

# Nexus

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**Abstract** – The Nexus is a research lab developed by Appalachian State University, NC, USA for alternative energy and sustainable living. The current scope is fivefold: Biomass, Agriculture, Energy, Water, and Community. This paper describes how and why the Nexus was developed, the current projects, and future goals. The lab success is based on the synergism of companion systems and a critical mass of projects; enough projects to attract an audience as follows: **1) Biomass conversion** - dry biomass is processed by the Biovolatilization (BV) system, which produces biochar, pyrolysis oil, fuel gas, heat, and electricity; While wet biomass is processed by biodigestion producing fuel gas and effluent; **2) Agricultural improvement** - biochar, a soil amendment is used to retain nutrients, lower soil pH, increase tilth/friability, and increase water retention; **3) Energy management** - energy use is optimized by growing food in the Bioshelter, an off the grid greenhouse, which is heated and powered using wind, solar, and biomass; **4) Water management** - biochar can be used as a water filter and as a medium to reduce nutrient runoff; and **5) Community enrichment** - the lab will produce food for the community, education by example (the Nexus), and serve as a gathering environment for participation interaction. This paper includes funding strategies for the different research areas and a synopsis of student involvement and educational outcomes.

*Keywords:* Alternative Energy, Biochar, Anaerobic Digestion, Biomass, Greenhouse heating, Community food

## INTRODUCTION

The evolution of the Nexus began with an EPA P3 (People, Prosperity, Planet) grant, which led to the need for a greenhouse. A greenhouse kit was moldering in tall grass at the Watauga County Landfill, NC. A year later, and thousands of dollars poorer in engineering drawings, a permit was issued to begin construction. The EPA project was the development of the Biovolatilization (BV) system to make biochar while heating a greenhouse. The original concept, based on a traditional gasifier, proved ineffective, so a new approach was developed. The process dubbed biovolatilization is a revived technology based on traditional, dry distillation of wood chips. The process was optimized for economic yield and simplicity. It is the center piece, technology for the Nexus and converts biomass into useful products. Testing and use of the products, along with managing the greenhouse renamed the Bioshelter,

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led to many additional technologies, concepts, and philosophies. This paper is the first attempt to document the symbiotic systems and guiding principles for the Nexus.

The primary impetus for the Nexus is the gathering of companion technologies; a critical mass, sufficient to draw an inquisitive crowd. Companion technologies either utilize different versions of the same raw material or utilize the waste from the first to feed a second. The crowd will come to learn, to participate, and for companionship. The Nexus is intended to be fun, productive, and exciting: 1) a place of continual refinement that fosters innovations and expansion; 2) a place that meets basic needs of a community while promoting sustainable and environmentally friendly practices; and 3) a place that is also self sufficient and economically profitable.

The Nexus concentrates on five areas: 1) Biomass conversion: dry biomass - BV system (produces: biochar, pyrolysis oil, fuel gas, heat and electricity) and wet biomass – Biodigestion (produces fuel gas and effluent); 2) Agricultural improvement: biochar is a soil amendment which retains nutrients, lowers the pH, increases tilth/friability, and increases water retention; 3) Energy management: energy use is optimized by growing food in the bioshelter. The bioshelter is off the grid for heat and power using wind, solar, and biomass; 4) Water management: biochar as a water filter - biochar is used to reduce nutrient runoff; and 5) Community enrichment: the Nexus lab will produce food for the community, education by the Nexus example, and serve as a gathering environment for participation interaction. The five areas all share the common goals of environmental friendliness, simplicity, and sustainability. These five areas, associated systems, create a good site for workshops that can attract a lot of people and provide the opportunity to influence social change. Food and economy are two areas that also attract interest. The Nexus is intended to help people learn about technologies that will allow them to earn or supplement their income; food production and consumption is always a crowd magnet. The ultimate intent of the attention is replication of the principals and creating a Nexus in every community. A successful example of community gardening is Growing Power Inc., in North Milwaukee; “What started as a simple partnership to change the landscape of the north side of Milwaukee has blossomed into a national and global commitment to sustainable food systems” [1].

## NEXUS COMPONENTS

The Nexus is a combination of systems that work well together, companion systems. This is a list of the systems and components that are currently in place or in the planning stages: anaerobic digestion (AD), biovolatilization (BV), compost heating, off the grid greenhouse (bioshelter), wind, solar, solar thermal, community food, bread oven, ceramic kiln, hydroponics, biomass management, gas works, workshops, water treatment, bioshelter environmental control, geothermal, thermal mass, biochar testing, nexus replication, and water cistern. This paper describes some of the key components along with their purpose and interrelationship. This is not a traditional engineering or science report. This is a description of a very complex but vague concept that will hopefully provide the infrastructure and inspiration for grant funding and research projects.

### **Anaerobic Digestion (AD)**

The Nexus is all about biomass management and particularly – waste management. Wet waste, particularly food scraps and manure is well suited for AD. The digester consists of a long PVC bag in a four foot diameter, corrugated pipe, twenty feet long. The plumbing is similar to a septic tank: waste in, excess water out, but the vapors are captured instead of vented to the atmosphere and adding to the green house gas problem. The excess water, effluent, is stored in an intermediate bulk container until it is needed to help inoculate biochar. The gas, primarily methane is either used for heat, electricity, or stored with the gas works.

### **Biovolatilization (BV)**

The BV system uses biomass gasification to convert waste biomass into fuel gas. Instead of burning the biomass with direct flame, the biomass is sealed in a barrel and heat is applied externally [2]. A wood fired kiln surrounding the barrel traps in heat and raises the temperature of the biomass, usually wood chips, to 400 degrees Celsius. As

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the biomass breaks down (dry distillation), it produces gas and oil that are collected for future use. The gas produced from the process is mostly methane and is also composed of carbon dioxide, carbon monoxide and hydrogen. This gas can be used to run a generator or burned as a source of heat, including heating the biochar kiln. This is the same process that steel mills use to make coke and producer gas. Before storage, the gas is piped through a condenser in order to remove water and oils. This step in the system serves to both clean the gas and to collect another useful waste product. The condensed smoke is referred to as pyrolysis oil, or py-oil. This liquid smoke has potential to be refined into a fuel and can also provide useful ingredients for pharmaceuticals. The creosote in the oil can also be used to treat wood and research is being done on the py-oil's ability to serve as a natural herbicide or pesticide. The process is complete when the biomass is fully charred and no longer produces gas at a sustained temperature. The biochar left in the barrel can be used as a soil amendment and has been proven to improve the characteristics of soils to achieve higher plant yield. This system has great potential to stimulate local economy because it is simple enough to be built and run on a small scale. Research is currently being done on how to use waste heat from this system to heat a greenhouse in the wintertime and extend the growing season for local farmers. There are also small business opportunities in the production and sale of biochar as a soil amendment.

Biochar production and use as soil enhancement is not a new technology. The benefits of Biochar can be witnessed in the rich Terra Preta soils of the Amazon. Biochar changes the characteristics of the soil by adding more surface area and pore space for water and nutrients to be stored. The water and nutrient retention time is thus lengthened and plants are able to uptake greater amounts of these essential growth ingredients. This also reduces nutrient leaching into the ground water and can be used as a sustainable farming practice. A major topic of interest is using biochar as a carbon sequestration method. The pores in the biochar can also absorb carbon dioxide and prevent it from escaping into the atmosphere. Additionally, the biochar itself is composed of carbon and in its charred state; it can take hundreds to thousands of years to break down. Applying biochar to soil places the carbon in the soil instead of in the atmosphere where it can contribute to the greenhouse effect and climate change. The International Biochar Initiative has very good explanations and current uses for biochar [3].

Combined heat and power utilizes the BV system most effectively. Placing the waste stream and end products back into the system or using them alongside another system ensures that the potential of this system is maximized. Biogas collected can be burned to run the system and produce more products, burned in a gas stove, used to run a generator or burned to supply heat. The system also produces waste heat that can be captured and used to space heat or produce hot water. The condenser design is an important component in waste heat capture because at this stage in the system large amounts of heat are removed. Piping the hot gas through a water source will effectively condense out oils and the water acts as heat transfer fluid which can be piped for hot water production or for radiant floor heat. The history of the BV system and its performance are included in the 2013 conference proceedings of the ASEE-SE [4].

### Gas works

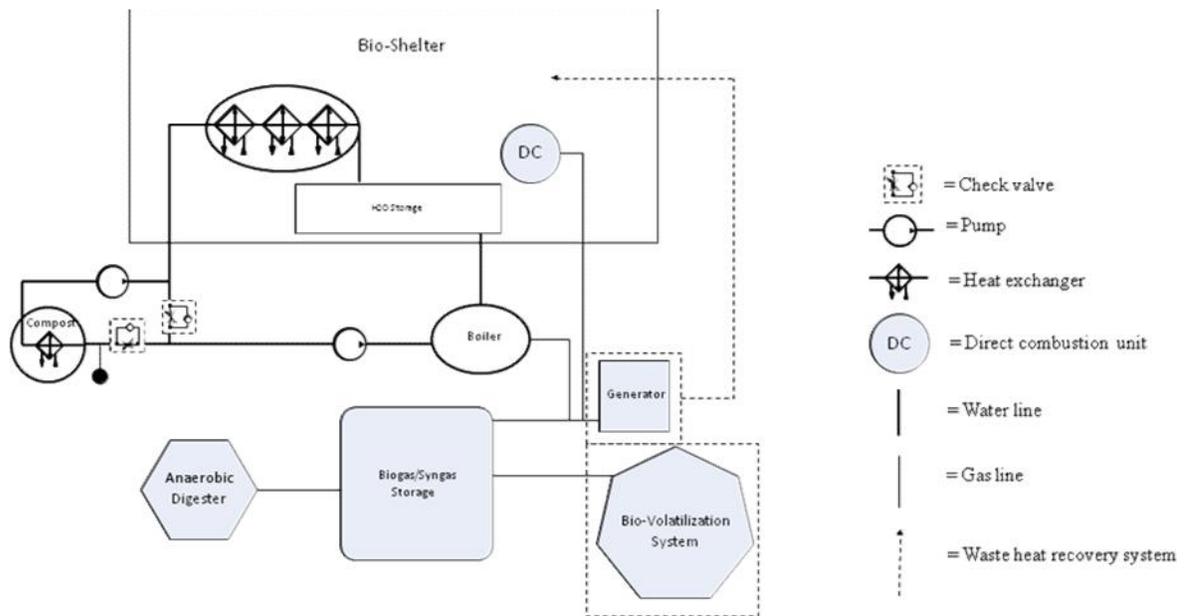
Practical utilization of the gas produced by the AD and BV systems requires a convenient storage method. The simplest system is a large bag – bag gas. The bag can be any size, but 500 to 1,000 gallons is easy to manage and affordable [1]. The gas bag provides storage, condensation, and cooling densification. Once the bag is filled the gas can be drawn to run the generator or heater, or as supply to the compressor. Excess gas is compressed and stored in pressure tanks. The BV system produces 2 CFM and the AD system produces 2 CFH. The gas energy density is 23 mJ/KG. A 500 gallon tank of compressed gas can supply the generator for 5 days and produce 2,000 KWH, or run the 50,000 BTU heater for 4 days. The same gas can be compressed to 1,000 PSI and run a light truck for 50 miles. Both storage methods allow any suspended creosote in the BV gas time to condense.

Biomass processing systems have a lot in common with being a vegetarian, gas management. The gas can be used as produced or stored, either in a large bag, (bag gas), or a pressure tank. The gas is compressed to 100 PSI and bubbled through water to remove the CO<sub>2</sub>, than the gas is stored in conventional propane tanks, (gas works). The compressed gas is regulated to half a PSI and used to either run the generator or forced, hot air, gas furnace. The gas works concept also opens the possibility of transportation fuel – gas powered cars and trucks.

**Green house heating**

Controlling a green house, (bioshelter) environment in mountain regions is very different from other areas. The mountains have tremendous temperature swings and dramatically changing weather; one day it can be 60 Fahrenheit and sunny and the next day sub freezing with a light snow. Three months of the year are usually too hot, six months have a forty degree temperature swing and three months will be cold. A comprehensive environmental control system is required but for the bioshelter it also has to be sustainable, use alternative energy and be economical. Bioshelter heating is also the primary customer for most of the energy systems including, 1) BV, 2) AD, 3) compost heating, 4) solar thermal, and the 5) gas works. These constitute the five heating system described in the next paragraphs, but this is only part of the solution. The systems also have to work in concert with electricity for lighting, air circulation, and control and thermal mass.

The greenhouse also will have a conventional gas furnace as a backup system. A 40,000 BTU, forced hot air furnace connected to a propane tank. If all of the earth friendly systems take a hippie break then good old reliable fossil fuel can save the day; perhaps once a month. The primary heating system uses the same gas furnace but with bio-gas instead of propane. The gas supply comes directly from the AD or BV systems, or the gas works via the bag-gas or the compressed gas tanks. The next heating systems are described in preferential order for use. The first system is just plain old thermal mass and a circulating fan. The bioshelter is designed to handle a 10-20 degree temperature drop without active heating. The shelter has a double wall and roof system with 20 pounds of thermal mass per square foot of floor area. The mass is an array of water barrels, cinder blocks, dirt, plant, tables, etc. The circulating fans are powered by the 24 volt – 400 amp battery bank. The bank is charge by the 400 watt solar panel and 400 watt wind turbine. The second system is solar thermal; four 3 by 6 foot solar hot water collectors are used to heat two water walls, one in the front and the other in the back of the shelter. The banks of black barrels also work at thrombe walls, collecting solar radiation during the day. A diagram follows.



## Electricity

Off grid power is fairly easy and straight forward. Companies sell everything needed to become your own power company. The Nexus is starting with a small windmill, 12 volt, 400 watt and one 400 watt solar panel, 24 volt. The electricity is stored in two 400 amp hour batteries connected in series. A nice full sine wave inverter is used to deliver 120 volts AC. The system has a couple of charge controllers, ground rods, power panels, and lots of 8 gage wire. Task lighting for the Bioshelter will be 12 volt LED using standard 14 gage residential romax and light switches. This is simple and economical. A second 120 volt circuit will be used to extend the growing day. This circuit can be powered by the inverter or a generator. The generator will be run off of methane from the gas works. The gas can come direct from the BV or AD system, bag gas, or from a compressed gas tank.

Future plans for the Nexus include a small wind farm with additional battery storage, three arrays of solar panels, and a possible grid tie to sell power. It is currently very difficult and expensive to grid tie so the ROI will have to dictate the decision. It is much for profitable to use off grid power at the buy rate of 7 cents/kwh than selling it for 4 cents/kwh. Electricity will also be used to run circulating and exhaust fans to help regulate the Bioshelter Temperature along with miscellaneous pumps, control systems, and components.

## Wind and Solar Power

The Nexus project strives to be a self-sustaining greenhouse and because of this, students are exploring many ways to satisfy this goal. The mountain region of North Carolina has abundant wind resources and students wanted to add this to our Nexus project. Since the sun has to eventually set, the wind turbine can continue to generate electricity into the night. This energy is stored in a battery bank until it is needed to provide light, heat, ventilation or power to pump water. Students would like to expand on our current wind turbine by utilizing an unused ridgeline that will give us better access to our renewable wind resources.

In order to become a fossil fuel free facility, the Nexus project has installed a photovoltaic system to provide electricity for use in the greenhouse. Our system, working in tandem with our wind turbine, stores the solar energy in a battery bank until it is needed. With this system, students are able to provide electricity for ventilation, grow lights and water pumping. This system is essential to our desire in becoming self-sufficient and it is also very practical for the average greenhouse user to install and maintain.

## Hydroponics

Within the Nexus, students are exploring the feasibility of small scale hydroponic grow systems for the local farmer. The technique allows the farmer more control over all the inputs required for plant growth. The system requires a simple grow apparatus easily assembled using PVC pipes, grow lights and a pump system. The electronic components can be easily powered by solar, wind or a methane supplied generator. Hydroponic growing is just another technique that can extend the growing season and provide additional revenue for a small scale farming operation.

The Nexus project was designed with the local small scale farmer in mind. In Appalachia, the growing season can end early or start late because of an unexpected frost, potentially ruining a harvest. The Nexus strives to end the unexpected weather that nature throws at us by extending the growing season and protecting delicate cash crops. Maintaining ideal temperatures and conditions year round can add significant value for a farmer by providing the growing conditions that ensure fresh produce in from fall until early spring.

### **Bread Oven**

The bread oven might appear to be just for fun, but is in reality, a center piece for the Nexus. It is part of community food and necessitates communal cooking. One of the goals of the Nexus is replication in developing countries, countries where communal cooking is an affordable way of life. Hopefully it might become affordable for car dependent urbanites like us. For Boone NC, it will have five functions: 1) education, 2) heat source testing, 3) crowd pleaser, 4) one of the critical mass technologies, and 5) an example of community. In addition a sixth function, one of the authors is fond of fresh, Middle Eastern, flat bread. The best loaves are slapped against the walls of the oven and have tremendous flavor. The five functions explained: 1) Education - workshop attendees can learn how to make bread or how to make the oven; 2) Heat source testing - the oven can be fired in the traditional way with wood to heat up the thermal mass, or with bio-gas (pardon the smell); 3) Crowd pleaser - even the most serious scientist and engineers look forward to snack time, the conference breaks. Fresh oven cooked bread will become an expected tradition for workshops and functions; 4) Technology - the oven itself is uncommon; how it's made and its function will be of interest to many people and a potential source of income [5]. Bags of fresh cooked pitas will go fast at a farmers market; and 5) Community - people are generally social. Most people will enjoy working together to fire the oven, prepare, and bake the bread. Groups or families will join to prepare the weeks bread, for an event, or for sale; perhaps while working in the greenhouse. The bread oven is one facet of community food, grow local, eat local, and eat together.

### **Water Cistern and Sewage**

The Nexus lab is currently paying the town of Boone, \$1.50/day for a water connection. This is not in line with the "off the grid" mentality but is reliable. An off the grid system will entail water collection, storage, filtering, plumbing, and pressure. The plan is collection with gutters on all the buildings, plumbed to a cistern; either a 500 gallon buried tank or a covered pond. The tank would be kept dark to prevent algae growth and fitted with a low voltage pump for circulation and pressure. The tank will allow sediment to settle with a series of baffles that limit agitation. A simple biomass or sand filters will be used to provide agricultural water. These filters can be back flushed for cleaning. The dirty biomass will eventually be dried and burnt in the BV system. Potable water will be a very different experiment. Biochar can be used to remove many impurities but reverse osmosis or an ultra violet light system will be used to insure that no live organisms can pass.

Sewage is also a consideration for an off the grid complex. The plan is incorporating a composting toilet. Human waste can be collected and introduced into either the AD or BV system. Incineration of human waste in the BV system is the safest. The AD system should work but would require testing to insure that no pathogens survive, and composting human waste is very controversial in the US. Urine is an excellent source of nitrogen and would be ideal for inoculating biochar but might be questioned for use on some plants.

## **CONCLUSIONS AND RECOMMENDATIONS**

Managing and developing the Nexus is a massive project. It started with a simple concept to make biochar and heat a greenhouse, and developed into everything described so far. The initial motivation to embark on this task was university promotion and tenure. The current motivations include educational opportunities for students and the possibility of helping people in general and hopefully doing something good for the environment. It takes about 15 minutes to dream up five years' worth of research and work. The limiting factor is principally financial. With five times the funding, five times the progress; a million instead of 50,000 would help a lot. This paper is the first documentation of the Nexus concept and will be used as the basis for a series of grant submissions. Hopefully presentations will help promote the concept and nurture interest which will lead to realization of the project.

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### Biographical Information

**David Domermuth** is an associate professor at Appalachian State University. He has been teaching for since 1986. His career began in metals manufacturing, shifted to furniture, and now Industrial Design. David teaches the engineering aspects of product design. He has three degrees in Mechanical Engineering and has lived abroad for five years. David's current research is concentrated on gasification of biomass as a renewable energy source and using biochar for soil augmentation. He is a follower of Jesus Christ and a member of Highlands Christian Fellowship. His primary hobby is road cycling in the Appalachian Mountains which he began in 1976.

**Ok-Youn Yu** is an assistant professor in the Department of Technology and Environmental Design at Appalachian State University, NC, USA. He earned his Ph.D. from the Zachry Department of Civil Engineering at Texas A&M University in May 2009. He received his M.S. in Construction Management from Texas A&M University and before that he worked in South Korea as a bridge and tunnel engineer for nearly five years. He is a licensed Professional Engineer in Texas. His research interests include renewable energy system development (e.g., real-time landfill gas monitoring and controlling systems, thermochemical conversion of biomass to useful product systems), infrastructure sustainability (e.g., remote structural health monitoring, early warning system development for natural hazard mitigation), and risk and decision analysis for project system management (e.g., Bayesian probability, forecasting, optimal modeling).

**James B. Houser** is an assistant professor in the Department of Technology and Environmental Design (TED) at Appalachian State University, NC, USA. He earned his Ph.D. from the Department of Agricultural and Biological Engineering at Cornell University in May 1994. He received his M.S. in Appropriate Technology from Appalachian State University and his B.A. in Biology from Wake Forest University. He has a Grade III Wastewater Treatment Plant Operator license in North Carolina and worked in Washington D.C. lobbying for an NGO concerned with international conflict resolution. These experiences developed his interest in sustainable resource management, which became his main area of research. He studied sustainable resource management at Cornell (e.g., dairy manure management), and then modeled watershed water quality in the top dairy county in Texas for the Texas Institute for Applied Environmental Research (TIAER). As a member of TED's faculty his research has focused on biomass energy systems (e.g., anaerobic digestion (biogas), biodiesel and ethanol production) and sustainable water quality management (e.g. biologically based "living systems" for waste water treatment).

**Miranda Harper** is a graduate student at Appalachian State University. She is studying appropriate technology in the department of technology and environmental design. Her bachelor's degree was obtained at North Carolina State University in Biological and Agricultural Engineering. Her graduate research is currently being conducted on how adding biochar to soil affects plant growth. Miranda is passionate about resource conservation and hopes to work in a career that implements sustainable design. Her interests include camping and attending music festivals.

**Alan Smith** is a graduate student at Appalachian State University. He is currently studying Appropriate Technology. In 2009, he received his undergraduate degree in Business Administration. Since graduating, Alan has taught English in Spain and worked in the financial sector.