pathways proposed that try to account for NOx formation during the combustion process, one of which is the Fenimore mechanism. In the Fenimore mechanism, it is postulated that fuel radicals formed during the combustion process react with nitrogen from the air to form NO_x. We proposed that if these radical reactions could be terminated, NO_x production from biodiesel combustion would decrease. To test this hypothesis, the ability of antioxidants to terminate these radical reactions and reduce NOx levels in biodiesel exhaust was investigated. Several antioxidants added to a 20% biodiesel/80% diesel fuel blend (B20) were screened using a small minimally instrumented diesel engine to test their ability to reduce NO_x emissions from the fuel. The engine used for these studies was a single cylinder, direct injection, air-cooled, naturally aspirated Yanmar engine. The NO and NO_2 in the exhaust stream were quantified using electrochemical sensors, and differences in NO_x emissions from the combustion of B20 with and without antioxidant compared. Preliminary data show that antioxidant addition does not significantly decrease or increase NO_x emissions. This information is pertinent in light of the possibility that antioxidant addition will be employed to improve the storage stability of biodiesel.

Eliminating the NO_x Emissions Increase Associated with using Biodiesel as a Fuel. E. Chapman[1] and A. Boehman[2], [1]Pennsylvania State University, United States, [2]Pennsylvania State University, United States. *Contact:* Elana Chapman, Pennsylvania State University, 930 Cricklewood Dr., State College, Pennsylvania 16803, United States.

Abstract: As emissions regulations around the world force engine and vehicle manufacturers to find methods to reduce the emissions, the efforts to find the most economical and easiest approach become more important. Multiple studies show that most diesel engine emissions can be reduced through the use of biodeisel either blended with diesel or neat form. Implementing greater biodiesel use is inhibited in part because of the observed increase in NO_x emissions as compared to conventional petroleum diesel fuel. A relation between the saturation of the fuel with NO_x emissions has been established by researchers. Additional research by the author and co-workers explored two approaches of achieving a more saturated biodiesel fuel and observed its effects on NO_x emissions blended as B20. The first option explored was blending of the biodiesel fuel with short-chained, saturated methyl esters. The second was the hydrogenation of soybean oil prior to transesterification. A 60% capylic/40% capric blend was mixed with B100 as a means of increasing the fuel's saturation. Another fuel containing a high percentage of oleic acid methyl ester was used as an example of hydrogenated fuel. Emissions testing revealed expected percentage decreased NOx levels for the caprylic/capric blend, but the high oleic "hydrogenated" blend revealed a smaller NO_x emissions decrease than was expected. The focus of this research is to determine if there is an actual reduction in NO_x emissions attributed to a re-formulated biodiesel, used in a Detroit Diesel 2.5 L turbodiesel engine. A sample of a acual light hydrogenated biodiesel will be used. The discovery will need to clarify if the change is due to a chemical change in the fuel, a physical change in the amount of fuel injected, or change in injection timing of the fuel. This can be understood through the use of pressure trace analysis and monitoring of fuel injection timing.

Combustion and Emissions from a Diesel Engine Fueled with Isopropyl Esters. J. Van Gerpen and P. Wang, Iowa State University, United States *Contact:* Jon Van Gerpen, Iowa State University, Room 2022, Black Engineering Bldg., Ames, Iowa 50011, United States.

Abstract: Biodiesel consists of the monoalkyl esters of fatty acids from vegetable oils or animal fats and is an alternative fuel for diesel engines. Biodiesel has the advantages of being renewable, having cleaner emissions than diesel fuel, and it is usable in diesel engines without any modifications. However, biodiesel consisting of methyl esters have poor cold flow properties around 0°C as it can crystallize and plug fuel filters and lines. Isopropyl esters have better cold flow properties when compared to methyl esters.

The objective of this study was to investigate the emissions from a diesel engine running on isopropyl esters made from soybean oil and yellow grease. The emissions from the combustion of isopropyl esters were compared to methyl esters from the same source material and No. 2 diesel fuel, which was the baseline fuel for this study.

The emissions from the diesel engine running on biodiesel were strongly affected by the source material of soybean oil or yellow grease. While the isopropyl esters have better cold flow properties when compared to methyl esters, the exhaust emissions were quite similar for the two different esters from the same source material.

Biofuels and Their Use in Boilers. C. Krishna and T. Butcher, Brookhaven National Laboratory, United States. *Contact:* C. Krishna, Brookhaven National Laboratory, Building 526, Upton, New York 11973, United States.

Abstract: Brookhaven National Laboratory has been researching the use of home heating oil in residential boilers and furnaces for a long time. Over three years back, we started researching the use of biodiesel in such residential and small commercial boilers for heating applications. At that time, the primary interest in the use of biodiesel had been in diesel engines. Results from these early tests with small boilers indicated benefits in the use of biodiesel blends that were not seen in diesel engine use, such as reductions in nitrogen oxide emissions. These results and other effects specific to such equipment will be reported.

A possible difficulty in the expanded use of biodiesel is its cost compared with petroleum diesel. Environmental benefits could partially offset this disadvantage. Also, for boiler applications, it seems that, the ASTM fuel specifications currently available that have been developed with diesel engines in mind, could be less stringent. As an example, the cetane number requirements are not of much concern. This indicates that a less 'refined' biofuel might offer the benefits seen with biodiesel, but with a lower fuel cost. The results from the identification of such fuels and of their testing in small boilers will also be given.

Tuesday Afternoon

IOP 3: Alternative Crops: Cuphea 2004 Commercialization

Chairs: B. McCormick, Procter & Gamble, USA; and S. Knapp, Oregon State University, USA.

Herbicides and Desiccants for Managing Cuphea, a New Oilseed Crop. F. Forcella and R. Gesch, USDA, ARS, NCSCRL, United States. *Contact:* Frank Forcella, USDA, ARS, NCSCRL, 803 Iowa Ave., Morris, Minnesota 56267, United States.

Abstract: The cuphea line known as PSR-23 is a partially domesticated potential new crop that produces seeds with high levels of medium chain fatty acids (primarily capric acid, but also lauric acid). PSR-23 is a cross between two annual species: Cuphea viscosissima and C. lanceolata. The plant appears to grow well in Minnesota and adjacent states under conditions roughly analogous to those of soybean. At this stage of domestication, the highest seed yields obtained have been 1400 kg/ha under irrigation. Seeds contain about 30% oil. Very slow growth in spring and indeterminate growth in late summer necessitate the use of herbicides for weed control and desiccants for harvest aids. However, no chemicals have been labeled for use in cuphea at this time. Consequently, we undertook basic agronomic research to find herbicides that cuphea tolerates and desiccants that facilitate harvesting of this shatter-prone crop. Cuphea adequately tolerates the following soil-applied herbicides: ethalfluralin, isoxaflutole, mesotrione, and trifluralin (all applied at rates typical for corn or soybean). It also has some tolerance to postemergence appli-

cations of imazamox, imazethapyr, and mesotrione. Useful harvest aids include paraquat, sodium chlorate, and tank mixes of both. Cuphea can be harvested within one week after treatment with these desiccants in early to mid September. Swathing and windrowing for 2 to 3 weeks before combining also is useful for harvesting cuphea. Up to 40 ha (100 acres) of cuphea will be grown in 2004 to increase seed supplies, and much greater acreage is anticipated in 2005. Commercialization is sponsored, in part, by large international companies that seek new sources of capric and lauric acids.

Physiological Response and Seed Yield of Irrigated Cuphea. R. Gesch[1], B. Sharratt[2], F. Forcella[1] and A. Olness[3], [1]United States Department of Agriculture, United States, [2]United States Department of Agriculture, United States, [3]Agricultural Research Service (ARS) –Midwest Area, United States. *Contact:* Russ Gesch, United States Department of Agriculture, 803 Iowa Ave, Morris, Minnesota, United States.

Abstract: Cuphea is a potential new oilseed crop being developed as a domestic replacement source for medium-chain oils that are important feed stocks for chemical manufacturing. Previous studies have shown that cuphea lacks a deep root system and inefficiently utilizes water in producing seed, making it potentially prone to drought-stress. The present study was conducted to determine maximum seed yield under non-limiting soil moisture conditions. Cuphea was grown in 2002 and 2003 on a Barnes loam soil in west central Minnesota. Plots 6 × 6 m were drip-irrigated to maintain soil moisture at 100% field capacity (fully irrigated) and 50% field capacity (partially irrigated); soil matric potential was measured twice weekly using tensiometers buried at 10, 30, 80, and 100 cm. Non-irrigated check plots were included and all treatments were replicated three times in an RCBD. Additionally, soil water content was assessed weekly by neutron attenuation at 15, 45, 75, and 105 cm. Midday leaf water potential and photosynthesis were measure periodically between early July and mid August in 2003. Seed yield did not differ between irrigated and non-irrigated cuphea in 2002, and averaged 795 kg/ha across treatments. Lack of yield variation in 2002 was mainly due to receipt of ample precipitation throughout mid to late summer (i.e. July through early September). As a consequence, the soil in the upper 45 cm of the soil profile stayed relatively moist throughout the growing season, even on non-irrigated plots. In 2003, precipitation was below normal throughout July and August. By mid August, when peak seed development occurs in this region, midday leaf water potentials of non-irrigated plants were about two-fold lower than those fully or partially irrigated. Drought-stress symptoms (e.g. leaf rolling and wilting) were apparent for non-irrigated cuphea later in the growing season and leaf photosynthesis declined as much as 82% as compared to irrigated plants. This severe decline in assimilation rate translated into substantially lower seed yield. Non-irrigated cuphea yielded 530 kg seed per ha, while that of fully irrigated plants produced 1400 kg seed per ha. Evidence clearly indicates that soil moisture is a critical factor for cuphea production. Landscapes with coarse textured soils or regions that are prone to dry growing season conditions will likely require supplemental irrigation to maximize cuphea seed yield.

Cuphea—The Process and Milestones to Commercialization. A. Hebard, Technology Crops Inc., United States. *Contact:* Andrew Hebard, Technology Crops Inc., 4035 University Pkwy Suite 100, Winston Salem, North Carolina 27106-3325, United States.

Abstract: Cuphea has been developed into a crop suitable for mid western arable agriculture through an intensive breeding and agronomic program. 2004 will see the first commercial crops of cuphea being grown for capric acid as part of a rapid scale up plan to meet projected industry demand. To take a new crop from a few small trial plots to a potential future area of >1.0m acres requires a clear process that identifies specific technical and commercial milestones. These include breeding and agronomy work to optimize field performance, logistics planning to reduce "on costs" of freight and storage, oil extraction, co-product utilization and risk assessment / management to address sustainability and viability questions. The Cuphea Consortium has developed a commercialization plan that predicts cuphea will become an important crop for mid western agriculture and as an oleochemical feedstock over the next 10 years, delivering a reliable and cost effective source of short/medium chain fatty acids. Through projecting field performance and conducting cost modeling, we have estimated future oil prices to be very competitive with the current alternative sources of the fatty acids, notably palm kernel and coconut.

Recent Developments in the Industrial Utilization of High Capric Cuphea Oil. T. Isbell[1], S. Cermak[1] and R. Evangelista[2], [1]USDA, ARS, NCAUR, United States, [2]United States Department of Agriculture, United States. *Contact:* Terry Isbell, USDA, ARS, NCAUR, 1815 N. University Street, Peoria, Illinois 61604, United States.

Abstract: Cuphea is a new oilseed crop currently being domesticated as a rotation crop in the Midwestern United States. The current cuphea lines that have been developed are high in capric fatty acid (70%). Capric is supplied in limited quantities as a by-product of lauric acid production from coconut (6%) and palm kernel oils (3%). Since high capric cuphea is a new crop in the initial phases of commercial production all phases from farm to consumer will need to be throughly researched for its successful introduction. We report here preliminary seed oil processing and derivatization research efforts within our laboratory.

Freshly harvested cuphea seed is high in moisture (25 to 50%) due to the indeterminate nature of the plant and the need to harvest seed prior to shattering. This high water content requires immediate drying and cleaning to ensure seed quality. Seed cleaning was also required to remove both trash and aborted seeds prior to oil pressing operations. Oil content of the bulk material was increased from 14% (dwt) to 33% by a series of screening, aspiration and gravity table separations. Subsequent, full pressing of cuphea seed gave a 76% oil recovery.

Cuphea oil was then converted to its fatty acids and condensed with oleic acid using 0.05 equivalents of perchloric acid at 60°C for 24 hours. In situ esterification with 2-ethylhexanol gave the corresponding cuphea capped estolide. Physical properties of this estolide had very good low temperature properties (pour point = –42°C) and good oxidative stability. The cuphea estolide has good potential for a variety of lubricant applications.

Breeding and Genetics of Cuphea, a New Medium-Chain Oilseed. S. Knapp[1], R. Brunick[2], J. Crane[2], C. Powers[2], M. Slabaugh[2] and V. Karkmarkar[2], [1]Oregon State University, United States, [2]Oregon State University, United States. *Contact:* Steven Knapp, Oregon State University, CRS 451-C, Corvallis, Oregon 97331-3002, United States.

Abstract: Cuphea, a new oilseed crop and source of saturated medium- chain oils, was developed from interspecific hybrids between two diploid (x = 6), annual, high-capric acid (10:0) species, one native to the United States (*C. viscosissima*) and one native to Mexico (*C. lanceolata*). Our research has focused on domesticating Cuphea, increasing seed and oil yields, developing genetically superior cultivars, cataloguing genetic diversity, developing novel genetic stocks, and molecular breeding. We review the development of fully self-pollinated, partially non-shattering cultivars, breeding for high oil, high capric acid, and semi-determinant flowering, and strategies for developing high lauric and fully non-shattering cultivars. The development of high capric cultivars is underway using high capric acid (85–89% 10:0) germplasm sources. The molecular breeding program was restarted two years ago to build the foundation for forward genetic analyses and marker-assisted selection in Cuphea. More than 200 sequence-tagged-site (STS) markers have been developed, molecular genetic diversity in *C. viscosissima* and *C. lanceolata* has been surveyed, the development of an STS map of the Cuphea genome is underway, and segregating populations and near-isogenic lines have been developed for mapping and manipulating phenotypic loci and quantitative trait loci for seed dormancy, seed shattering, self-pollina-