Project 001(E) Alternative Jet Fuel Supply Chain Analysis

University of Tennessee

Project Lead Investigator

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University Participants

The University of Tennessee

- CO-PI: Burton C. English (Professor)
- FAA Award Number: 11712069
- Period of Performance: [August 1, 2016 to July, 31, 2017]
- Task(s):
    1. Develop a rotation based oil seed crop scenario and evaluate potential with POLYSYS
    2. Develop database on infrastructure and needs for Southeast
    3. Initiate aviation fuel supply chain study in the southeast
    4. Continue with sustainability work for both goals 1 and 4

Project Funding Level

FAA = 91,009
Match=69,444

Investigation Team

Tim Rials – Project Director(s)/Principal Investigator (PD/PI)
Burton C. English – Co-Principal Investigator (Co PD/PI)
Chris Clark – Faculty – Policy analysis
Lixia He – Other Professional – GAMS programmer
Kim Jensen – Faculty – By-product Markets
Dayton Lambert – Faculty – Rural Development
Jim Larson – Faculty – Production Economics
Ed Yu – Faculty -- Logistics
Evan Markel – Graduate Student

Project Overview

The University of Tennessee (UT) is responsible for generating the feedstock availability database for further analysis by the project team. Assessment work has been completed for forest residues and woody crops, and is advancing for agricultural crops (including cover/rotational crops). Also, sustainability information (environmental and socioeconomic) is underway to complete the Year 3 goals. Year 2 work will continue to tailor the feedstock database by incorporating pennycress as a winter cover crop providing an oil feedstock. POLYSYS and related models will be used to determine the potential impact of this new scenario. Additionally, work will continue gathering information needed for a comprehensive supply chain analysis for the southeast region. This will involve identification of current infrastructure, as well as garnering stakeholder input on supply chain challenges through a structured workshop. This effort will produce an assessment report to establish the foundation for detailed analysis in subsequent project periods.

Task 1

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Objective(s)

Develop a rotation based oil seed crop scenario and evaluate potential with POLYSYS
Conduct research on Pennycress and ran POLYSYS

Research Approach

Use POLYSYS to estimate the impact that a cover crop would have in meeting renewable fuel needs. Literature review was conducted on the agronomic features of pennycress and a rotation was developed. Yield and cost parameters were developed. POLYSYS was run using price ranging from $0.5 to $0.5/pound. To estimate yield impacts, monthly climate data 48 states and 344 climate divisions were collected from 2000 through 2014 The months of June, July and August are removed from the sample. Then the frequency of reaching the lower and upper bound temperature is calculated within each climate division and each year, for the months September through May. The frequencies are then aggregated over the years 2000 through 2014. Using the aggregated frequencies, we calculate the median number of times an upper or lower bound temperature is reached for each of the 344 climate divisions. This information is then disaggregated to the county level using a spatial union. Used median values range from zero to three over the sample. Median of one will imply a 25% yield reduction, a median of two will imply a 50% yield reduction, and a median of three will imply a 75% yield reduction. Estimated potential yields for each county in the 48 contiguous states using a base yield of 1500 pounds per acre.

Information on pennycress

- Large scale cultivation has not yet been undertaken for pennycress, thus management practices and stand establishment practices are still in research and development.
- Variety trials have been undertaken throughout the Midwest, particularly in Western Illinois, Minnesota, and Nebraska.
- A variety of planting methods have been tested, including drill, broadcast and aerial seeding.
- Aerial seeding over standing corn canopy or a broadcast with light incorporation after corn harvest has been successful.
- Aerial or broadcast seeding rates of 5lbs/acre have generated yields ranging from approximately 1400 lbs./acre to 2200 lbs./acre with an average yield of1800 lbs./acre.
- To establish a stand of pennycress ready for harvest in May-June to not interfere with soybean planting, aerial seeding over corn canopy may generate the best results.
- However, planting earlier than September 1st should be avoided, because if the plant flowers too early in winter months, survival rates are low.
- September planting dates should be identified by producers to ensure stand establishment. Phippen, John et al. (2010), conducted a study of five different September planting dates and found that seed oil content was not significantly different among the various planting dates.
- However, stand establishment declined as temperatures declined throughout the fall.
- Plants of the brassica family are susceptible to a fungus following an unusually wet spring. Insects and pests however, are not likely to pose a risk.
- The pennycress plant completes its life cycle in the spring when insects are emerging so insects do not pose a substantial risk.
- Pennycress is very cold tolerant and can grow in wide range of conditions. However, the plant is sensitive to high heat conditions.

- Pennycress has been known to survive very cold conditions with the ability to survive Canadian Prairie winters where temperatures can drop to negative 30 degrees Celsius. Sharma, Cram et al. (2007), found that Pennycress exhibits a higher freezing tolerance than its close relatives of Arabidopsis thaliana and Brassica napus (Canola).
- With a three week cold acclimation period, pennycress was freeze tolerant at -16.8 degrees Celsius or less than 2 degrees Fahrenheit.
- Temperatures above 85 degrees Fahrenheit pose a risk to pennycress and are found to have an impact on pod and seed numbers (Parker and Phippen 2012).
- Higher temperatures of 92 degrees Fahrenheit and above cause the plant to abort flowering (Sedbrook, Phippen et al. 2014).

Yield Variability

- Yields are not expected to be constant across varying geographic regions.
- The freeze tolerance and heat stress characteristics of pennycress imply a minimum and maximum range of temperatures of 20F to 930F for plant survival.
- However, heat exposure seems to pose the more significant risk and temperatures of 860F and above have a significant impact on pod and seed numbers.
- Therefore, we identify geographic regions across the United States which poses a risk to pennycress production yield, using a lower bound of 50F and upper bound of 880F.
- To identify those regions which pose a risk to pennycress we calculate the median number of times an upper or lower bound temperature is reached for each region

Outcome

Land use changes will occur when the production of one crop is incentivized with respect to others. Over the period of analysis, the average annual land use change was estimated for cotton (-18%) wheat (-17%), rice (-12%), oats (-11%) and grain sorghum (10%) with the corn/pennycress/soybean acreage increasing 13% (Table 1) resulting in a 5% increase in corn acreage and a 10% increase in soybean acreage. This change in acreage allowed a supply of Pennycress seed to be harvested on 25.8 million acres along with corn and soybeans. Prices also changed as production changed. The average change in production and prices are shown in Figure 1. For most crops an inverse relationship between price and production exists. Corns increase in production results in a decrease in price. The same is true for soybeans. Location of the pennycress production occurs largely in the western Corn Belt and Great Plains area (Figure 2). The above analysis was done when the pennycress price was set to $0.50 per pound. However, one important aspect might be what happens as price is reduced. Figure 5 contains a supply curve moving from $0.05 to $0.50 per pound. At five cents per pound, enough pennycress seed is harvested to produce over a billion gallons of aviation fuel. Increasing average realized net farm income $7.7 billion or 25%.

Conclusions and Next steps

It appears that pennycress is a potential feedstock for aviation fuel. The agronomic characteristics of the plant allow for it to be planted between corn and soybeans allowing for a farmer to get three crops over a two-year period if they use a corn/pennycress/soybean rotation. Cost will change as demand for pennycress oil increases. In this project pennycress price is varied between $0.05 and $0.50 per pound. Land does shift out of some crops and toward soybeans while corn acreage shifts are small in comparison. Production is predominately in the western corn belt and great plains though some production does occur in the pacific north west.

The next steps will involve analysis of other oil seed crops to evaluate their potential in developing an oil to aviation fuel market without impact

This project has shown that it is possible to produce enough pennycress feedstock to produce over 6 billion gallons of aviation fuel. Using POLYSYS, the potential of a corn/pennycress/soybean rotation is modeled and allowed to compete with traditional cropping systems. An analysis was conducted of runs from $0.05 to $0.50 per pound, Most of the potential is achieved at $0.20/pound. However, if the nation is to have 50% of the aviation fuel in alternative fuel, a single feedstock like pennycress will not meet the goal.

Table 1. Average Planted acres (Mil Ac)			
Crop	Without Pennycress	With PennyCress	% Change
Corn	79.6	84.5	6%
Grain Sorghum	5.1	4.6	-9%
Oats	0.9	0.8	-9%
Barley	2.6	2.4	-9%
Wheat	44.1	36.9	-16%
Soybeans	80.1	86.9	8%
Cotton	8.4	6.9	-18%
Rice	2.9	2.5	-13%
Hay	56.8	56.5	0
Pennycress	0.0	24.5[a]	NA[b]
Total All Crops	280.4	282.0	1%

[a] Acres already included in corn acres as a double crop

[b] Not Applicable

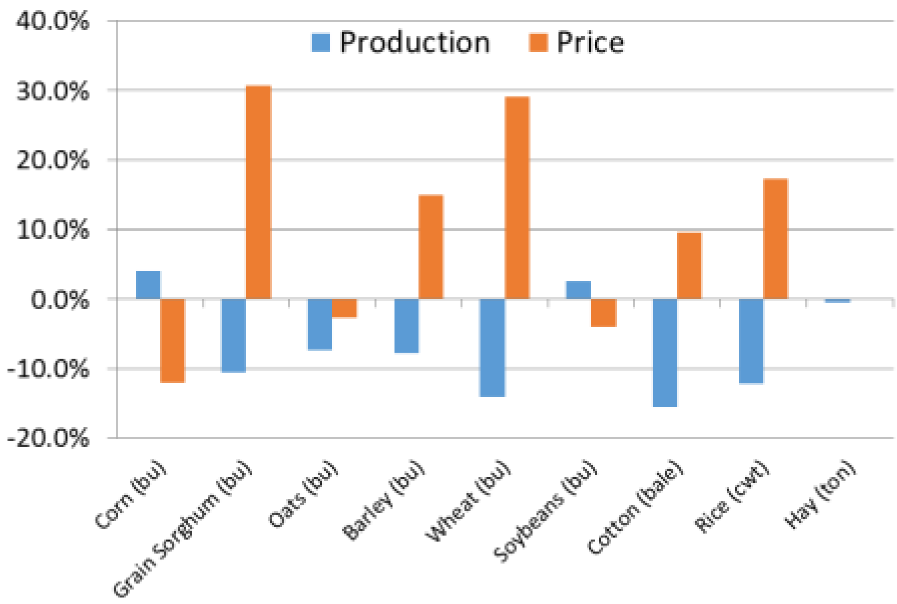

Figure 1. Land Use Changes : Pennycress Price = $0.20/pound

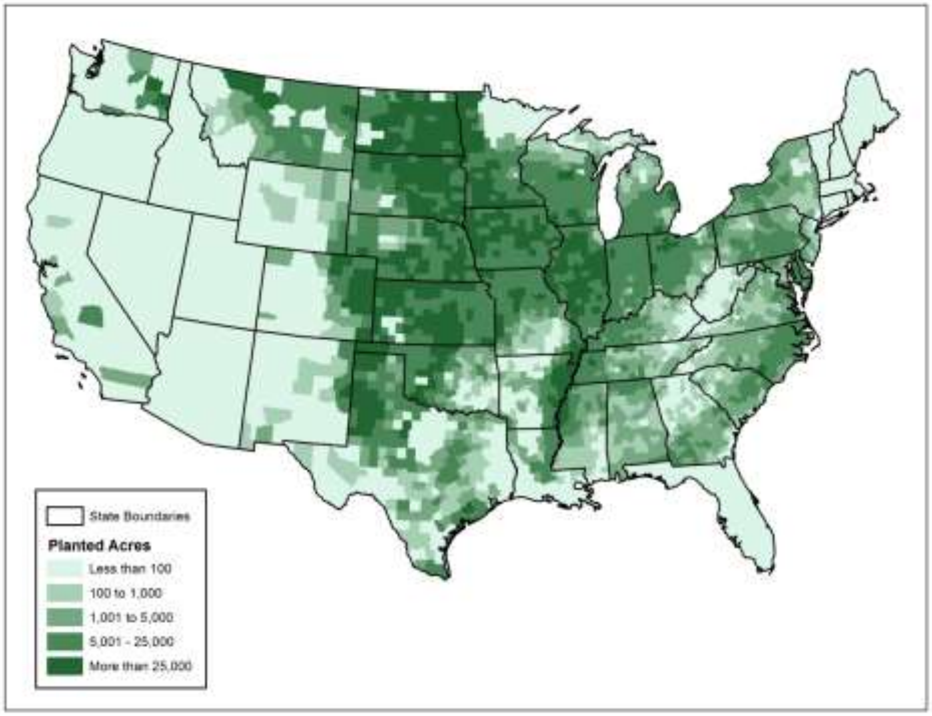

Figure 2. Locations where pennycress comes into solution

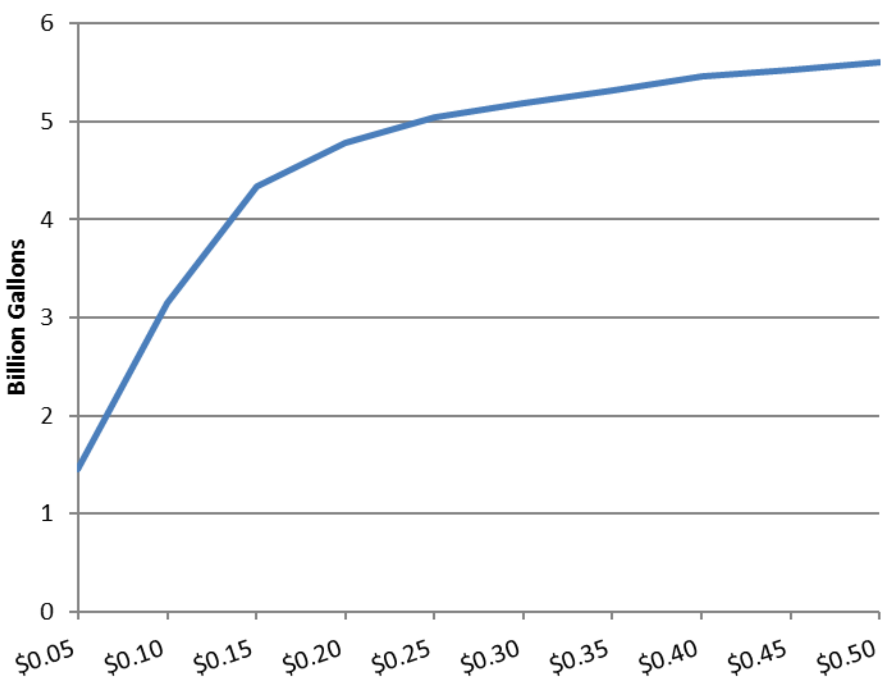

Figure 3. Pennycress supply curve

Objective(s)

Develop information on other cover crops.

Research Approach

Conduct Literature review and determine how other cover crops might work in providing feedstock for renewable aviation fuel. PSU was contacted in September and a copy of a dissertation done on potential cover crops was provided. Crop selection began keeping it to a maximum of four. Crops selected included Camelina, Triticale, Winter Rye, and Oilseed Radish.

Plant characteristics are defined in figures 4 through 6

Camelina: Camelina is an oilseed from mustard family with potential for industrial biofuel production. Camelina can be produced both as a winter cover crop and spring crop. The plant performs well under drought stress conditions and may be better suited to low rainfall regions than most other oilseed crops. Camelina is more cold tolerant and matures earlier than canola, and could therefore be more compatible with shorter rotational windows or later planting.

- Planting and harvesting dates vary by region and plant hardiness zones.

	Planting Dates	Harvest Dates	Possible Rotation
Zone 3-4	Sept 1 - Oct 15	June 26 - July 16	Spring Wheat > Camelina
Zone 5-7	Sept 15 - Oct 25	June 15 - July 5	Corn > Camelina > Soybean
Zone 8-9*	Oct 15 - Nov 20	April 25 - May 15	Cotton > Camelina > Peanut

*Camelina has been succesfully double-cropped in California and Florida

Equipment

- Chisel: Tractor 215 HP and Chisel Plow
- Disk: Tractor 215 HP and Tandem Disk
- Planting: Tractor 215 HP and Grain Drill
- Fertilize: Tractor 215 HP and Spreader
- Harvesting: Combine with Grain Head
- Haul: Tractor 215 HP with Grain Cart
- Haul: Semi Tractor/Trailer

Seed characteristics

- Camelina seeds contain 35-45% oil, roughly double that of soybeans. However the erucic acid content is only about 2.3%, similar to canola.
- Seed meal is low in glucosinolates, can serve as a potential livestock feed and is approved by the US Food and Drug Administration for use in cattle and chicken feeds for up to 10% of total ration.

References

- Winter Oilseeds as "Cash" Cover Crops for Sustainable Crop Production.
- Gesche and Cermak (2011) Sowing Date and Tillage Effects on Fall-Seeded Camelina.
- Sindelar, Aaron J., et al. "Winter oilseed production for biofuel in the US Corn Belt: Opportunities and limitations." *GCB Bioenergy* (2015).
- George, Nicholas, et al. "Canola and camelina: winter annual oilseeds as alternative crops for Ca
- Moser, Bryan R. "Camelina (Camelina sati biofuels feedstock: Golden opportunity or hope?." *Lipid Technology* 22.12 (2010): 27

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Figure 4. Information on Camelina

Triticale (trit-ih-KAY-lee): Cross between wheat and rye, includes the grain quality, productivity and disease resistance of wheat with the vigor and hardiness of rye. Most management practices for growing triticale can be taken directly from winter wheat.

- Planting and harvesting dates vary by region and plant hardiness zones.

	Planting Dates	Harvest Dates	Possible Rotation
Zone 3-4	Aug 20 - Sept 20	July 15 - Aug 25	Triticale > Soybean*
Zone 5	Sept 3 - Oct 15	June 15 - July 20	Corn > Triticale > Soybean *
Zone 6-7	Sept 10 – Oct 10	June 1 - July 15	Corn > Triticale > Soybean
Zone 8-9	Oct 5 – Dec 5	May 1 - July 5	Cotton > Triticale > Peanut

* May require an earlier harvest of Triticale or plant Soybean into standing Triticale

Equipment
- Chisel: Tractor 215 HP and Chisel Plow
- Disk: Tractor 215 HP and Tandem Disk
- Prepare Seedbed: Tractor 215 HP and Do-All
- Planting: Tractor 215 HP and Grain Drill
- Weed Control: SP Boom Sprayer

Equipment Continued
- Insecticide: SP Boom Sprayer
- Fertilize: Tractor 215 HP and Spreader
- Insect Control: SP Boom Sprayer
- Harvesting: Combine with Grain Head
- Haul: Tractor 215 HP with Grain Cart
- Haul: Semi Tractor/Trailer

Note: Equipment requirements follow that of conventional tillage, non-irrigated wheat production: http://economics.ag.utk.edu/budgets/2016/Crops/Wheat.pdf

References
- NASS, USDA. "Field Crops: Usual Planting and Harvesting Dates." *USDA National Agricultural Statistics Service, Agricultural Handbook* 628 (2010).
- Smith, S.A., B. Bowling, S.C. Danehower, D. Bilderback, D. Manning, H. Young-Kelly, A. McClure, L. Steckel, S. Stewart, E. Burns, R. Buntin, and J. Lannom. 2015. "Field Crop Budgets for 2016." University of Tennessee Extension Department of Agricultural and Resource Economics Publication AE 15-01

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Figure 5. Information on Triticale

Winter Rye: Cereal Rye, (a.k.a. Winter Rye) holds significant promise as feedstock for cellulosic biofuels. Relative to other cover crop/double crop feedstocks, cereal rye has an extensive growing range, robust germination and establishment, frost tolerance and ability to accumulate large amounts of biomass during cool weather periods

- Planting and harvesting dates vary by region and plant hardiness zones.

	Planting Dates	Harvest Dates	Possible Rotation
Zone 3-4	Aug 15 - Sept 10	July 10 - Aug 20	Winter Rye > Soybean*
Zone 5	Aug 30 - Sept 26	June 30 - July 30	Corn > Winter Rye > Soybean*
Zone 6-7	Sept 3 - Oct 15	June 3 - July 2	Corn > Winter Rye > Soybean
Zone 8-9	Sept 20 - Nov 10	May 10 - June 20	Cotton > Winter Rye > Peanut

* Soybean planted into Rye by early June

Equipment
- Chisel: Tractor 215 HP and Chisel Plow
- Disk: Tractor 215 HP and Tandem Disk
- Prepare Seedbed: Tractor 215 HP and Do-All
- Planting: Tractor 215 HP and Grain Drill
- Weed Control: SP Boom Sprayer

Equipment Continued
- Insecticide: SP Boom Sprayer
- Fertilize: Tractor 215 HP and Spreader
- Insect Control: SP Boom Sprayer
- Harvesting: Combine with Grain Head
- Haul: Tractor 215 HP with Grain Cart
- Haul: Semi Tractor/Trailer

Note: Equipment requirements follow that of conventional tillage, non-irrigated wheat production: http://economics.ag.utk.edu/budgets/2016/Crops/Wheat.pdf

References
- North Dakota – Cover Crops Report 2015-2016. http://www.mccc.msu.edu/meetings/2016/2015%20State%20reports/2015%20MCCC%20report%20for%20North%20Dakota.pdf
- NASS, USDA. "Field Crops: Usual Planting and Harvesting Dates." *USDA National Agricultural Statistics Service, Agricultural Handbook* 628 (1997).

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Figure 6. Infromation on Winter Rye

- Oilseed radish is of the Brassicaceae family, the mustard family of flowering plants. The family includes many plants of economic importance such as those of the genus Brassica, including cabbage, broccoli, kale, turnips, horseradish, radish, white mustard and others (EOE Brittanica 2015).
- Oilseed radish is composed of a taproot and several stemmed leafs which flower and produce oilseeds. The taproot can grow to 2 inches in diameter and up to 1 foot in length. This large taproot can break up and aerate the soil, alleviating soil compaction, which is why it is sometimes referred to as tillage radish (Weil, White, & Lawley, 2006).

Management:

- Oilseed radish establishes quickly and management is minimal. Seed harvest should be done when pods turn from green to yellow/brown. Seedpods do not readily shatter and require mechanical separation using stationary threshers with rollers to remove chaffy material (Novazio, 2007). However, large scale seed harvest is difficult. Using a combine to harvest seeds requires custom attachments (Jacobs, 2012b).

Region of Growth:

- Temperatures below 20 degrees F will damage or terminate the plant. Therefore, cover/feedstock production may be limited to regions with mild winters. The Mid-Atlantic and Southeast regions are likely to be suitable areas for growth as a feedstock (Weil et al 2006 & Chammoun 2013).

Potential as Feedstock

- Prior research has examined the potential of oilseed radish as a biodiesel feedstock. Extracted oil was converted to a fatty acid methyl ester (biodiesel) via transesterification.
- Chammoun, Geller, and Das (2013), find oilseed radish to have an oil yield and fatty acid profile similar to rapeseed. The authors also find that biodiesel from oilseed radish meets ASTM limits. However, the cold filter plugging point (CFPP) is determined to be 6 degrees Celsius, which may limit its fuel use in colder environments.

Invasiveness Potential:

- Oilseed radish is a non-native species. It is coded as an introduced species to the Lower 48 and Alaska within the USDA-NCRS PLANTS database. However, it is widely distributed throughout North America.
- Oilseed radish has potential to become weedy and invasive, although there are no restrictions on its use as a cover crop (Jacobs, 2012b).
- We decided that there was to much that was unknown about the harvest equipment for the oilseed radish.

Estimated Cost of Production

Costs per Acre			
cover crop	operating costs	fixed costs*	total costs of production
Triticale	108.59	44.02	152.61
Winter Rye	160.57	55.66	216.23
Pennycress	67.47	18.24	85.71
Camelina	61.44	46.22	107.66
*Does not include land ownership costs			

Objective(s)

Develop database on infrastructure and needs for Southeast.

Research Approach

Collect spatial datasets that exist and initiate a southeast regional analysis. The Forest Sustainable and Economic Analysis Model (ForSEAM) is a linear programming model can be used to estimate forestland production over time, and its capacity to produce not only traditional forest products but also products of woody biomass to meet energy feedstock demand. It solves and reports the quantity and types of woody biomass that can be available as energy feedstock with respect to certain marginal costs at the 305 Crop Report District (CRD) level of United States. This model can be divided into three major sections including supply, demand, and sustainability. The supply component includes general timber production activities for 305 production regions or crop reporting districts (CRD). Each region has a set of production activities defined by the U.S. Forest Service. These production activities include saw timber, pulpwood, and energy feedstock (woody biomass). Two sources of energy feedstock were considered in the model: logging residue generated from saw timber and pulpwood harvest activities; removal of whole pulpwood and un-merchantable trees. Demand component is based on six U.S. Forest Service Scenarios with estimates developed by the U.S. Forest Products Module (USFPM). The sustainability component insures that harvest in each region does not exceed annual growth, that roads have been constructed and forest tracts are located within mile of the roads, and that current year forest attributes reflect previous year's conventional wood product harvests and woody biomass as energy feedstock removals. Dynamic tracking of forest growth is incorporated into the analysis.

Spatial Datasets Collected

We have spatial information on airports, pipelines, and forest product mills. We have information also on forest residues at the POLYSYS region level. The forest residue data were generated for the Billion Ton 16 study using ForSEAM. ForSEAM is a forest model that can estimate the potential supply of forest residues, and trees harvested for biomass once traditional products are harvested. ORNL has developed procedures to downscale the supply curves developed by ForSEAM at the POLYSYS region level. These data are downloadable from ORNL

Objective(s)
Initiate aviation fuel supply chain study in the southeast

Research Approach

Develop feedstock layers of alternative dedicated crops and develop an analysis with VOLPE's assistance.

Develop feedstock layers that have supply curves imbedded for each county.

Initiated feedstock layer development. We have layers for the yield and cost layers for the following feedstocks:
1. Corn Stover
2. Wheat Straw
3. Sorghum Residue
4. Oat Residue
5. Barley Residue
6. Pennycress,
7. Cotton Seed,
8. Trees – Supply curves for small and medium diameter natural pine, planted pine, lowland hardwood, upland hardwood, and mixed, and
9. Wood Residue that are available as a result of traditional harvests.

Objective(s) Continue with sustainability work for both goals 1 and 4]

Research Approach
Develop modules for POLYSYS that estimates changes in erosion, develop modules for POLYSYS that estimates changes in erosion, sediment Delivery, chemical purchases, and N and P application. This will be an export analysis for now. POLYSYS results will be placed in ACCESS and used to estimate changes in the parameters mentioned above.

Methodology Developed
Access has been used to estimate the parameters. Programming has commenced so that the system will be automated. The pennycress solution will be the initial trial of the system and should be completed by April.

Milestone(s)
Pennycress has been evaluated as a feedstock and a manuscript is being written.

Major Accomplishments
The potential of three additional cover crops have been identified and analysis for these will begin in April.

Publications
None

Outreach Efforts
Evan Markel, Chad Hellwinckel, and Burton C. English, 2016. Project 1: Pennycress to Aviation Fuel: Its Potential Impact on U.S. Agriculture. Poster presented at the Sept 27-28 annual ASCENT meeting, Washington D.C.

Evan Markel, Burton C. English, R. Jamey Menard, 2016. Project 1: Pennycress to Aviation Fuel: Its Impact on U.S. Agriculture and the Nation's Economy, Poster presented at the October CAAFE annual meeting, Washington D.C.

Burton C. English, Lixia He-Lambert, Evan Markel, and Tim Rials, 2016. Feedstock, presented at the semi-annual ASCENT meeting, Seattle, WA., March.

Burton C. English, Evan Markel, Umama Rahman, and Chad Hellwinckel, 2016. Cover Crop Potential as a Feedstock for Aviation Fuel, Webinar Dec. 6, 2016

Burton C. English, Edward Yu, Dayton Lambert, and James Larson, 2016. Determination of the Environmental Impact of Growing Feedstock for Aviation Fuel, Webinar Dec. 12 2016.

Awards
None

Student Involvement
Evan Markel – Ph D student, developed the Pennycress work, leading effort on gathering information on other cover crops.
Umama Rahman -- Worked on Camalina information

Plans for Next Period
I plan on continuing to work on the 4 objectives or tasks. These tasks wil provide information on impacts to the ag sector and to the environment. I also will continue to estimate the impacts to the economy in terms of GDP and employment opportunities. Finally, a techno-economic analysis of the feedstocks will be initiated so that important factors are identified that might impact the economic sustainability of the feedstock.