Buswell Energy Final Scientific/ Technical Report
Cover Sheet

I. DOE Award No. DE-FC02-06CH11353 / Amendment No. A000/ 2011 Ext.

Project Title: Electrical Core Transformer for Grid Improvement Incorporating Wire Magnetic Components
Principal Investigator: Harrie R. Buswell

Report Date: March 20, 2012
Final Scientific/ Technical Report
Activity through December 31st, 2011
With Follow-Up Data

2. **No limitation of authorized distribution**

3. EXECUTIVE SUMMARY

The research reported herein adds to the understanding of oil-immersed distribution transformers by exploring and demonstrating potential improvements in efficiency and cost utilizing the unique Buswell approach wherein the unit is redesigned, replacing magnetic sheet with wire allowing for improvements in configuration and increased simplicity in the build process. Exploration of new designs is a critical component in our drive to assure reduction of energy waste, adequate delivery to the citizenry, and the robustness of U.S. manufacturing. By moving that conversation forward, this exploration adds greatly to our base of knowledge and clearly outlines an important avenue for further exploration. This final report shows several advantages of this new transformer type (outlined in a report signed by all of our collaborating partners and included in this document). Although materials development is required to achieve commercial potential, the clear benefits of the technology if that development were a given is established. Exploration of new transformer types and further work on the Buswell design approach is in the best interest of the public, industry, and the United States. Public benefits accrue from design alternatives that reduce the overall use of energy, but it must be acknowledged that new DOE energy efficiency standards have provided some assurance in that regard. Nonetheless the burden of achieving these new standards has been largely shifted to the manufacturers of oil-immersed distribution transformers with cost increasing up to 20% of some units versus 2006 when this investigation was started. Further, rising costs have forced the industry to look closely are far more expensive technologies which may threaten U.S. competitiveness in the distribution transformer market. This concern is coupled with the realization that many units in the nation's grid are beyond their optimal life which suggests that the nation may be headed for an infrastructure crisis that U.S. industry is ill prepared to handle which could further challenge U.S. competitiveness.

IV/ V Accomplishments versus Goals and Objectives/ Summary of Project Activities

The following revised milestone chart was originally submitted with the fall, 2009 request to the Department of Energy. Note that items 6 – 12 are dependent upon timely delivery of suitable wire for prototype production.

No.	Milestones	Plan Date	Est. Date	Actual Completion	Status
1	Finalize Design	10/1/2006	12/31/2006	12/31/2006	Iterative Process- Initial Design Completed- Few modifications
2	Process Design Single Phase (10KVA)	10/1/2006	12/31/2006	10/31/2006	Parameters iteratively established/ 10 KVA Prototype Design
3	"Build Prototype/ 10 KVA/	12/31/2006	12/31/2006	12/31/2006 Low-Magnetics	Black iron wire components- Poor Magnetic Quality anticipated- No Surprises
4	Determination	05/31/	05/31/20	June 31,	1st. Silicon Iron wire selected,

	of Working Magnetic Material	**2007**	**07**	**2007, sufficient to prototype.**	**coated with a magnesium oxide resistive coating. Sufficient material was delivered and processed.**
5	**10 KVA magnetic “Baseline Prototype”**	**03/31/ 2007**	**02/28/20 08**	**April/ 2008**	**Data from this prototype has been presented to partners and DOE**
6	**Construct Additional 10 KVA prototype**	**08/31/ 2007**	**June, 2011**	**A new iterative prototype was constructed in May-June, 2011 and has been tested. Results were very promising, and are appended**	**Baseline** **2nd. Sufficient flat SiFe wire 10/1 ratio with improved characteristics was delivered in May, 2011.** **Achieved in June, 2011. Testing is ongoing, but up to date results have been shared.**
7	**Product Design/ 167 KVA/ Single Phase**	**03/31/ 2009**	**08/31/20 07**	**Complete but could evolve**	**Product design of the 167 KVA (which can be extrapolated to a 500 KVA 3-Phase unit) remains a part of the Buswell work plan, but production of accompanying prototypes was de-scoped. Actual data from a 10 KVA prototype utilizing appropriate materials will inform these design specifications before finalization.**
8	**Specification by (ORNL) (now Bekaert), of “Suitable” coated magnetic wire material.** **Final specifications will be made by Buswell**	**12/31/ 2007**	**07/2011 was the last reporte d anticipa ted complet ion date.** **Previou**	**This material has not been specified as agreed, and Bekaert indicates a need for outside assistance to**	**Not achieved within the project period. Completion relegated to post project dates based upon Buswell’s success in achieving a funding partnership to engage Ames Laboratories in the project.**

	Energy and Bekaert Corporation.		**s Revise date 4-01-11 Again, Bekaert has been unable to provide chemistry and process specifications for a "suitable: wire**	**accomplish this. We have initiated a conversation with Ames Laboratories & materials development with their assistance seems likely to yield desired outcome, but funding and time do not allow for us to explore this under the current funding and time constraints.**	
9	**Processing and delivery of a "Suitable" coated magnetic wire material from Bekaert**	**June 2010**	**Incumbent on report from Bekaert. It is not anticipated that Bekaert will be able to provide this material in the grant period**	**It was previously projected that a commercially appropriate wire would be provided by May, 2011 according to reports from Bekaert. 2011 - Regrettably**	**The date for completion of this milestone is dependent upon completion of milestone # 8 and not achieved in the course of the project.**

			specified.	**, this material provided showed only iterative improvement.**	
10	**Provide thorough process design analysis & completed costs analysis**	**03/31/ 2009**	**12/ 01/ 1010** **Draft completed Dec. 31, '10**	**This information is now included in the report.**	**This milestone is addressed, however "true cost advantages" can only be determined with suitable/ commercializable material as the cost of such material can not be clearly established.**
11	**Design, Construct and Assemble final 10 KVA Unit appropriate for use.**	**08/31/ 2008**	**08/31/2010** **Delay** **No new date has been established**	**Bekaert was unable to achieve the characterization and delivery of "suitable" wire in the time period and scope of this grant**	**Not Achieved:** **We are completing all possible testing on the latest10KVA iterative prototype to take greatest advantage of our progress to date despite materials delays**
12	**Comprehensive Testing, Mathematical Analysis, Modeling Analysis, Comparative Analysis, and Final Report Delivery**	**09/30/ 2011**	**Dec. 2011**		**Primarily Completed on the best available unit at KAEC, Bekaert, Western Kentucky University, and other external labs including Tennessee Technical University on iterative 10 KVA Unit** **The final report will be delivered within the required period and will contain updated data.**

Project Definition

As consistently reported throughout this project, Buswell Energy LLC (Buswell), a small business headquartered in Berea, Kentucky, has led a strategic team comprising industry, academia, and a host of industry consultants to produce a prototype 10 KVA oil-immersed transformer in which the magnetic components circumenvelop the electrical components and promise compact size, efficiency, and cost advantages. The magnetic components are constructed of wire rather than wide sheets to enable envelopment that is homogeneous, symmetrical, balanced, and robust.

Embedded in this report is a recent revision of a report of a working prototype of the proposed 10 KVA oil-immersed distribution transformer manufactured at the Kentucky Association of Electric Cooperatives transformer manufacturing plant in Louisville, Kentucky.

Timeframe: The original time frame was three years and has been extended over time to 5 years as we have enjoyed both no-cost and cost-added extensions. No further extensions are possible as per Patrice Brewington, project manager for the Department of Energy who facilitated our last no-cost extension through December 31st, 2011, the current report date

Buswell Energy is pleased to announce significant progress over the course of this project despite materials development delays beyond our control. That progress is shown most clearly in the most recent draft of the prototype report and earlier iteration of which has already been shared with Patrice Brewington and Gilbert Bindewald. Some of the data from that report is updated in this final report.

This report includes the following:

As earlier reported, that document summarized developmental work by the Buswell Team over an extended period from 1997-2011 wherein an innovative distribution transformer containing a wire wound magnetic core is analyzed and compared to a present vintage conventional transformer containing a sheet wound magnetic core. The attraction to wire-wound core technology is the inherent exceptionally low eddy current loss that can be achieved as well as the high producibility through modular core construction. Present conventional design distribution transformers have always struggled with the limitation that automation of the magnetic core has been difficult to achieve. This report provides multiple comparisons of design aspects between the Buswell wire wound core and conventional designs. The report describes the several important aspects of the design and provides experimental and analytical backup to demonstrate the validity of the design.

Key Definition of Terms (Items 1 and 2 repeated from numerous previous reports)

1. Baseline- As consistently reported development and testing of the May, 2008- 10 KVA prototype is completed. This prototype was constructed of SiFe wire made by Bekaert Corporation with input from ORNL. The magnetic characteristics of this material are measurable and demonstrable in the finished unit, but not suitable for production, not grain oriented, and not adequately enhanced.

a. We are currently working with Dr. Satish Mahajan and Dr. Jay Cui of Tennessee Technological University, Dr. Walter Collett of Western Kentucky University, Phil Hopkinson, president of HVolt, and Dr. Buswell to write a paper that will contextualize finding from that prototype in light of what we are learning from flux and thermal modeling work currently taking place. *As ongoing improvements in the material are made, the enhanced wire will be utilized in successive 10 KVA prototypes.*

2. Working- Building of further prototype(s) with process improvements using the next generation of material with some improvement in the material utilized for the prototype outlined in #1. In this quarter, we have constructed and tested coils and sectors. We remain hopeful of more marked improvements in the wire in the short term.

3. Suitable- Progress has been shown related to the coating and processing of wire material in this quarter. This progress contributed to advancements in our June, 2011 prototype over our last iteration. However, given that the chemistry of the base material for the wire has not been altered to facilitate adequate grain orientation in the materials to produce a manufacturable design, it has been impossible for us to achieve what we have defined as a suitable prototype during the project period.

The June, 2011, prototype was constructed in collaboration between Buswell and Kentucky Association of Electric Cooperatives in Louisville, Kentucky based on a design completed by Phil Hopkinson of HVolt featuring the Buswell technological approach. Bekaert remains committed to work with Buswell Energy through the end of the year. It is our hope that we will be able to achieve new progress in materials development and make steps toward joint partnerships with additional transformer manufacturers, a move that would likely propel Bekaert to make the on-going structural and financial commitment necessary for the ultimate success of this project.

As reported over the last several quarters, the absence of “suitable” material has resulted in some remaining milestones not being addressed as outlined in the existing timeline. Completion of these milestones can only be achieved within the project period by revising them to report the ways in which the prototype illustrates the success and promise of the Buswell design without development of a commercial unit. In each case, we will obtain the data outlined related to the iterative “working” prototype:

Although some advancement in the materials development arena has resulted from conversation that Dr. Buswell initiated with Dr. Thomas Lograsso, Director of Materials Science at the Department of Energy Laboratory in Ames, Iowa, we have as yet been able to achieve funding to take advantage of those advances. Dr. Lograsso has indicated both the skill and the desire to partner with Buswell toward development of the wire material. In an August meeting among representatives of Buswell, Ames Lab, and Bekaert, it was agreed that such a partnership would be the best possible pathway forward.

MILESTONES REMAINING WERE ALL DEPENDENT UPON THE DEVELOPMENT OF A COMMERCIALLY ACCEPTABLE MATERIAL FOR THE MAGNETIC COMPONENT OF THE BUSWELL TRANSFORMER

a. Construction of an additional 10 KVA prototype using silicon iron to contain the magnetic properties of the wire and with a suitable resistive coating.
    i. Buswell, utilizing the Orthostatic winding machine obtained in last quarter, wound distinct coils and sectors utilizing wire with an improved coating methodology made available by Bekaert.
    ii. As anticipated, the wire demonstrated some improvement.

b. Specification (achieved through collaboration with Bekaert Corporation) of composition and method for making a magnetic material suitable for commercialization as well as recommendations for adjustment as the actual material is developed and tested. Advancement in this arena will require that Bekaert make an expanded commitment toward utilization of a material with chemical/magnetic properties improved over the current iteration.

c. Processing and delivery of material suitable for commercialization of a Buswell Energy transformer has not been achieved.

Design, construction, and assembly of a 10 KVA prototype using the material outlined in items b & c to establish that the Buswell design can be utilized to create a commercially competitive 10 KVA oil-immersed distribution transformer. *Construction of an iterative unit was completed in June, 2011 although the magnetic properties of the wire were inadequate for commercial consideration.*

RESEARCH TEAM FINAL Summary

This report summarizes developmental work by the Buswell Team over an extended period from 1997-2011 wherein an innovative distribution transformer containing a wire wound magnetic core is analyzed and compared to a present vintage conventional transformer containing a sheet wound magnetic core. The attraction to wire-wound core technology is the inherent exceptionally low eddy current loss that can be achieved as well as the high producibility through modular core construction. Present conventional design distribution transformers have always struggled with the limitation that automation of the magnetic core has been difficult to achieve. This report provides multiple comparisons of design aspects between the Buswell wire wound core and conventional designs. The report describes the several important aspects of the design and provides experimental and analytical backup to demonstrate the validity of the design.

Some of the Key features of the Design that are noted in this report:

1. Circumferential electrical windings with improved cooling duct efficiencies and very low hot spot increments for enhanced expected life.
2. Inherently tight windings that achieve the highest space utilization possible without the need for secondary compressing operations.

3. Utilizes Conventional (electrical) winding materials and insulating practice for the highest reliability
4. Revolutionary design uses best existing stable insulating and electrical winding materials while enabling continued use of most manufacturing processes.
5. Highly automatable magnetic core configuration for minimum labor content and for world-wide cost competitiveness leading to job retention within the United States.
6. Size and weight advantages in the order of 5-10% over present designs.
7. Robustness with inherently high short circuit strength largely due to magnetic circumenvelopment.

A. Introduction

Buswell Energy LLC provides leadership to a strategic team comprising industry, academia, and a host of industry consultants and partners to produce an oil immersed transformer in which the magnetic components circumenvelop the electrical component and promise compact size, efficiency, manufacturing, and cost advantages. The magnetic components are constructed of a coated ferrous wire rather than wide sheets to enable envelopment that is homogeneous, symmetrical, balanced, and robust.

This report outlines progress to date on DOE project Award No. DE-FC02-06CH11353 / Amendment No. A000/ 2011 Ext., especially as corroborated by data emerging from a June, 2011 prototype including:

a) Extensive thermal and flux modeling, being carried out with partners at Tennessee Technological University and Western Kentucky University.

b) Performance versus conventionally designed oil immersed transformers both in their manufacturing and in their operation in collaboration with Kentucky Association of Electric Cooperatives

c) Changes in the configuration of the magnetic and electrical components as displayed in the design rendered by Phil Hopkinson of HVOLT Inc.

d) Progress toward advanced materials for incorporation in the design achieved with partners at Bekaert Corporation

e) Challenges and emerging solutions to assure commercial success of the design.

Recent testing verifies the efficacy of the technology and the proposed design and indicates the need for improvements in the specialized wire. Recent dialogue among Buswell, Bekaert, and Ames Laboratories reveals a pathway to successful completion of and commercialization of this unique design.

B. The Design and Comparison to Conventional Transformers

A number of features compare the Buswell design to the present design meeting the DOE energy efficiency requirements of 2010:

a. Pictures right and left of old versus new

Figure 1 The Buswell core and coil assembly on the assembly line and in the tank. The round configuration is particularly well suited for round tanks as in single phase pole type transformers.

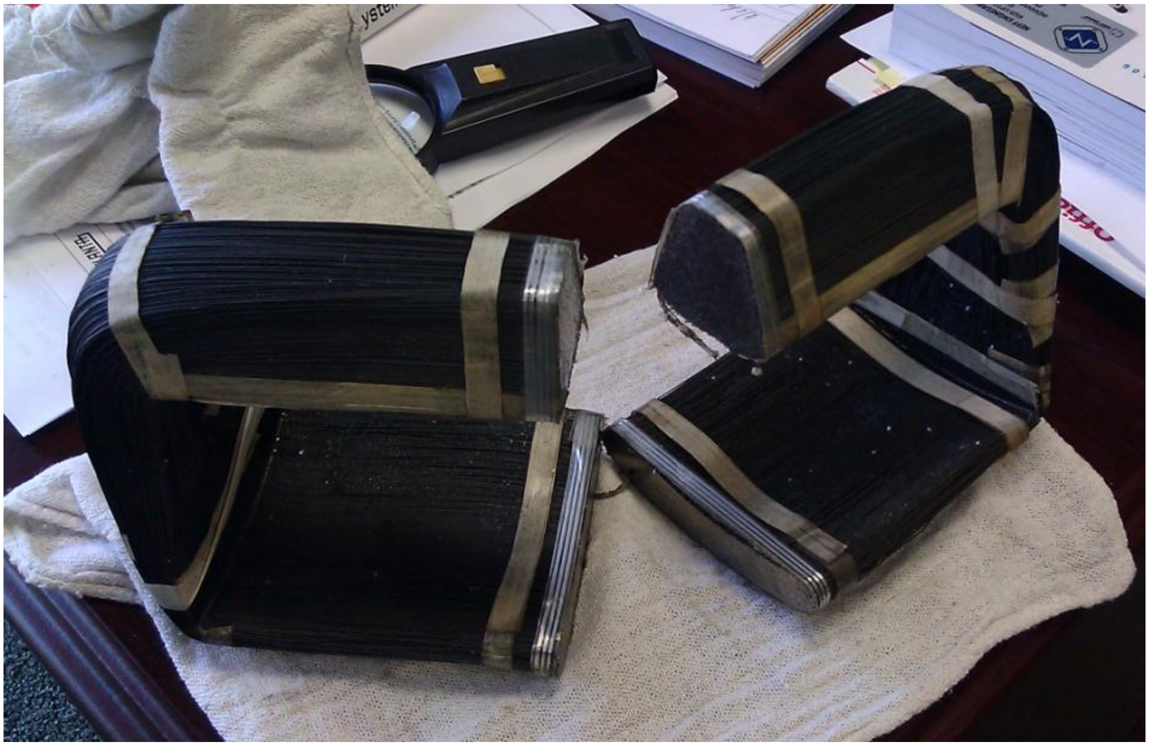

Figure 2 shows the wire wound core segment. Note that the core segments are in modular form for rapid assembly.

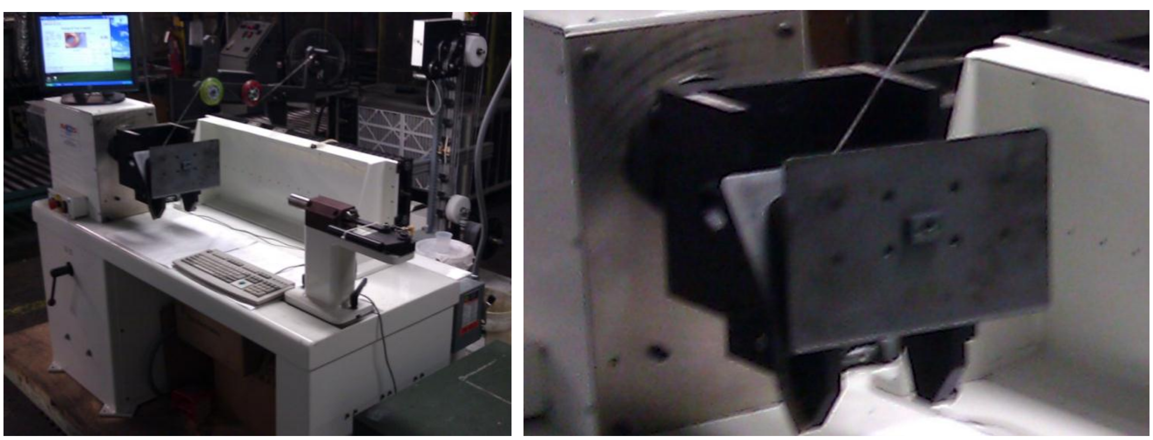

Figure 3a on the left shows the Buswell core winding machine, while figure 3b on the right shows the tooling and fixture.

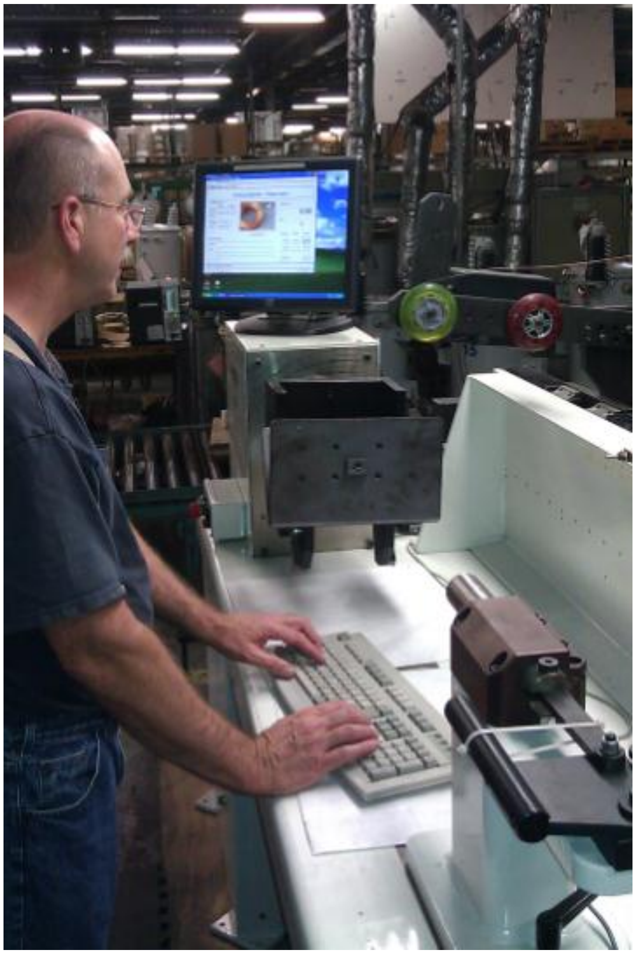

Figure 4 shows Manufacturing Engineer Bill Lowder at the core winding machine.

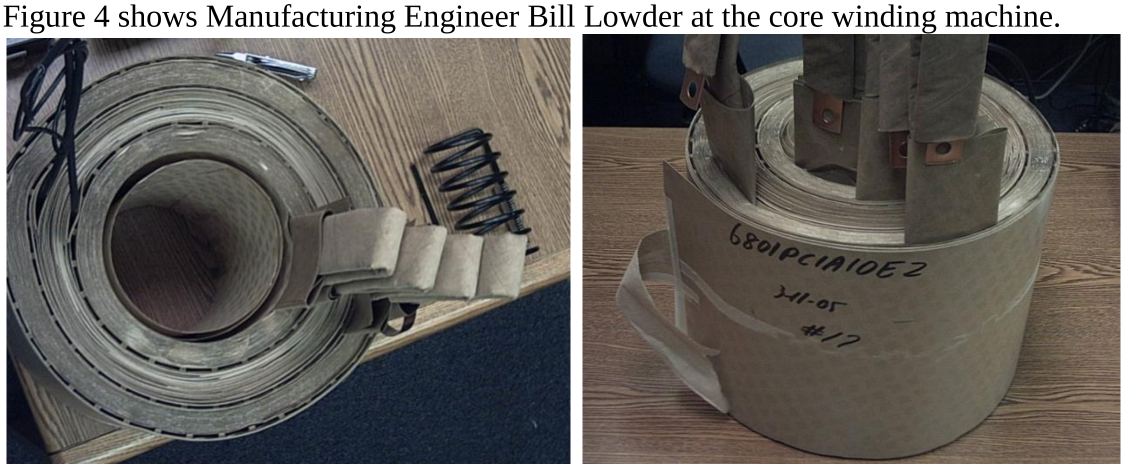

Figure 5a and b shows the electrical windings. Note the full circumferential cooling ducts in the windings which are particularly efficient at removing heat and with very little hot spot increment over average (typically in the range of 8 degrees C). This is quite different than the conventional rectangular windings presently in use where heat has to travel relatively long distances to find a cooling duct and where hot spot increments can reach up to 15 degrees C.

Design comparison for a recent calculation:

Design	Conventional	Buswell
Core Material	M3	0.010 Rd
Core Material Cost/lb.	$1.50	$1.50
Core watt/lb. at 15 kG	0.440	0.355
Volt/Turn	3.00	3.00
Core Stack Factor, %	97	70
B max in kG	14.57	15.50
HV material	CU	CU
HV Current density, ASI	780	950
LV Material	Al	Al
LV Current Density, ASI	500	500
LV sheet width, in.	7.0	8.0
HV Electrical length, in.	6.2	7.2
Winding MLT, in.	28.5	25.5
Core weight, Lb.	**83**	**84**
LV Material weight, Lb.	19.2	17.1
HV Material Weight, Lb.	41.0	30.1
Core height, in.	10.3	11.5
Tank Diameter, in.	14.1	12.5
Total Weight, lbs.	**257**	**229**
Winding loss, watts	148	148
Core Loss, watts	34	34
Total Loss, Watts	182	182
Electrical efficiency, % at 50% lo	**98.67**	**98.67**
% IR	1.48	1.48
% IX	1.45	1.16
%IZ	2.07	1.88
Temp Rise LV, in degrees C	42.4	34.8
Temp Rise HV, in degrees C	37.6	35.7
Material Cost, $	**$497.15**	**$436.18**

Figure 6 shows a recent comparison for the 10 KVA rating.

C. Performance against IEEE C57.12.00 and C57.12.90 for Routine and Type Tests

Item	Calculated	Measured	Comments
1. Winding resistance			
a. HV	46.7	46.7	Passed
b. LV	0.043	0.043	Passed
2. Ratio	5.15	5.15	Passed
3. No-load watts	27	117	Needs Work
4. % Exciting Current	5.0	8.4	Needs Work
5. Impedance	3.15	3.15	Passed
6. Impedance watts	167	167	Passed
7. Applied Potential Test	34 kV	34 kV	Passed
8. Induce Test	2XN	2XN	Passed
9. Temperature Rise HV	45	44.7	Passed
10. Temperature Rise LV		33.7	Passed

Discussion:

1. **The Buswell electrical windings are excellent in their dielectric and thermal characteristics.**
2. **The magnetic core has high losses due to the wire that is available to date. Fix is the wire.**

3. **The magnetic core also has high exciting current attributable to the gaps in the core and should be reduced through lapping of the core faces. Fix is the wire**

D. The Electrical Component

1. **Round coils** are able to enclose the maximum area for a given perimeter of winding material. This fact was one of the earliest concepts that Harrie Buswell applied in this revolutionary design approach. Not only is the resulting design efficient in its utilization of material but full bolted fault short circuit strength is easily achieved with almost no impedance change.
2. **Sheet wound Low Voltages** are a central aspect of the Buswell design. Through sheet windings in the low voltage windings and wire windings in the high voltage, current in the sheets redistributes to balance the primary winding amp-turns and axial short circuit forces are virtually eliminated, further improving short circuit strength.
3. **Full Circumferential Ducts** result in up to 3-4 times the cooling efficiency over end ducts only due to the close proximity of the cooling surface to the heat generating windings and dramatically reduce hot spots associated with end ducts only. The result of this is that fewer ducts are required to cool the windings in the Buswell design than for conventional transformers.
4. **Provisions for Leads as well as oil flow** are accommodated by the core segments which leave open spaces for oil entry and departure and allow sufficient space for low voltage leads at one end and high voltage leads at the other end. The results of such a configuration was a prototype that passed all dielectric tests including impulse and did so with a winding hottest spot temperature rise over ambient of only 26 C compared to the allowable 80 C by standards as well as to the calculated rise of 31 C.

Gapped Cores provide high tolerance for half wave rectified loads Modern high efficiency distribution transformers have very low exciting current that averages well under 1% of the rated load current. This very low exciting current minimizes the need for power factor correction devices on the Electric Utility System. While this is true and generally good, any DC as from half wave rectified loads may quickly produce core saturation and overheating of the transformer. The Buswell design with gapped cores effectively tips over the B-H magnetic core sufficiently to provide high tolerance to DC. This can be problem in the field and thus offers an advantageous design alternate.

E. A look at Manufacturing Labor:

Conventional transformer designs are difficult to mechanize and have not had appreciable improvements in the build and assembly productivity for many decades. However, as a result of the round windings with very few cooling ducts which minimizes electrical winding labor and the modular core construction that minimizes core labor, the Buswell design appears to be able to reduce total transformer labor appreciably over the present designs as shown in figure 7 below:

TASK	CONVENTIONAL	BUSWELL
BUILD CORES	0.5 HRS	0.5 HRS
ANNEAL CORES	0.1 HRS	0.1 HRS
COIL BUILD	0.8 HRS	0.6 HRS
ASSEMBLE C&C	0.3 HRS	0.1 HRS
ALL ELSE	1.7 HRS	1.7 HRS
TOTAL	3.4 HRS	3.0 HRS

For an in depth examination of the Manufacturing Process Analysis See Appendix II:

Computer Modeling DATA

Computer calculations have been rendered by two academic researchers at two universities to investigate magnetic flux projected operational parameters. Further work at a third university has investigated simulation of heat flow with this new design and new approach using wire form factor magnetic materials.

F. Thermal modeling by Satish Mahajan:

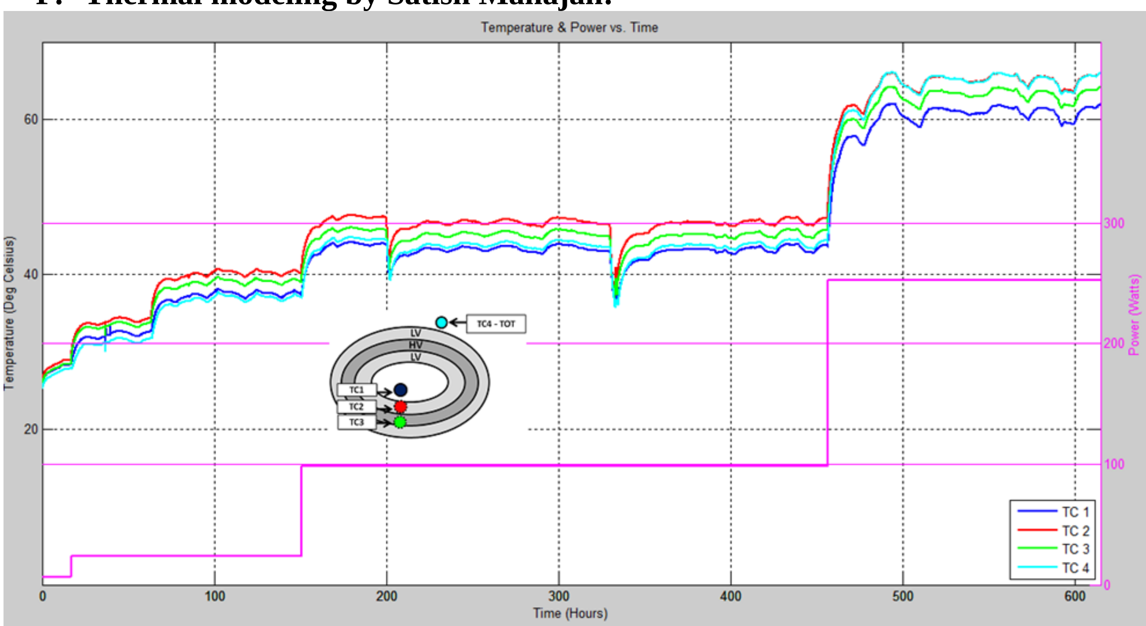

Figure 8 shows measured temperatures over a 600 hour period on the Buswell design when carrying progressively larger amounts of load. The respective plots are for the thermocouples that were placed in the windings.

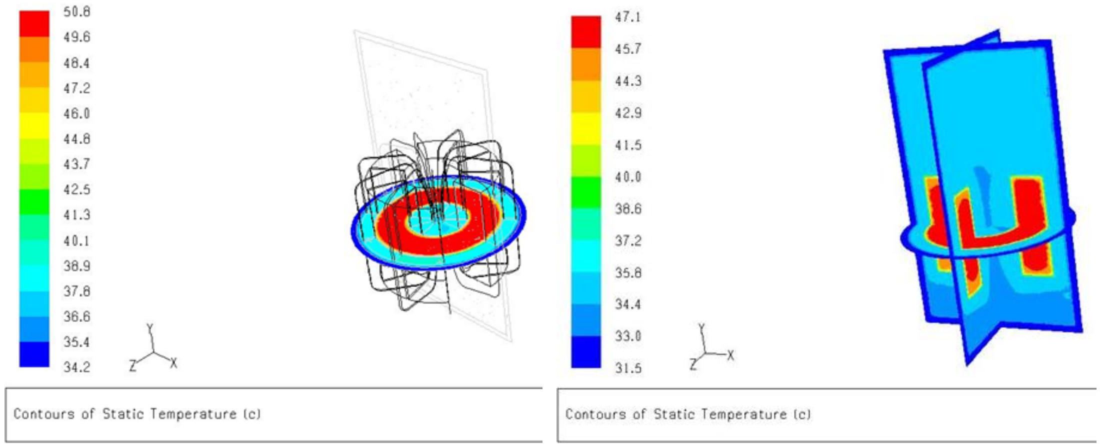

Figure 9 shows temperature contours with no core loss and 1.0 pu Load

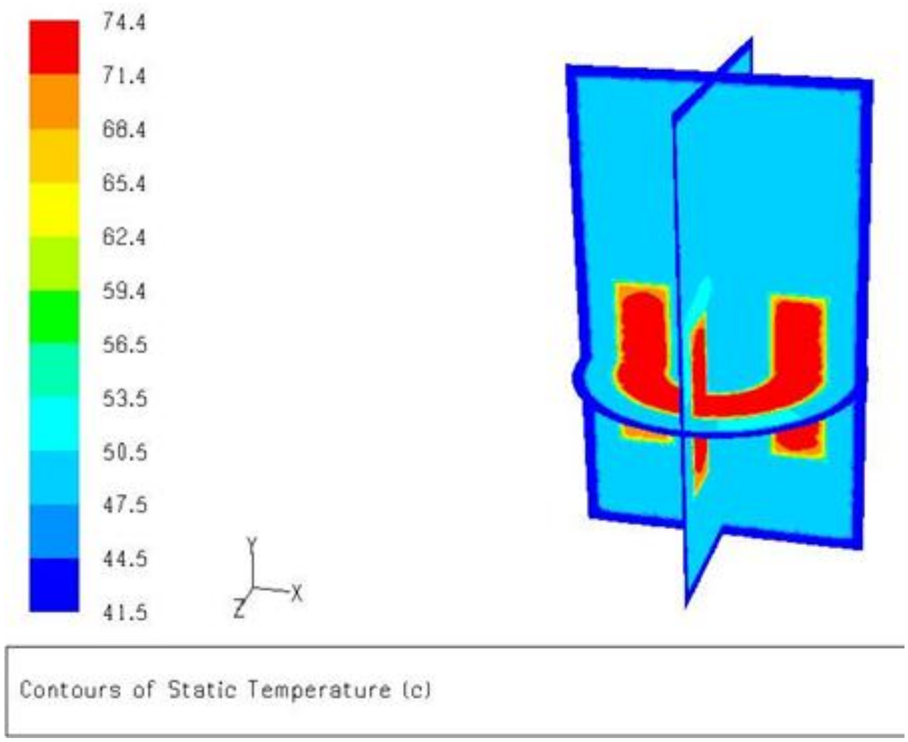

Figure 10 shows temperature contours with 21 W core loss and 2.0 pu Load

FINITE ELEMENT ANALYSIS by Walter Collett, PhD

a. Model description, key assumption, version, source and intended use;

There have been a couple of different configurations modeled: a 10 kVA conventional unit and a 10 kVA wire core design. Both cores were modeled as solid objects with the material properties of each assumed to capture the 'effect' of either the laminations (for the former case) or the wire stacking factor (for the latter). The models were put together in Maxwell 3D Transient solver, with the latest version employed being version 14 (earlier versions were used some time back with the learnings incorporated into the newer version). The models involved calculating excitation current, induced voltage, flux density, and core loss.

b. Performance criteria for the model related to the intended use

The model was able to calculate required performance parameters,
including: core loss, excitation current, induced voltage, and core flux density. See the next item for comments on performance validation.

c. Test results to demonstrate the model performance criteria were met (e.g.
code verification/ validation, sensitivity analyses, history matching wit lab or field data as appropriate)

The conventional 10 kVA transformer was analyzed due to available test data to compare to. The resulting core loss calculations were made initially assuming a certain number of turns on the high voltage winding which was inaccurate, leading to answers that were 15 - 20% higher than test data. In fact, we would expect FEA results to actually be a bit lower than test results due to the fact that FEA cannot account for certain effects in a physical model. When the conventional models were re-run using a corrected number of turns, the results did drop below test results, by about 15%, which is closer to what we would expect for the aforementioned reason. This modeling led to a greater level of confidence in the software's ability to reasonably calculate core loss for the wire core design, and to compare different configurations.

d. Theory behind themodel, expressed in non-mathematical terms

The theory behind the model involved calculating the core loss based on both the BH characteristics of the core material and the Power Loss curve (Watts loss versus induction). If core flux density can be accurately estimated, the latter curve has the potential to provide a reasonable estimate of resulting core loss. The model was developed with primary and secondary windings, the electrical steel core material, and appropriate boundary and source conditions applied. The flux density in the core magnetic circuit was determined using finite element analysis (FEA) via the Maxwell 3D Transient solver. The Transient solver was used to allow the computation of flux density for nonlinear materials such as the core in the transformer. The core material parameters were assumed to be substantially equivalent to M3 electrical sheet steel; parameters for this material were extracted from material suppliers' data sheets. It is important to note that material properties may vary somewhat from one supplier to the next, or even from one batch of material to the next.

e. Mathematics to be used, including formulas and calculation methods;

The precise mathematics of the solution method is presented in great depth in the ANSYS Maxwell software documentation, which can be accessed via the software itself. The methodology provided therein has been employed by ANSYS and by ANSYS clientele making use of the software for these types of applications for several years, and the software capabilities have grown over time; the most recent version, for example, actually allows for the user to specify stacking factor in core material for transformer/machine applications.

f. Whether or not the theory and mathematical algorihms wer peer reviewed, and, if so, include a summary of strengths and weaknesses

See above.

h. Hardware requirements; and documentation. (user guide and code)

The hardware employed by the work was a quad-core desktop workstation.
ANSYS Maxwell makes use of multiple processor cores, although increasing the number of cores beyond four does not apparently increase computation speed substantially. The documentation employed was to be found in the Maxwell help index, which contains the entire user guide for the software.

ACCELERATED AGEING MODELING

As of January, 2012, a 10KVA prototype oil immersed distribution transformer is undergoing accelerated aging testing at facilities at Tennessee Technological University Electrical Engineering Department under the direction of Dr. Satish Mahajan. Early results are good for this testing indicating that this design, using wire for the primary magnetic media does indeed offer some advantage in operation as well as in manufacturing of such units. The premises and the projections that advantages are inherent in such design are being borne out. The major advantages are total cost to manufacture including less intensive hand labor, a lessening of eddy (Foucault) current generation, and a dramatic lessening of hot spots. Amelioration of hot spots means that less derating is necessary in the design and a longer life can be expected. This also means that a unit can withstand more over current conditions with less deterioration and consequent shortening of useful life. These three major advantages (manufacturing cost, eddy (Foucault) current lessening, and hot spot amelioration) are interactive such that by design and perceived need the relative advantages can be traded back and forth; if one advantage feature is maximized it likely means less than maximal for the other two. Certainly this is true for the first noted (manufacturing advantage) versus the other two (eddy current production and hot spot amelioration). Classic transformer design constraints (tradeoffs) are rendered with an overall lessening of constraints when the design is accomplished using wire magnetic media rather than the sheet as has been used exclusively in industry for over 100 years.

It is important to note that decreasing losses in transformers such as distribution transformers and indeed in all transformers dedicated to the delivery of electric power carries double advantage always. It is that not only does the lessening of loss mean each Watt so saved is passed on for end use, but also it means that same “each Watt” is not wasted as low level degrading-to-the-transformer heat which must then be dissipated to the environment.

G. The Magnetic Component Core Comparison of newest prototype to conventional transformers

The nominally rated 10KVA new prototype is compared to a conventional 10KVA rated transformer.

The graphs below portray the Wattage levels at no load with a range of frequencies applied which traverse from 60 Hertz to 5000 Hz.

Both units display a characteristic curve which begins at a level, drops to a low at about 1000 Hz then rises non-linearly to a high at the 5000 Hz level.

These graphs are with the condition of voltage level applied being held constant over the entire range of inquiry.

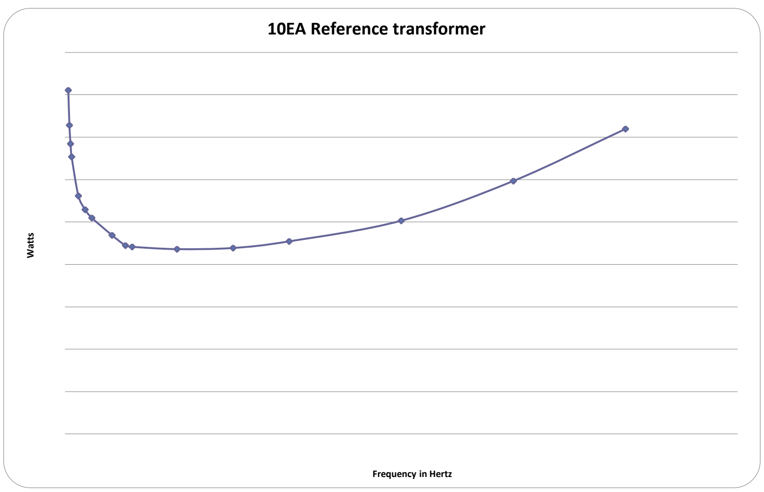

Figure 11a and b shows a plot of watts loss versus frequency in Hz

It is understood that at a constant voltage the flux will be approximately inversely proportional to the frequency.

Various means of comparison of losses are available (see footnote #1). One is to compare readings at two levels of temperature. Another is to compare readings at two levels of flux density. Another is to compare readings at two levels of excitation voltage. Another is to compare is direct current hysteresis method.

Accordingly constraints on each measurement method must be observed. For example, with the two frequency method:[1]

1. Hysteresis losses vary directly with frequency.

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[1] Bozarth, R. M., (1978) Ferromagnetism. IEEE Press. IEEE Magnetic Society.
Staff, MIT, (1943) Magnetic Circuits and Transformers. John Wiley & Sons. NY, NY.
Heathcote,M.J., (2007).13th Ed., The J&P Transformer Book Elsevier Press. London.

2. Eddy current losses vary with the square of the frequency.
3. Temperature is held constant.
4. Applied source AC is sinusoidal.

Whereas with the two temperature method the constraints to be observed are:

1. Iron core electrical resistivity increases linearly with temperature
2. Temperature coefficient of the iron alloy is known
3. Peak magnetic flux remains constant
4. Hysteresis losses assumed to be independent of temperature (at least for the range tested).

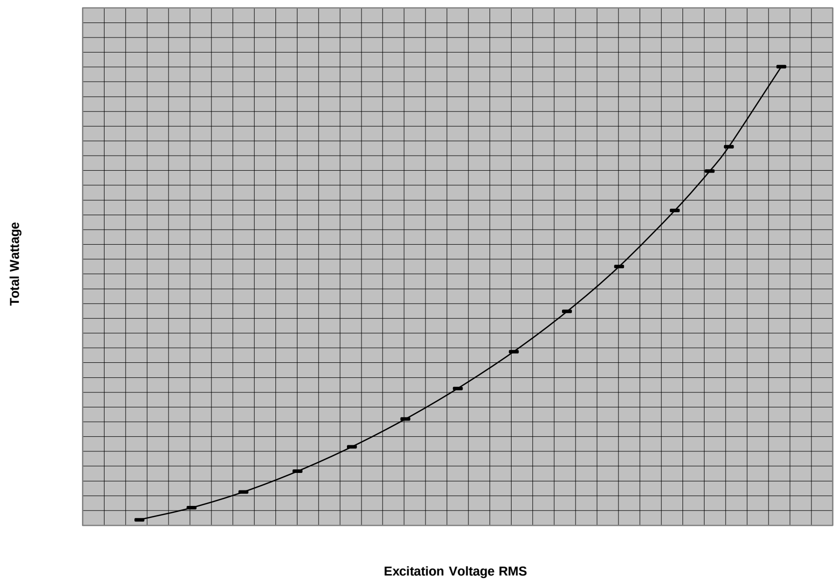
However, anomalies and discrepancies are present and complicate exacting calculations. The current flow through the conductor, although small, accounts for some of the no-load losses. The presence of anomalous losses adding to the classical hysteresis losses and the classical eddy current losses, however, are very difficult to fully identify and to account for. The flux in a no-load measurement is non-sinusoidal thus has higher frequency components[2]. Accordingly we have approached the loss calculations from a less complicated means which is to accurately measure total no-load losses then to chart distinctions involving hysteresis losses and eddy current losses.

Eddy current losses with the new prototype are higher than the eddy current losses of the reference unit. Given all else equal, the anticipated eddy losses should be lower with the new prototype since a wire form factor is used for the all of the magnetic components while the strip is used for the reference unit. However, all else is not equal in that the coating of the wire is not as thick or as robust on the wire as that enjoyed by the wide strip of the reference unit. This feature was expected as sample coils and sectors tested also displayed this shortcoming. Further (post prototype) testing at various frequencies revealed more fully that such coating processes as used achieved much lower eddy current losses in round wire form factor than for the flat wire as used in the prototype.

This shortcoming can be overcome in several ways. One way is that more than one coating be engaged, which would be similar to the conventional wide material's preparatory treatment. Another is that another coating process and material is engaged. A third means of improving the coating performance (lessening the electrical conductivity between adjacent wires) is the use of a round wire form factor rather than the presently attempted flattened wire. Eddy current (Foucault current) losses can be addressed and lessened by available

[2] Arsenuau,R. et al, (1984). A Method For Estimating The Sinusoidal Iron Losses Of A Transformer From Measurement Made With Distorted Voltage Waveforms. <u>IEEE Transactions on Power Apparatus and Systems. Vol. 103.</u> October 1984.

Buswell Prototype Watts @60 Hertz range 10 to 130 V RMS



strategies as noted above. However, hysteresis losses are the greatest and most important loss source of this prototype unit. The features of the wire-as-used that are untenable remain the same; too high coercivity and too low relative permeability. The wire chemistry and associated drawing processes have not yielded a magnetically suitable grain orientation along the linear length of the wire. The above graphs are clear; the level of losses at 60 Hertz is acceptable for the reference unit and unacceptable for the prototype unit. The magnitude of the difference is about 4X with the level being 12 Watts @60 Hertz for the prototype and ~3.3 Watts @ 60 Hz for the reference unit. This is a factor of about 3.6 times greater hysteresis loss with the prototype unit. Allowing 1/3 of the losses at 60 Hertz to be due to eddy currents, the losses would be about 8 Watts versus 2.2 Watts which is still a ~3.6 ratio. The measurements given for the comparisons of the two units (and also a third unit, another reference transformer) were enacted at reduced voltage levels (37 volts) which is a level that allowed the test equipment to perform reliably across a broad frequency range from 30 Hertz to 5000 Hertz. Figure 12 shows watts core loss versus excitation voltage.

Referring to the above graph which was generated by a single 60 Hertz (line) frequency, it is clear that reducing the losses by that 3.6 factor would yield a satisfactory set of no-load losses, even given a set of conditions with too high eddy current losses. At an excitation level of 117 Volts RMS, the no-load current was 5.76 Amps and 95.84 Watts. Reduction of the 95.84 Watts by a factor of 3.6 yields 26.62 Watts. This figure places the prototype unit in an acceptable range of total losses bearing in mind that the weight of the magnetic wire components was short of the design specification by 2.38-Kg (5.25 pounds). Projection of the data to account for this brings the 95-Watts total loss to 87-Watts no-load losses.

Accommodating for the 3.6 magnitude factor projects the 87-Watts to 24-Watts. This value brings the range of the prototype to within the range of currently manufactured transformers meeting current DOE requirements.

Finally, these projections can be joined to a further projection which conservatively adjusts the overly large eddy current losses to a reasonable value. Four Watts at 60 Hertz is a reasonable and conservative value to adjust for the prototype magnetic material shortcoming due to coating limitations. The final projected and conservative value for the new prototype is then 20-Watts total no-load losses. The final no-load Watts of the benchmark reference transformer as measured at the assembly line by KAEC was 23.1 Watts.

Comparison table of data collected as of report date

Parameters	Units	Projected Buswell	Buswell Transformer	benchmark Transformer
No load losses	W	20	95	23.1
Primary cu	Lb	30.4	30.1	33.9
Sec al	Lb	19.0	19.2	21.2
Core steel	Lb	98	84	100.8
Load loss	W	180	167	190.5
Temp rise low voltage	deg C	35	34.8	42.4
Temp rise high voltage	deg C	35	35.7	37.6

Additionally, Dr. Mahajan at TTTu has sent an interim report on heat tests with accelerated aging.:

Interim Report from Tennessee Technological University date of December 5, 2011 includes the following:
So far we have gone up to 200 % of normal load (2 p.u.) on the Buswell transformer.
1. The HST at 1 p.u. is comparable to the conventional design; however, a slightly lower HST at elevated load (2 p.u.) is a ***definite advantage****. We need to wait and see if the trend continues at higher (2.6 p.u.) loadings.*
2. The TOT on the other hand is slightly higher; however, that is a reflection on the design of the tank (including volume of oil).
Once we conclude testing (180,000) hours, we will know more about these trends

Transformer	*Loading (per unit)*	*Hot spot temp (°C)*	*Top Tank (°C)*
DT2 (reference)	*1.0 (100%)*	*48.15*	*40.12*
	2.0 (200%)	*103.98*	*79.58*
Buswell (proto)	*1.0 (100%)*	*47.21*	*44.4*
	2.0 (200%)	*97.92*	*92.11*

H. The Wire Material:

The goal of Bekaert and Buswell (working with ORNL until 2009) to create and apply a unique ferrous wire with magnetic properties equivalent to or better than those found in silicon iron M3 sheet. This enables magnetic components that circumenvelop the electrical components. The magnetic components are constructed of wire rather than wide sheets to enable envelopment that is homogeneous, symmetrical, balanced, and robust. Critical steps include providing development through material composition, coating, and process specifications through modeling, sample experimentation, production and verification. No suitable wire material is available, but we have made strides in the development of that product.

I. **Coating**:

It is critical that the coating will be sufficiently robust to maintain its integrity through the winding and cutting process. While the move to flat wire is a far greater challenge for the coating which has not yet been overcome, there is no clear barrier to Bekaert's development of this coating. They are currently experimenting with both oxide coatings and glassine coatings, but have not ruled out other approaches. This challenge is neither as great nor as critical as is the composition plus process of the wire achieving suitable soft magnetic properties. .

J. Critical path to energy efficiency improvement and lower costs are the wire.

Buswell Energy LLC has developed new transformer designs that promise energy usage reductions in both the manufacturing (the making of the units) and the years of operation.. Much has been accomplished in the development of these designs and recent prototypes demonstrate the energy efficiencies and commercial advantages inherent. The critical path chosen to commercialization of the Buswell transformer is the use of iron based iron alloy wire in constructing the transformer's magnetic component in **substitution** for the silicon iron electrical steel strip material employed in conventional designs.

K. The Mission is possible through strategic alliances with Bekaert and Ames Laboratories.

Buswell Energy and its project partners, Ames Laboratories & Bekaert Corporation, believe that wire with magnetic characteristics equivalent to or exceeding the conventional M3 grade electrical steel strip can be achieved and produced through the joint project proposed including incorporation of the innovative wire in a prototype dry type power transformer of the Buswell design. Ames Laboratories have heat treatment and hot and cold fabrication capacity to cast ingots. Dr. Lograsso is expert in the processing of crystallographic texture and the identification of properties required for this application and has been developing this type of processing for iron based alloys under investigations for other projects. Along with Ames Laboratories and Buswell, Bekaert Corporation will produce sufficient quantities of this material for proof in the units designed.

L. What do we need

Buswell Energy and partners, including Ames Laboratories are seeking funding to engage this critical materials development research and for demonstration of the efficacy of the Buswell design in transformer types for commercial markets.

Conclusion

Clearly there are advantages to the design utilizing wire rather than sheet for the bulk of the magnetic materials. Even though as of this date there has not been a wire material available that meets or exceeds the target material of "M3" electrical steel sheet, the design, the calculated component values, and the prototype built fall in line with expectations. Given the performance of a new prototype with some room for improvement of winding magnetic material and cutting of the magnetic material …and that the amount of magnetic material is less weight than specified…and that the magnetic material is not grain oriented and even further is not as good as could be even without orientation, the prototype performs as expected. With a suitable magnetic material transformers made in this way would not only perform more efficiently but would be expected to have longer life (due to hot spot amelioration) …even as manufacturing costs could be kept equal or even lessened.

It will be realized that various tradeoffs can optimize or maximize various conditions and parameters. Projections by Phil Hopkinson in one optimization were for saving maximally on conductors but not saving on magnetic material. This comes to for the 10 KVA size transformer 26% less copper and 11% less aluminum with a total weight advantage (this includes the tank) of 10.9 %

HVOLT, INC calculations:

Material;	Conventional	Buswell	% Change
Copper lbs	41.0	30.1	26.6 %
Aluminum lbs	19.2	17.1	11.0 %
Iron lbs (magnetic material)	83	84	-1.2 %
Total Weight lbs	257	229	10.9 %

Appendix I: Background **report summarizing some of the earlier design work from 2003-2008.**

Following up from our June 27-28 of 2006 meetings in Louisville, Phil Hopkinson prepared (7) designs for comparison that should be helpful to the team. The designs are in Excel Spreadsheets 4, 5, 7, 10, 11, 12, and 13. They are summarized in Spreadsheet 14. Descriptions of the options are shown in table 1 below:

Table 1 Description of Design Spreadsheet Options:

Spreadsheet	Description
5	Present 10 kVA Sheet Core meeting NEMA TP-1
11	Option 1 with wire wound core and 0.010" thick wire core at 70% Space factor to replace sheet core.
7	8-segment Buswell 0.010" thick core at 78.5% Space factor in cylindrical L-H-L coil
10	8-segment Buswell 0.010" thick core at 70% Space factor in cylindrical L-H-L coil
12	8-segment Buswell 0.010" thick core at 70% Space factor in Obround (Football shape) H-L-H coil
13	8-segment Buswell 0.010" thick core at 70% Space factor in Spherical H-L-H coil
4	Prototype 8-segment Buswell 0.040" thick MX core at 65% Space factor in cylindrical L-H-L coil

For the comparisons, spreadsheet 5 shows the existing 10 KVA sheet-wound core that meets NEMA TP-1 today. A view of the configuration of the existing Shell Form design is in Figure 1 below:

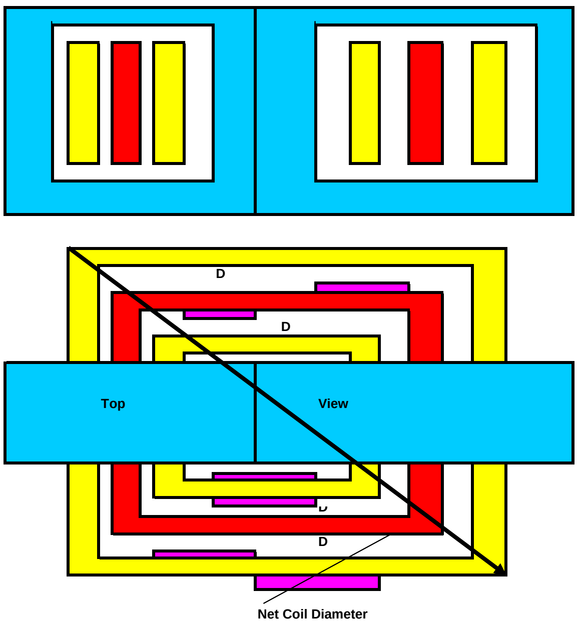


Figure 1: Existing 10 KVA 7.2 kV primary to 120/240 V secondary Shell Form sheet-wound core from spreadsheet 5. Note distortion is due to spreadsheet cells that were used for calculations and descriptions.

For the existing design, M3 core steel was used with an assumed purchase cost of $1.10/lb. and a core loss performance of 0.44 watts/lb. at 15.0 KG. Aluminum sheet low voltages were used and Copper round wire high voltages.

All of the alternative design options were calculated using wire cores instead of sheet cores. The early prototype 10 KVA design was constructed to test the performance of a wire core concept, using 0.040" diameter iron wire. Spreadsheet 3 (cell L33) shows the assumed performance of such a wire. The purchase price for this wire was $8.00 / lb. and should perform in the vicinity of 4.4 watts/lb. at 15.0 KG, due mostly to excessive eddy losses from both internal and inter-laminar contact. The configuration for this design is as shown in Figure 2 below:

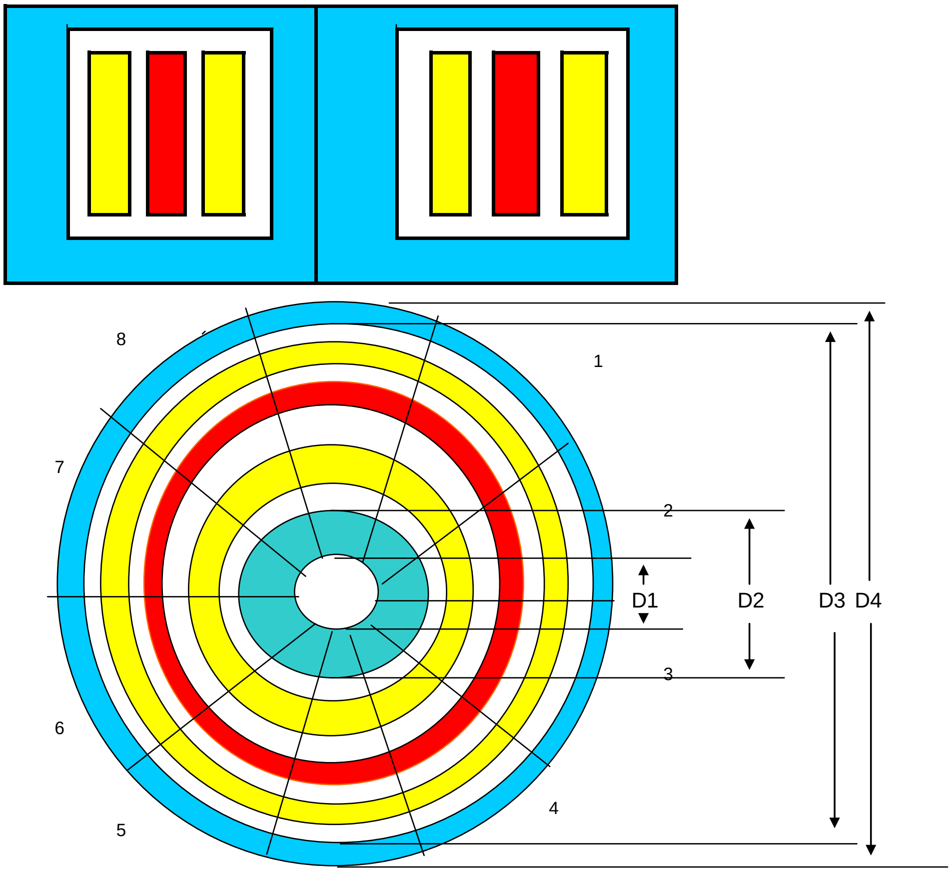


Figure 2 shows core and coil configuration of Spreadsheet 4 Prototype design with 0.040" iron wire to replace M3 0.009" thick core steel.

The winding is round with the low voltage in yellow and the high voltage in red, in a Low-High-Low arrangement. Figure 3 below shows the winding arrangement in better detail:

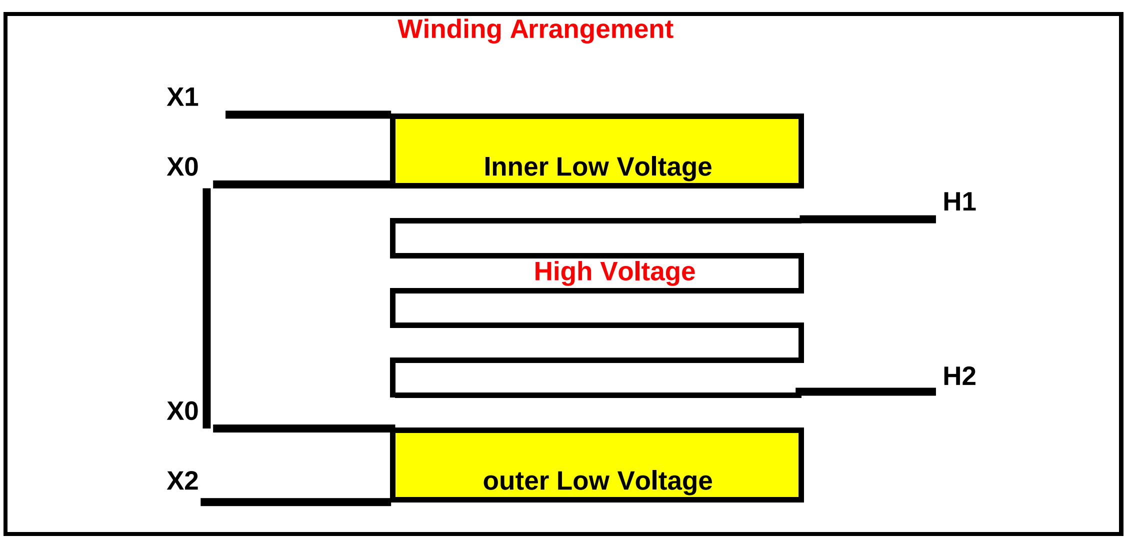


Figure 3 showing winding arrangement for Spreadsheet 4 prototype 0.040" thick wire core design.

Eddy currents in the steel magnetic wires vary as the square of the wire diameter. Per spreadsheet 3, cell N33, it appears that wire or 0.010" Diameter, and insulated to 0.1 ohm-in should be able to achieve 0.355 watts/lb. at 15.0 KG. This assumption is used for all of the remaining design options with wire cores (spreadsheets 7, 10, 11, 12, and 14). The assumed cost of wire is $1.10 / lb., the same as M3 core steel at date of first calculation.

Spreadsheet 7 uses an assumed steel wire packing density of 78.5%. This is the theoretical maximum fill of a round wire in a square boundary. With a random wound core, there will be crossovers that will decrease space factor. However, there will also be wire nests that will increase the space factor. It is not clear what space factor can be achieved, and this may need to be determined from empirical results. Spreadsheet 7 is also constructed with as assumption of 8 core segments out of a theoretical 10 section pie. The two pieces that are not used allow oil to enter from both open ends and allow low voltage lead connections at one end and high voltage leads at the other end.

Spreadsheet 10 continues to use 8 core segments, but the steel wire packing factor is 70% instead of 78.5%.

Spreadsheet 11 is a Shell Form design like spreadsheet 5, but 0.010" thick steel wire is used at 70% packing factor in place of the M3 core steel at 97% space factor.

Spreadsheets 13 examine the potential of a spherical shaped coil with a spherical 8-segment core. The core/coil looks like figure 4 below:

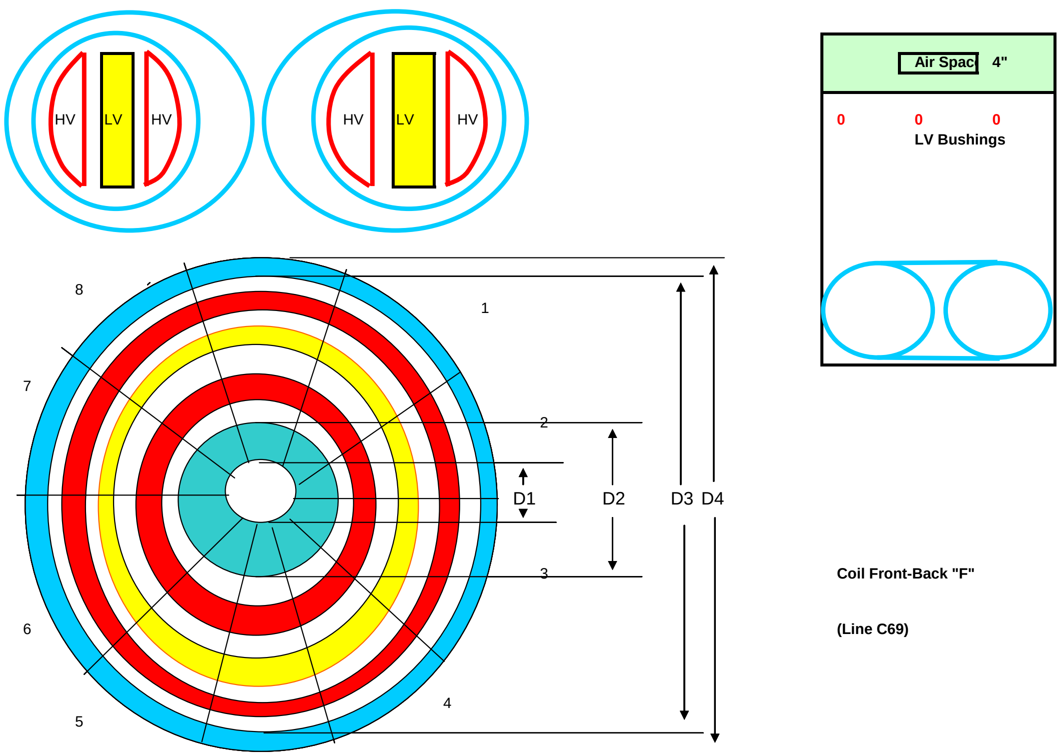


Figure 4: shows the core and coil arrangement for Spreadsheet 12, wherein both the coil and the core are in spherical shapes. Note that the Windings are arranged Hi-Low-Hi as in figure 5 below:

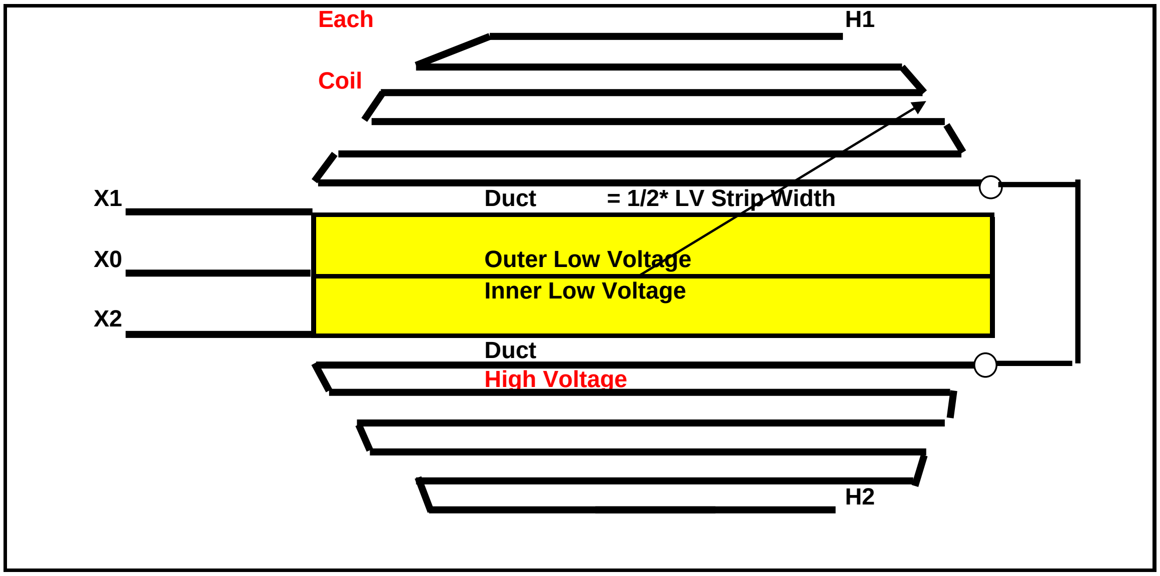


Figure 5: shows the windings arranged in Hi-Lo-Hi around the sheet low voltage winding.

Spreadsheet 12 is the same configuration as spreadsheet 13, but the coil is more football shape (Obround) to achieve a more cubical net core and coil shape. This results in both lower cost, weight and tank size.

Table 2 below summarizes key parameters from each of the 7 spreadsheets. They should be compared both to each other and to the overall constraints in the right column.

Table 2 summarizing key parameters for the 7 design options

Spreadsheet	Description
5	Present 10 kVA Sheet Core meeting NEMA TP-1
11	Option 1 with wire wound core and 0.010" thick wire core at 70% Space factor to replace sheet core.
7	8-segment Buswell 0.010" thick core at 78.5% Space factor in cylindrical L-H-L coil
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13	8-segment Buswell 0.010" thick core at 70% Space factor in Spherical H-L-H coil
4	Prototype 8-segment Buswell 0.040" thick MX core at 65% Space factor in cylindrical L-H-L coil

Spreadsheet	**5**	**11**	**7**	**10**	**12**	**13**	**4**	**Requirements**
Core Material	M3	0.010 Rd.	0.010 Rd	0.010 Rd	0.010 Rd	.010 Rd	0.040 Rd.	
Core Material Cost/lb.	$1.10	$1.10	$1.10	$1.10	$1.10	$1.10	$8.00	
Core watt/lb. at 15 kG	**0.440**	**0.355**	**0.355**	**0.355**	**0.355**	**0.355**	**4.359**	
Volt/Turn	3.00	3.16	3.00	3.00	3.53	3.53	2.40	
Core Stack Factor, %	**97**	**70**	**78.5**	**70**	**70**	**70**	**65**	
B max in kG	16.12	17.21	17.52	17.52	15.50	14.73	10.85	**< 18**
HV material	CU	CU	CU	CU	CU	CU	CU	
HV Current density, ASI	1000	1000	1200	1100	1000	1000	1100	
LV Material	Al	Al	Al	Al	AL	AL	Al	
LV Current Density, ASI	650	650	650	650	600	500	350	
LV sheet width, in.	7.0	7.0	7.0	8.0	7.0	5.0	8.0	
HV Electrical length, in.	6.2	6.2	6.2	7.2	6.0	4.2	7.2	
Winding MLT, in.	26.4	27.7	23.3	23.6	25.2	27.8	28.8	
Core weight, Lb.	**72**	**74**	**68**	**70**	**118**	**137**	**106**	
LV Material weight, Lb.	13.7	13.7	12.1	12.2	11.9	15.7	23.0	
HV Material Weight, Lb.	29.7	29.5	21.8	24.1	22.9	25.2	34.9	
Core height, in.	10.1	10.9	10.2	11.3	10.9	9.0	11.8	
Tank Diameter, in.	12.9	12.9	11.6	11.6	15.7	18.3	15.0	< 16
Total Weight, lbs.	**214**	**220**	**184**	**194**	**305**	**359**	**341**	**Low Weight**
Winding loss, watts	174	174	171	165	138	139	215	
Core Loss, watts	39	40	40	41	48	47	250	
Total Loss, Watts	213	213	210	206	186	187	465	
Electrical efficiency, % at 50% load	**98.45**	**98.45**	**98.46**	**98.46**	**98.45**	**98.45**	**94.37**	**98.4**
% IR	1.74	1.74	1.71	1.65	1.38	1.39	2.15	
% IX	1.15	1.04	1.16	0.98	1.25	2.74	2.34	
%IZ	2.09	2.02	2.06	1.92	1.86	3.08	3.18	< 3.0
Temp Rise LV, in degrees C	55.2	50.0	44.4	43.1	27.2	25.7	56.2	< 65
Temp Rise HV, in degrees C	49.4	46.2	45.7	44.0	26.7	25.5	58.9	< 65
Material Cost, $	**$333.26**	**$336.70**	**$293.06**	**$305.43**	**$373.89**	**$442.85**	**$1,195.83**	**Low Cost**
Apparent team priorities	**Reference**	**3**	**Goal=1**	**2**	**Drop**	**Drop**	**Prototype**	

Note that efficiency is calculated at 50% load. Mathematically, it is expressed:

Efficiency = 100% * (DC * 1000*(P))/(DC * 1000* (P) +NL watts + LL watts * (P)^2 * T

Where (P) = per unit load
T = temperature correction factor (adjusting temperature down from 85 C to 55 C.
NL watts is equal to the core loss watts.
LL watts is the full load winding loss in watts.

For NEMA TP-1, P = 0.5, and T = 0.93.

The 10 DC efficiency level has not been officially decided by the US Department of Energy (DOE), however they are likely to use NEMA TP1's requirement as they did for Low Voltage Dry type transformers. This Fall, they plan to issue their decision. The TP1 efficiency for a 10 DC rating is 98.4% efficiency. In order to consistently meet 98.4%, a design efficiency of 98.45% will be required. All but the first prototype option in Spreadsheet 4 are designed to meet the 98.45% requirement.

From these designs, clearly core space factor and core loss watts/lb. are important parameters. We need to work hard to maximize space factor and to minimize losses. Spreadsheet 7 appears to be our goal. Spreadsheet 10 at 70% space factor is our fallback position.

Appendix II: In Depth Examination of Manufacturing Process Analysis

1. **Buswell Power Transformer:**
2. **10 KVA Single Phase Distribution Type**
3. **23000 Transformers Per Year**

Buswell Power Transformer
10 KVA Single Phase Distribution Type
23,000 Transformers Per Year-Manufacturing Process Analysis

Buswell Energy with consultant, Donald Ballard
The Buswell transformer design concept is a unique configuration for any type of transformer. Power transformers are classified as core type or shell type. The single phase core type design has one core and two coils; the single phase shell type design has two cores and one coil. There is no clear advantage to either design.

The Buswell transformer would best be described as a toroidal design. The most notable toroidal transformer is the current transformer. It is made by wrapping electrical conductors around a toroidal shaped core made from high permeable material. The Buswell design is made by assembling a core made from high permeable material around an electrical coil. The Buswell deign could be called a shell type and the current transformer a core type. The advantage of the toroidal designs is the close physical coupling between the magnetic and electrical components.

Developing a method to build the Buswell design proved to be a challenge. All power transformers had been constructed using high permeable strip steel. Even the narrowest strip steel would not work for this design because the steel must be wrapped around a torus creating many problems including low space factor. Wire was needed to take care of the winding problems but no high permeable steel wire was available. Another problem was that high permeable steel strip requires a stress relief anneal after it is in its final form. In power transformers this is done before the electrical coil is assembled with the core so as not to destroy the conductors and insulation. This would not be possible if the core was already wound over the coil.

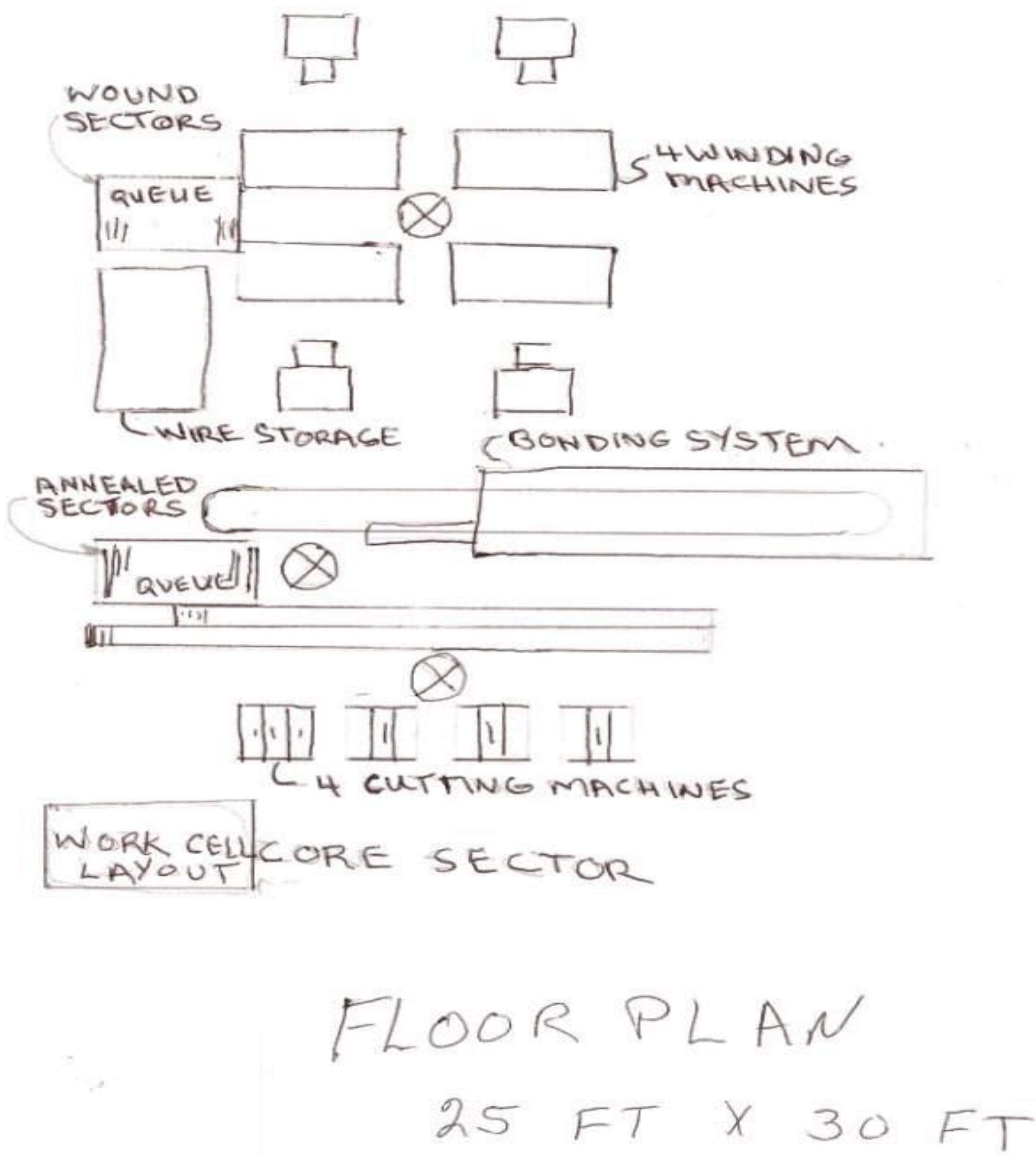
Buswell needed to develop a high permeable steel wire, preferably one that would not require a stress relief anneal. Buswell also looked at methods of assembling the core over the coil without winding onto the torus. It was decided that the best solution was to wind several sectors of the core that would fit tightly over the coil and then cut the sectors so they could be assembled. The resulting assembly is close coupled as in a current transformer and has the added advantage of not requiring a large center hole to perform the winding process.

Developing the wire material took much longer than anticipated. The development process was engaged using whatever wire could be obtained. The design process was completed with assumed wire characteristics. Process development was initiated with the understanding that winding and cutting processes are greatly affected by the characteristics of the wire.

- As wire development progressed it was determined that the wire needed to be much smaller than anticipated in the original design. This requires a faster winding machine for the same results.
- Without proper insulation on the wire it couldn’t be determined if the turns were shorting together.
- The life of a cutting wheel and the finish of the cut depend greatly on the material being cut. Silicon, which is normally in high permeable steel, is a big factor in cutting wheel life.
- Further development of the wire determined that flattening the wire improved magnetic characteristics. Another advantage is that flattening wire increases space factor (percentage of steel in the core sector) when compared to round wire.
- Process development tasks were aimed at making the cores with a minimum of labor as a typical transformer has one or two cores but this design has eight core sectors. The process chart below shows four processes to complete a core sector.

Process Chart

RECEIVE WIRE
WIND WIRE
ANNEAL WOUND SECTOR
CHANGE FIXTURE ON WIRE
BOND (IMPRENATE) WIRE
CUT SECTORS



The annealing process is considered an 'off work cell' task for this analysis because a manufacturer will not be purchasing an annealing oven for the level of manufacture analyzed. Annealing is a low labor content process. If justified, a pick and place unit could be used to load and unload anneal racks. The manufacturing cell will require three operators per shift. This could be reduced to two operators per shift with some development in material handling in the core sector bonding area.

Efficient manufacturing requires low cost material flow between work stations. Because the work pieces are light weight and well protected simple roller conveyor is all that is required. The only materials required are steel wire and bonding resin. Consumables include tape and cutting wheels. A work cell layout is presented below. This is only an idea generator. Undoubtedly a transformer manufacturer will want a different layout, maybe different material handling, and even different processes.

Winding a core sector will be automatic except for loading the empty fixture, attaching the wire to the fixture, and removing of the winding and fixture.

The Total cycle time is estimated to be about three minutes and the process availability is estimated to be 80%. Some of the down time is replacing spent wire spools. Other factors are operator breaks and machine failures. An operator can service four or five machines but in this analysis (s)he will be responsible for four machines. Estimated throughput is 12 per hour per machine or 48 per hour total. The process steps and times follow.

- Get fixture, attach fixture, and attach wire to fixture. 14 seconds
- Press start button 3 seconds
- Automatic wind sector, wire two high at 2500 RPM 3.5 minutes
- Cut wire and fasten both ends, off sector and fixture 14 seconds
- Total cycle time 4.0 minutes

Bonding a core sector will be automatic except for changing fixtures, removing the bonded sector from the overhead conveyer, and placing the not yet bonded sector on the overhead conveyor. The total cycle time is estimated to be 2.5 hours and one operator will be required. Estimated throughput is 48 per hour. The process steps and times follow.

- Get fixtured sector and remove side plate 10 seconds
- assemble bonding frame onto sector 5 seconds
- Flip over sector and remove side plate and center arbor 10 seconds
- Attach sector hanging hook 5 seconds
- Remove bonded sector from overhead conveyor 5 seconds
- Hang unbonded sector on overhead conveyor 5 seconds
- Remove bonding fixture and away sector 5 seconds
- Clean bonding frame and hook (batch process) 5 seconds
- Input queue (five hooks) 6 minutes
- Dip process (10 hooks) 12 minutes

- Curing process (80 hooks) 96 minutes
- Cooling process (30 hooks) 36 minutes
- Total cycle time 2.5 hours

Cutting a core sector will be automatic except for removing the cut sector and mounting the uncut sector into the cutting fixture. After the cycle is started the blade will come up to speed and the sector will proceed slowly through the cutting wheel. When the sector clears the cutting wheel the blade will stop rotating and the sector will return to the starting position. The actual cutting cycle is estimated to be three minutes and the total work station time is estimated to be four minutes. Availability of the machine is estimated to be 80% with blade change out being a major factor. One machine will cut 12 sectors per hour and four machines will cut 48 sectors per hour. One operator could service 8 or 10 machines if required.

- Get bonded sector 5 seconds
- Mount sector in fixture 10 seconds
- Start cutting process 5 seconds
- Cut sector 3 minutes
- Return sector 0.5 minutes
- Remove 10 seconds
- Total cycle time 4 minutes

Assembly of the core and coil is expected to be much faster with the Buswell design than with the current designs that require lacing core steel sheets through coil windows. After the sectors are made they will be transported to the transformer assembly area. A table mounted fixture will be used to make the assembly. Clamps, center bolt, and core insulation will also be delivered to the assembly area. The making of these parts are not considered in this analysis as it will be similar in cost and will use existing equipment. One assembly fixture will be required and one part time operator.

- Get the bottom core clamp with center bolt attached 10 seconds
- Get 8 sectors and place sector halves on bottom clamp 40 seconds
- Get and place core insulation 10 seconds
- Get and place coil 30 seconds
- Get and place core insulation 10 seconds
- Place upper sector halves on bottom sector halves 30 seconds
- Get the top core clamp, washer, and nut and assemble 20 seconds
- Get and assemble core grounding wire 10 seconds
- Off core and coil assembly 20 seconds
- Total cycle time 3 minutes

10 KVA Single Phase Distribution Type
23000 Transformers per Year
Cost Analysis

Invest Cost Analysis

EQUIPMENT	COST (K$)	QUANTITY	TOTAL (K$)
ANNEAL FURNACE	NA	NA	NA
WINDING MACHINES	60	4	240
BONDING SYSTEM	150	1	150
CUTTING MACHINES	32	4	128
MATERIAL HANDLING	25	1	25
WINDING FIXTURES	0.05	670	33
BONDING FIXTURES	0.05	120	6
TOTAL			582

Consumables Yearly Cost Analysis

Item	COST PER ITEM	QUANTITY	TOTAL (K$)
BONDING RESIN	$20 PER GALLON	3000 *	$120
CUTTING BLADES	$35 PER SHARPENING ***	460 **	$16
TAPE AND OTHER	$10,000	1	$10
TOTAL			$146

- * BASED ON 1/4 CUP PER SECTOR AND 184000 SECTORS PER YEAR
- ** BASED ON BLADE LIFE OF 400 SECTORS PER SHARPENING.
- ***BLADE COST BASED ON 10 SHARPENINGS PER BLADE @ $25 PER SHARPENING AND $100 PER NEW BLADE.
- NOTE THAT THE WINDING FIXURES AND BONDING FIXTURES ARE ALSO CONSUMABLES AS THEY HAVE A FINITE LIFE

Direct Labor

The sector manufacturing cell requires three operators per shift on two shifts for 48 weeks to produce the sectors to make 23000 transformers. Assembling the transformers requires one operator part time on one shift for 48 weeks. Comparative labor costs can be derived from this data.

Problems or Delays

As consistently reported, all project partners are aware that materials development delays have delayed and redefined this project. All requests for another extension of time or funding have been rejected. Additional joint efforts toward materials development are underway, but funding is not yet negotiated. Bekaert remains highly committed. Representatives of Bekaert, Buswell, and Ames Laboratories have been working to determine a pathway forward, and all believe that successful completion of this project would require that partnership. We again request that the Department of Energy consider ways of funding our work beyond December, 2011 and including a partnership with Ames Laboratories for materials development.

Personnel

Termination of project staff is consistent with budgetary constraints. All project cost are terminated December 31st, 2011.

Submitted:

March 20, 2012

Dennis Jacobs, PhD Date

Buswell Energy
P. O. Box 1452
Berea, Kentucky 40403

DOE F 2050.11
(2-87)
(Previous GC-792)

OMB Control No.
1910-0800

PATENT CERTIFICATION

Buswell Energy LLC
Contractor

CH 1353
DOE Prime and/or Subcontract Nos.

☐ Interim Certification
☒ Final Certification

Contractor hereby certifies that:

1. All procedures for identifying and disclosing subject inventions as required by the patent clause of the contract have been followed throughout the reporting period.

2. There were no subcontracts or purchase orders involving research, development, and demonstration except as follows: [State none when applicable.] Tennessee Technological University; Western Kentucky University

3. No inventions or discoveries were made or conceived in the course of or under this contract other than the following (Certification includes ☐, does not include ☐ all subordinates):

[State none when applicable.]

TITLE	INVENTOR	DATE REPORTED	DOE "S" NO.*

4. The completion date of this contract is as follows: December 31, 2011

5. The following period is covered by this certification:

January 1, 2006 to December 31, 2011
Month Day Year Month Day Year

Contractor

Signature
Harrie R Buswell

101 Holly St. Suite #3
PO Box 1452
Berea, Ky 40403
Address

3/26/2012
Date of Certification

* Also include Subcontract No. If available

U.S. DEPARTMENT OF ENERGY — JUNE 2005

FINANCIAL ASSISTANCE PROPERTY CLOSEOUT CERTIFICATION

Award Number	Recipient *(Name and address)*
CH11353	Buswell Energy LLC, PO Box 1452, Berea, KY 40403

The purpose of this report is to facilitate the closeout of the Award. Based on the records maintained by the Recipient in accordance with the Property Management standards set forth in the Award, the following data reflects the Recipient's closeout inventory of real and personal property that was provided by the Department of Energy (DOE) or partially or wholly acquired with project funds.

I. EQUIPMENT

A. **Federally-Owned**: *(Government Furnished Equipment): (10 CFR 600.133(a), 600.232, 600.322, or Federal Demonstration Partnership (FDP) General Terms and Conditions No. 33, as applicable):* X☐ No ☐ Yes

*(If **yes**, attach property inventory list that includes item description, manufacturer, model, serial number, original acquisition date, original acquisition cost and disposal condition code per the Federal Management Regulation 102-36.240)*

B. **Equipment Acquired with Award Funds where Title Vests in the Recipient with further obligations to DOE:** *(10 CFR 600.133, 600.134, 600.232, or 600.321, as applicable)*

☐ No X☐ Yes

If **yes,** does the equipment have a per unit fair market value of $5,000 or more? ☐ No X☐ Yes

*(If **yes**, attach a property inventory list that includes item description, manufacturer, model, serial number, original acquisition date, original acquisition cost, disposal condition code per the Federal Management Regulation 102-36-240 and one of the disposition codes listed below)* ***SEE PAGE 4 PROPERTY INVENTORY attached hereto.***

(1) The property will continue to be used for the purposes authorized in the Award.

(2) The property is no longer needed for the purposes of the Award, and will be used on another Federally sponsored activity *(List Activity and Federal Agency):*

(3) The Recipient wishes to retain the property and compensate DOE for its share of the current per unit fair market value. *(Identify the fair market value on the attached property inventory list and describe how the value was determined).*

(4) The property is no longer needed for the purposes of the Award or other Federally sponsored activities and the Recipient requests DOE disposition instructions.

II. SUPPLIES *(10 CFR 600.135, 600.233, 600.324, or FDP General Terms and Conditions No. 35, as applicable)*

Does the residual inventory of unused supplies exceed $5,000 in total aggregate value? X☐ No ☐ Yes *(if **yes**, check block below)*

☐ The supplies will be used on another Federally sponsored activity *(List Activity and Federal Agency).*

☐ The supplies will be sold or retained for use on non-Federally sponsored activities and the Recipient will compensate DOE for its share of the sales proceeds (or estimate of current fair market value). Attach a list of the supplies and complete the following Worksheet:

Sale proceeds or estimate of current fair market value.............................. $__________

Percentage of Federal participation .... __________%

Federal share .... $__________

Selling and handling allowance .... $__________

Amount to be remitted to DOE .... $__________

Buswell Energy LLC
Supporting information for SF425
Cumulative Period : 1/01/06 - 12/31/11
FINAL REPORT

COST CATEGORY	Federal Share Cumulative 1/01/06 12/31/11	Non-Federal Cost Share Cumulative 1/01/06 12/31/11	Total Project Expenditures Cumulative 1/01/06 12/31/11
TOTAL SALARIES & FRINGE BENEFITS	1254776	1180679	2435455
EQUIPMENT	108605	602	109207
TRAVEL	52914	58923	111837
PARTICIPANT / TRAINEE SUPPORT	0	1425	1425
OTHER DIRECT COSTS including subawards	363615	483076	846691
TOTAL DIRECT COSTS	1779910	1724705	3504615
INDIRECT COSTS	0	0	0
TOTAL DIRECT & INDIRECT COSTS	1779910	1724705	3504615

U.S. DEPARTMENT OF ENERGY

FINANCIAL ASSISTANCE
PROPERTY CLOSEOUT CERTIFICATION

III. REAL PROPERTY: *(Real Estate - 10 CFR 600.132, /600.231, 600.321, or FDP General Terms and Conditions No. 32, as applicable)* ☒ No ☐ Yes *(If **yes**, complete A –C)*

A. Description of Real Property:

B. Complete Address of Real Property:

C. Period of Federal Interest in the Property: From ________ To ________ (Unless the award specifies otherwise, the Federal Interest in the property ends when the award project period ends.)

D. Disposition Preference Request. If the period of Federal Interest in the property exceeds the project period, check one of the following blocks to indicate your disposition preference:

☐ Transfer property to another Federal award.

☐ Sell and compensate DOE.

☐ Return to DOE.

☐ Retain title and compensate DOE for its share of the current fair market value of the property.

Certification: I certify to the best of my knowledge and belief that all information presented in this report is true, correct and complete, and constitutes a material representation of fact upon which the Federal government may rely.

Name	Signature	Title	Date
HARRIE BUSWELL	Harrie R Buswell	PI	3/26/12

U.S. DEPARTMENT OF ENERGY

FINANCIAL ASSISTANCE
PROPERTY CLOSEOUT CERTIFICATION

To be completed by the Department of Energy:

DOE PROPERTY DISPOSITION

☐ **Negative Report**

☐ **Real Property:**

☐ **Equipment:**

☐ **Supplies:**

Property Management Official Name	Signature	Date

FINANCIAL ASSISTANCE PROPERTY CLOSEOUT CERTIFICATION

Buswell Energy LLC   Award # CH11353

Property Inventory List

DESCRIPTION: Model 610 Orthocyclic Coil Winding Machine with MCS4 Control & Coil Pro Software - Unique custom designed and built machine to wind magnetic wire into wedge shaped coils.

MANUFACTURER: Machine Control Specialists Inc.

MODEL: #610

SERIAL #: M1046-4145B

ORIGINAL ACQUISITION DATE: September 2010

ORIGINAL ACQUISITION COST: $ 97,291.00

DISPOSAL CONDITION CODE: 4 Usable. Property which shows some wear but can be used without significant repair.

DISPOSITION CODE: (1) The property will continue to be used for the purposes authorized in the award.

File: DOE financl asst property closeout equip list 3-13-12

FEDERAL FINANCIAL REPORT

(Follow form instructions)

1. Federal Agency and Organizational Element to Which Report is Submitted DOE Chicago Operations Office	2. Federal Grant or Other Identifying Number Assigned by Federal Agency (To report multiple grants, use FFR Attachment) CH11353	Page 1 of pages

3. Recipient Organization (Name and complete address including Zip code)

Buswell Energy LLC 101 Holly St. Suite #3, PO Box 1452 Berea, KY 40403

4a. DUNS Number 0969839650000	4b. EIN 010653032	5. Recipient Account Number or Identifying Number (To report multiple grants, use FFR Attachment) 04210126826818337	6. Report Type ☐ Quarterly ☐ Semi-Annual ☐ Annual ☑ Final	7. Basis of Accounting ☐ Cash ☑ Accrual

8. Project/Grant Period (Month, Day, Year) From: 01/01/2006	To: 12/31/2011	9. Reporting Period End Date (Month, Day, Year) 12/31/2011

10. **Transactions**	Cumulative
(Use lines a-c for single or multiple grant reporting)	
Federal Cash (To report multiple grants, also use FFR Attachment):	
a. Cash Receipts	1,762,378
b. Cash Disbursements	1,762,378
c. Cash on Hand (line a minus b)	0
(Use lines d-o for single grant reporting)	
Federal Expenditures and Unobligated Balance:	
d. Total Federal funds authorized	1,780,000
e. Federal share of expenditures	1,779,910
f. Federal share of unliquidated obligations	0
g. Total Federal share (sum of lines e and f)	1,779,910
h. Unobligated balance of Federal funds (line d minus g)	90
Recipient Share:	
i. Total recipient share required	445,000
j. Recipient share of expenditures	1,724,705
k. Remaining recipient share to be provided (line i minus j)	0
Program Income:	
l. Total Federal program income earned	0
m. Program income expended in accordance with the deduction alternative	0
n. Program income expended in accordance with the addition alternative	0
o. Unexpended program income (line l minus line m or line n)	0

11. Indirect Expense	a. Type	b. Rate	c. Period From	Period To	d. Base	e. Amount Charged	f. Federal Share
		NO INDIRECT RATE SET				**NO INDIRECT EXPENSE CHARGED**	**NONE**
				g. Totals:	0	0	0

12. Remarks: Attach any explanations deemed necessary or information required by Federal sponsoring agency in compliance with governing legislation:

See expenditure support details below - 12-31-11

13. Certification: By signing this report, I certify to the best of my knowledge and belief that the report is true, complete, and accurate, and the expenditures, disbursements and cash receipts are for the purposes and intent set forth in the award documents. I am aware that any false, fictitious, or fraudulent information may subject me to criminal, civil, or administrative penalties. (U.S. Code, Title 18, Section 1001)

a. Typed or Printed Name and Title of Authorized Certifying Official	c. Telephone (Area code, number, and extension) 859-986-5367
	d. Email Address smeng@kih.net
b. Signature of Authorized Certifying Official Harrie R Buswell X	e. Date Report Submitted (Month, Day, Year) 3-15-12
	14. Agency use only:

FINAL SCHEDULE OF COSTS BY ELEMENT & CERTIFICATION

Company: Buswell Energy LLC Agreement No: CH11353
Address: PO Box 1452
Berea, KY 40403 Project Period: 01/01/06 – 12/31/11

Total Estimated Cost of Project: $ 3,504,614

	GOVT SHARE	RECIPIENT & COST SHARE
Labor	1,041,464	
Fringe Benefits @%	213,312	1,182,104
Overhead @%		
Equipment	108,605	602
Travel	52,917	58,923
Materials and Supplies	33,509	153,379
Subcontracts		
Subcontract #1 (Univ. of KY)	84,882	
Subcontract #2 (TN.Tech Univ.)	75,899	
Subcontract #3 (Western KY Univ)	9,999	
Subcontract #4(Bekaert Corp.)	83.360	
Other Direct Costs	75,963	329,697
Adjustments (Explain)	0	0
Total Costs (less G&A)	1,779,910	1,724,705

G&A @%____	0
Total Costs Incurred	$ 3,504,615
Fee @%_____ (if applicable)	0
Total costs incurred and fee	3, 504,615
Credit (Explain)	0
Recipient's share (if any)	$ 1,724,705
Government's share	$ 1,779,910

CERTIFICATION:

I certify that this schedule is correct and in accordance with the terms of the agreement and that the costs included herein have been incurred, represent payments made by the Recipient except as otherwise authorized in the payments provisions of the agreement, and properly reflect the effort performed.

Harrie R Buswell 3/26/2012
Signature and Date

HARRIE R. BUSWELL, Ph.D. (PI)
Printed Name and Title

EXPLANATION:$ 1,182,104 entry in Recipient Cost Share includes Labor, Benefits, Overhead.