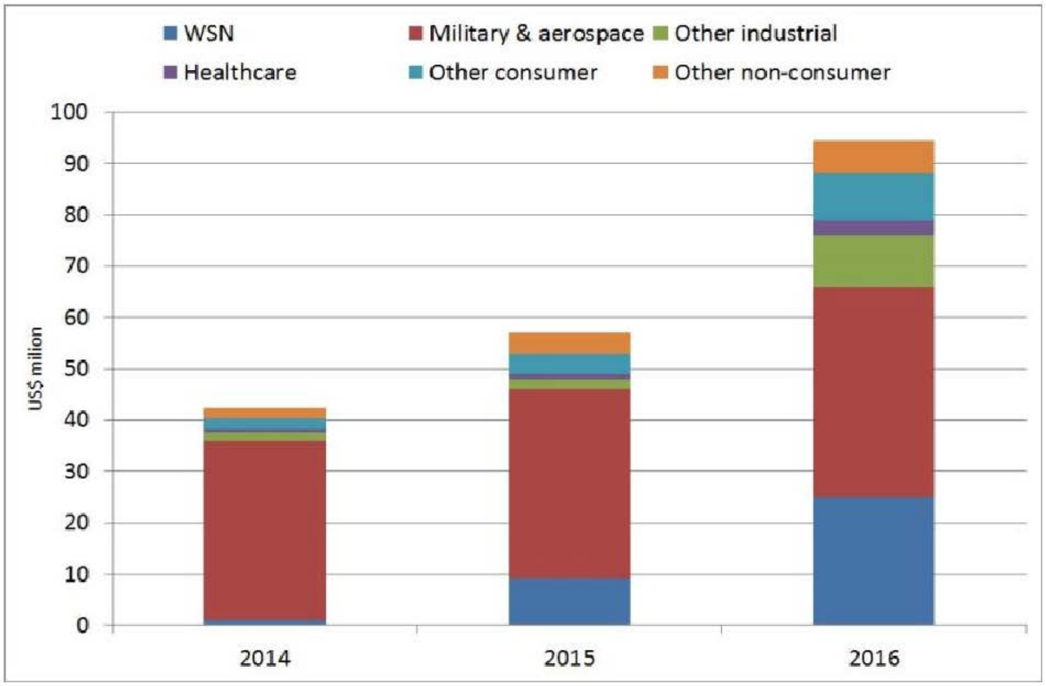

Figure 4. Thermoelectric market size and sectors. The key market to note is the $10 million industrial sector. The exponential growth from 2015 to 2016 is expected to continue. Figure borrowed from Idtech [4].

system. Raw material cost was factored into the analysis, reaching the conclusion that 250 27 x 27 cm2 aluminum plates lined with PST ingots and proportionally large fins on either side maximize the cost-benefit. More dimensional details may be found in the appendix.

Market Analysis

Currently, the main consumers of thermoelectric technology are military and aerospace, but industrial consumers are expected to have an exponentially increasing demand in the coming years [4]. The waste heat produced by industry is staggering. The oil industry produced over 320 billion kWh of waste heat in 2010 [5]. According to the U.S. Energy Information Administration, during that year, energy costs were approximately $0.06 per kWh for oil refineries. This equates to about $19 billion worth of heat energy wasted in 2010. In Figure 1, it can be seen that a 16.8% efficiency can be achieved with n-PST at that temperature. If n-PST could be exposed to just 10% of that waste heat, it would conserve over $320 million worth of energy per year.

Other industries will benefit even more, and a similar calculation can show that the steel industry wastes $10 billion worth of heat energy, annually. n-PST has higher efficiency at those temperatures (see Figure 1), so exposing PST to 10% of steel industry waste heat would save them over $230 million per year.

Sales

Thermodynamic will hire two sales people within the second year of founding the company, as the technology is being fine-tuned. The sales people will be hired as independent contractors, and we will offer them a generous 5% commission on sales, allowing them an unlimited earning potential so as to motivate them and drive sales. They will be highly experienced in the field, with broad technical knowledge and knowing the key players.

Competitor Analysis

According to Smart Grid and Consumers, SBI Energy 2010, the following companies are potential competition: Tempronics, Promethean Power, GMZ Energy, Komatsu, and Cypress Semiconductor. GMZ was recently acquired by Evident Thermoelectrics, while the other companies are still in the development stage. Other competitors include Micropower, which could be a potential collaborator with Thermodynamic, and Gentherm, which had revenues exceeding $660 million in 2013. None of these companies have saturated the market, and our goal is to be bought out by one of them by 2021.

Expected Outcome of the Project

With the funds received, during the course of the project, we will refine the bulk material production process, determine optimal doping concentration, develop a heat sink, and construct a prototype for the device. Additional market research will be performed during this time, as well, so that Thermodynamic will be able to make its first sale at the conclusion of the program period. To engineer the thermoelectric device, we will need equipment to produce the bulk material in a cost effective manner. To achieve nanoscale grain sizes of PbTe and SnTe crystals, we will need a high performance mortar grinder and a plasma sintering system. These, and other capital expenditures cost over $250,000.

Financial Projections

	2016		In Thousands										
	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Year**
Direct Cost													
Direct Labor	0	20	20	20	20	20	20	20	20	20	20	20	220
Direct Materials	10												10
SPS System	200												200
Mortar Grinder	8												8
Metal Casting Equip	20												
Total Direct Cost	**238**	**20**	**20**	**20**	**20**	**20**	**20**	**20**	**20**	**20**	**20**	**20**	**458**
Indirect Cost													
Warehouse Rent	3	3	3	3	3	3	3	3	3	3	3	3	36
Utilities	3	3	3	3	3	3	3	3	3	3	3	3	36
Insurance	1	1	1	1	1	1	1	1	1	1	1	1	6
Acct & Legal	1	1	1	1	1	1	1	1	1	1	1	1	6
Office Supplies	1	0	0	0	0	0	0	0	0	0	0	0	3
Total Indirect Cost	**8**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**87**
Total Cost	**246**	**27**	**27**	**27**	**27**	**27**	**27**	**27**	**27**	**27**	**27**	**27**	**545**
Revenue	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Profit	**(246)**	**(27)**	**(27)**	**(27)**	**(27)**	**(27)**	**(27)**	**(27)**	**(27)**	**(27)**	**(27)**	**(27)**	**(545)**
Cash Flow	**(246)**	**(273)**	**(300)**	**(327)**	**(354)**	**(382)**	**(409)**	**(436)**	**(463)**	**(490)**	**(518)**	**(545)**	

	2017		In Thousands										
	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Year**
Direct Cost													
Direct Labor	20	20	20	20	20	20	20	20	20	20	20	20	240
Direct Materials	10											60	70
SPS System													0
Mortar Grinder													0
Shipping												2	
Installation												20	
Total Direct Cost	**30**	**20**	**20**	**20**	**20**	**20**	**20**	**20**	**20**	**20**	**20**	**102**	**332**
Indirect Cost													
Warehouse Rent	3	3	3	3	3	3	3	3	3	3	3	3	36
Utilities	3	3	3	3	3	3	3	3	3	3	3	3	36
Insurance	1	1	1	1	1	1	1	1	1	1	1	1	6
Acct & Legal	1	1	1	1	1	1	1	1	1	1	1	1	6
Office Supplies	1	0	0	0	0	0	0	0	0	0	0	0	3
Total Indirect Cost	**8**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**87**
Total Cost	**38**	**27**	**27**	**27**	**27**	**27**	**27**	**27**	**27**	**27**	**27**	**109**	**419**
Revenue	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Profit	**(38)**	**(27)**	**(27)**	**(27)**	**(27)**	**(27)**	**(27)**	**(27)**	**(27)**	**(27)**	**(27)**	**(109)**	**(419)**
Cash Flow	**(583)**	**(610)**	**(637)**	**(664)**	**(692)**	**(719)**	**(746)**	**(773)**	**(800)**	**(828)**	**(855)**	**(964)**	

	2018		In Thousands										
	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Year**
Direct Cost													
Direct Labor	20	20	20	20	20	20	20	20	20	20	20	20	240
Direct Materials	0	60	0	60	0	60		60		60		60	360
SPS System													0
Mortar Grinder													0
Shipping		2		2		2		2		2		2	
Installation		20		20		20		20		20		20	
Total Direct Cost	**20**	**102**	**20**	**102**	**20**	**102**	**20**	**102**	**20**	**102**	**20**	**102**	**732**
Indirect Cost													
Warehouse Rent	3	3	3	3	3	3	3	3	3	3	3	3	36
Utilities	3	3	3	3	3	3	3	3	3	3	3	3	36
Insurance	1	1	1	1	1	1	1	1	1	1	1	1	6
Acct & Legal	1	1	1	1	1	1	1	1	1	1	1	1	6
Office Supplies	1	0	0	0	0	0	0	0	0	0	0	0	3
Total Indirect Cost	**8**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**87**
Total Cost	**28**	**109**	**27**	**109**	**27**	**109**	**27**	**109**	**27**	**109**	**27**	**109**	**819**
Revenue	**200**	**0**	**200**	**0**	**200**	**0**	**200**	**0**	**200**	**0**	**200**	**0**	**1,200**
Profit	**172**	**(109)**	**173**	**(109)**	**173**	**(109)**	**173**	**(109)**	**173**	**(109)**	**173**	**(109)**	**381**
Cash Flow	**(792)**	**(901)**	**(728)**	**(838)**	**(665)**	**(774)**	**(601)**	**(710)**	**(538)**	**(647)**	**(474)**	**(583)**	

	2019		In Thousands										
	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Year**
Direct Cost													
Direct Labor	20	20	20	20	20	20	20	20	20	20	20	20	240
Direct Materials	60	60	60	60	60	60	60	60	60	60	60	60	720
SPS System													0
Mortar Grinder													0
Shipping	2	2	2	2	2	2	2	2	2	2	2	2	24
Installation	20	20	20	20	20	20	20	20	20	20	20	20	240
Total Direct Cost	**102**	**102**	**102**	**102**	**102**	**102**	**102**	**102**	**102**	**102**	**102**	**102**	**1,224**
Indirect Cost													
Warehouse Rent	3	3	3	3	3	3	3	3	3	3	3	3	36
Utilities	3	3	3	3	3	3	3	3	3	3	3	3	36
Insurance	1	1	1	1	1	1	1	1	1	1	1	1	6
Acct & Legal	1	1	1	1	1	1	1	1	1	1	1	1	6
Office Supplies	1	0	0	0	0	0	0	0	0	0	0	0	3
Total Indirect Cost	**8**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**87**
Total Cost	**110**	**109**	**109**	**109**	**109**	**109**	**109**	**109**	**109**	**109**	**109**	**109**	**1,311**
Revenue	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**2,400**
Profit	**90**	**91**	**91**	**91**	**91**	**91**	**91**	**91**	**91**	**91**	**91**	**91**	**1,089**
Cash Flow	**(493)**	**(402)**	**(312)**	**(221)**	**(130)**	**(39)**	**52**	**142**	**233**	**324**	**415**	**506**	

	2020		In Thousands										
	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Year**
Direct Cost													
Direct Labor	40	40	40	40	40	40	80	80	80	80	80	80	720
Direct Materials	60	60	60	60	60	60	120	120	120	120	180	180	1,200
SPS System							800						800
Mortar Grinder							8						8
Shipping	2	2	2	2	2	2	2	4	4	4	4	6	36
Installation	20	20	20	20	20	20	20	40	40	40	40	60	360
Total Direct Cost	**122**	**122**	**122**	**122**	**122**	**122**	**1,030**	**244**	**244**	**244**	**304**	**326**	**3,124**
Indirect Cost													
Warehouse Rent	3	3	3	3	3	3	3	3	3	3	3	3	36
Utilities	3	3	3	3	3	3	3	3	3	3	3	3	36
Insurance	1	1	1	1	1	1	1	1	1	1	1	1	6
Acct & Legal	1	1	1	1	1	1	1	1	1	1	1	1	6
Office Supplies	1	0	0	0	0	0	0	0	0	0	0	0	3
Total Indirect Cost	**8**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**87**
Total Cost	**130**	**129**	**129**	**129**	**129**	**129**	**1,037**	**251**	**251**	**251**	**311**	**333**	**3,211**
Sales													
Service													
Revenue	**200**	**200**	**200**	**200**	**200**	**200**	**200**	**400**	**400**	**400**	**400**	**600**	**3,600**
Profit	**70**	**71**	**71**	**71**	**71**	**71**	**(837)**	**149**	**149**	**149**	**89**	**267**	**389**
Cash Flow	**576**	**646**	**717**	**788**	**859**	**930**	**92**	**241**	**390**	**539**	**628**	**894**	

	2021		In Thousands										
	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Year**
Direct Cost													
Direct Labor	80	80	80	80	80	80	80	80	80	80	80	80	960
Direct Materials	180	180	180	180	180	180	180	180	180	180	180	180	2,160
SPS System													0
Mortar Grinder													0
Shipping	6	6	6	6	6	6	6	6	6	6	6	6	72
Installation	60	60	60	60	60	60	60	60	60	60	60	60	720
Total Direct Cost	**326**	**326**	**326**	**326**	**326**	**326**	**326**	**326**	**326**	**326**	**326**	**326**	**3,912**
Indirect Cost													
Warehouse Rent	3	3	3	3	3	3	3	3	3	3	3	3	36
Utilities	3	3	3	3	3	3	3	3	3	3	3	3	36
Insurance	1	1	1	1	1	1	1	1	1	1	1	1	6
Acct & Legal	1	1	1	1	1	1	1	1	1	1	1	1	6
Office Supplies	1	0	0	0	0	0	0	0	0	0	0	0	3
Total Indirect Cost	**8**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**87**
Total Cost	**334**	**333**	**333**	**333**	**333**	**333**	**333**	**333**	**333**	**333**	**333**	**333**	**3,999**
Sales													
Service													
Revenue	**600**	**600**	**600**	**600**	**600**	**600**	**600**	**600**	**600**	**600**	**600**	**600**	**7,200**
Profit	**266**	**267**	**267**	**267**	**267**	**267**	**267**	**267**	**267**	**267**	**267**	**267**	**3,201**
Cash Flow	**1,161**	**1,427**	**1,694**	**1,961**	**2,228**	**2,495**	**2,761**	**3,028**	**3,295**	**3,562**	**3,829**	**4,095**	

	2022		In Thousands										
	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Year**
Direct Cost													
Direct Labor	80	80	80	80	80	80	120	120	120	120	120	120	1,200
Direct Materials	180	180	180	180	180	180	360	360	360	360	360	360	3,240
SPS System							850						850
Metal Casting Equip							40						
Mortar Grinder							20						20
Shipping	6	6	6	6	6	6	12	12	12	12	12	12	108
Installation	60	60	60	60	60	60	120	120	120	120	120	120	1,080
Total Direct Cost	**326**	**326**	**326**	**326**	**326**	**326**	**1,522**	**612**	**612**	**612**	**612**	**612**	**6,538**
Indirect Cost													
Warehouse Rent	3	3	3	3	3	3	6	6	6	6	6	6	54
Utilities	3	3	3	3	3	3	6	6	6	6	6	6	54
Insurance	1	1	1	1	1	1	1	1	1	1	1	1	6
Acct & Legal	1	1	1	1	1	1	1	1	1	1	1	1	6
Office Supplies	1	0	0	0	0	0	0	0	0	0	0	0	3
Total Indirect Cost	**8**	**7**	**7**	**7**	**7**	**7**	**13**	**13**	**13**	**13**	**13**	**13**	**123**
Total Cost	**334**	**333**	**333**	**333**	**333**	**333**	**1,535**	**625**	**625**	**625**	**625**	**625**	**6,661**
Sales													
Service													
Total Revenue	**600**	**600**	**600**	**600**	**600**	**600**	**600**	**1,200**	**1,200**	**1,200**	**1,200**	**1,200**	**10,200**
Profit	**266**	**267**	**267**	**267**	**267**	**267**	**(935)**	**575**	**575**	**575**	**575**	**575**	**3,539**
Cash Flow	**4,361**	**4,628**	**4,895**	**5,162**	**5,429**	**5,695**	**4,760**	**5,335**	**5,910**	**6,485**	**7,059**	**7,634**	

	2023		In Thousands										
	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Year**
Direct Cost													
Direct Labor	120	120	120	120	120	120	160	160	160	160	160	160	1,680
Direct Materials	360	360	360	360	360	480	480	480	480	480	480	480	5,160
SPS System							850						850
Mortar Grinder							20						20
Metal Casting Equip							25						
Shipping	12	12	12	12	12	12	16	16	16	16	16	16	
Installation	120	120	120	120	120	120	160	160	160	160	160	160	
Total Direct Cost	**612**	**612**	**612**	**612**	**612**	**732**	**1,711**	**816**	**816**	**816**	**816**	**816**	**9,583**
Indirect Cost													
Warehouse Rent	3	3	3	3	3	3	3	3	3	3	3	3	36
Utilities	3	3	3	3	3	3	3	3	3	3	3	3	36
Insurance	1	1	1	1	1	1	1	1	1	1	1	1	6
Acct & Legal	1	1	1	1	1	1	1	1	1	1	1	1	6
Office Supplies	1	0	0	0	0	0	0	0	0	0	0	0	3
Total Indirect Cost	**8**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**7**	**87**
Total Cost	**620**	**619**	**619**	**619**	**619**	**739**	**1,718**	**823**	**823**	**823**	**823**	**823**	**9,670**
Sales													
Service													
Revenue	**1,200**	**1,200**	**1,200**	**1,200**	**1,200**	**1,200**	**1,600**	**1,600**	**1,600**	**1,600**	**1,600**	**1,600**	**16,800**
Profit	**580**	**581**	**581**	**581**	**581**	**461**	**(118)**	**777**	**777**	**777**	**777**	**777**	**7,130**
Cash Flow	**8,214**	**8,795**	**9,376**	**9,957**	**10,537**	**10,998**	**10,880**	**11,657**	**12,434**	**13,210**	**13,987**	**14,764**	

References

[1] L. Zhao, et al., Nature 508 (2014) 373.
[2] P. Borges, et al., Journal of Solid State Chemistry 227 (2015) 123 .
[3] J. Petersen, et al., Materials Chemistry and Physics 146 (2014) 472.
[4] IDTechEx Report (2015).
[5] Frost and Sullivan Report (2010).
[6] Biswas, et al., Nature 2012
[7] I.P. Kandylas, A.M. Stamatelos / Energy Conversion & Management 40 (1999) 1057±1072

JOHN EMIL PETERSEN III, PHD, MS

Full Stack Dev | CAD | Materials Science | Physics | Engineering | Control Systems | Consulting

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Professional Experience

Business Owner, Founder, and CEO **Jan 2018 –**
N-Dimensional Engineering (http://n-dtech.com)
∞ Developed robotic positioning system (mount) from scratch for Alt-Az telescopes
∞ Achieved a level of performance appropriate for professional data acquisition
∞ Secured intellectual property such that valuation exceeds $100 million
∞ https://www.tiktok.com/t/ZTRTc5E4w/ (Basic demonstration – robotics and control systems)

Research Associate **Jan 2012 – Dec 2017**
Texas State University, Department of Physics
∞ Calculated physical properties of novel materials via quantum mechanical first-principles
∞ Utilized Linux high-performance computing clusters to compile, run, and/or write various scientific programs using C/C++, bash, and other programming languages
∞ Characterized structural and electronic properties of materials via x-ray diffraction, atomic force microscopy, and Hall measurements, often using LabView
∞ Presented original results at professional society conferences and in peer-reviewed journals

Teaching Assistant **Aug 2011 – May 2015**
Texas State University, Department of Physics
∞ Introduced students to fundamental laws of electrodynamics and basic electrical engineering principles, through theoretical lecture and practical demonstration
∞ Became exceptionally familiar with circuits and their components

Various independent contractor roles, including Financial Adviser **(2006-2011)**

Skills

∞ Demonstrated hard coding and mathematical modeling ability with C/C++, linking libraries
∞ Showcased systems engineering capability in the robotics, electrical, and mechanical engineering communities with both interpreted and compiled programming languages
∞ Seasoned scripting skills with bash, awk, and C#
∞ Well-practiced in both relational (SQL) and key-pair (non-SQL) development and query
∞ Developed several professional websites (html, css, and php)
∞ Versed in Linux and Windows, whether in the terminal, Visual Studio, or office suites
∞ Experienced at public speaking, as evidenced by professional society meetings
∞ Skilled in materials characterization by XRD, AFM, and Hall measurements
∞ Talented with both CAD and shop tools, bringing design to prototype

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Education

PhD, Materials Science, Engineering, and Commercialization **Dec 2017**
Texas State University
"Impurities in Antiferromagnetic Transition-Metal Oxides – Symmetry and Optical Transitions"
https://digital.library.txstate.edu/handle/10877/6921?show=full
GPA: 3.74

Master of Science, Physics **May 2013**
Texas State University
"First Principles Study of Structural, Electronic, and Mechanical Properties of Lead Selenide and Lead Telluride"
https://digital.library.txstate.edu/handle/10877/4556?show=full
GPA: 3.13, Excellence in Graduate Research Award (May 2013)

Bachelor of Science, Physics **Dec 2010**
University of Texas at San Antonio
GPA: 3.34
∞ Co-founder and treasurer of local branch of Society of Physics Students
∞ Best Paper award at ABES Student Conference, 2010
∞ Dean's list (multiple)
∞ Omicron Delta Kappa leadership honor society member

Bachelor of Arts, Liberal Arts **Aug 2005**
University of Texas at Austin
∞ Minor in Business Foundations
∞ Studied Business Spanish abroad at ESADE, in Barcelona, Spain (summer 2002)

Oral Presentations at National Conferences

APS March Meeting, New Orleans, LA **Mar 2017**
Ab Initio study on structural, electronic, magnetic and dielectric properties of LSNO within Density Functional Perturbation Theory, J. Petersen, et al.
http://meetings.aps.org/link/BAPS.2017.MAR.A8.2

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https://github.com/tarbalreboot

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APS March Meeting, Baltimore, MD **Mar 2016**

First Principles Study of Oxygen Vacancies and Iron Impurities on Electrical and Optical Properties of NiO, J. Petersen, et al.

http://meetings.aps.org/link/BAPS.2016.MAR.Y30.9

Selected Publications (Reverse Chronological)

9. Symmetry Considerations on Band Filling and First Optical Transition in NiO, J. Petersen, et al., **The European Physical Journal B** (**2019**) 92: 232.
https://doi.org/10.1140/epjb/e2019-100363-5

8. Spontaneous symmetry breaking and electronic and dielectric properties in commensurate $La_{7/4}Sr_{1/4}CuO_4$ and $La_{5/3}Sr_{1/3}NiO_4$, J. Petersen, et al., **Physical Review B** 97 (195129).
https://doi.org/10.1103/PhysRevB.97.195129

7. Carrier Lifetimes of Iodine-Doped CdMgTe/CdSeTe Double Heterostructures Grown by Molecular Beam Epitaxy, S. Sohal, et al., **Journal of Electronic Materials** 46 (9).
https://doi.org/10.1007/s11664-017-5646-y

6. Iodine Doping of CdTe and CdMgTe for Photovoltaic Applications, O.S. Ogedengbe, et al., **Journal of Electronic Materials** 46 (9).
https://doi.org/10.1007/s11664-017-5588-4

5. Effect of Free-Carrier Concentration and Optical Injection on Carrier Lifetimes in Undoped and Iodine Doped CdMgTe/ CdSeTe Double Heterostructures Grown by Molecular Beam Epitaxy, S. Sohal, et al., **Journal of Physics D Applied Physics** 49 (50).
http://stacks.iop.org/0022-3727/49/i=50/a=505104

4. Factors Influencing Photoluminescence and Photocarrier Lifetime in CdSeTe/CdMgTe Double heterostructures, C. Swartz, et al., **Journal of Applied Physics** 120 (16).
https://doi.org/10.1063/1.4966574

3. The Effect of Anisotropic Valleys on Phonon Scattering and the Magnetotransport Properties of n-Type PbTe, C. Swartz, et al., **Journal of Electronic Materials** 45 (1).
https://doi.org/10.1007/s11664-015-4184-8

2. Thermoelectric Properties of IV-VI-Based Heterostructures and Superlattices, P. Borges, et al., **Journal of Solid State Chemistry** 227 (123).
https://doi.org/10.1016/j.jssc.2015.03.027

1. Elastic and Mechanical Properties of Intrinsic and Doped PbSe and PbTe Studied by First-Principles, J. Petersen, et al., **Materials Chemistry and Physics** 146 (3).
https://doi.org/10.1016/j.matchemphys.2014.03.055

Referee with Physical Review Letters and Physical Review B