

# **Burning High-Grade, Clean Fuel Made from Low-Grade Used Agricultural Plastics**

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**Abstract:** For waste agricultural plastics that cannot be economically recycled, high temperature controlled combustion to produce heat is a viable option. A new plastic-derived fuel boiler system has been introduced to the USA from Korea, and is currently being evaluated at the Pennsylvania State University Horticulture Research Farm. It burns pea-sized pellets made from waste mulch film or granules made from rigid plastic items. The hot water is used to heat greenhouses and other structures. In May, 2005, continuous emissions monitoring and stack testing conforming to US EPA standards were conducted by an independent US testing company. Three main groups of pollutants were analyzed:

- Gases (sulfur dioxide, oxides of nitrogen, and carbon monoxide)
- Particulate matter
- Dioxins / furans

Test results proved that this is an extremely clean burning system in all three groups. The Korean company is in the process of scaling-up their burner design to burn Plastofuel, a low-energy input fuel production process which makes marshmallow-sized nuggets from waste thermoplastics.

**Keywords:** Plastic-derived fuel; plastics; polyethylene; combustion; emissions; agricultural energy

## **Introduction**

The use of plastics in agriculture -- called plasticulture -- is a multi-million dollar industry worldwide. Thanks to plasticulture, feeding the world has become easier. High-yield, high-quality crops and livestock can be grown under controlled conditions where pests and disease are limited, fluctuations in temperature are reduced, light intensity and

duration are managed, water use is optimized, and so forth, all because of plastics. Besides this, materials arriving at the farm gate are packaged in plastic, and products leaving the farm for market are enhanced with plastics of all sorts.

Despite the myriad advantages of plasticulture, there is a downside. Once plastic items have served their useful life, they become difficult to discard properly. Against best wishes, plastic items are often open burned on-site, causing air pollution and bad community relations. Additionally, they are discarded in remote areas, resulting in water quality concerns. Due to contamination by soil, debris and plant material, agricultural plastics are seldom recycled. Most recycling industries do not want to incur the expense of washing and drying dirty, low-value plastics, especially when they can recover only a few cents per pound in the marketplace. In rare instances, niche markets exist for feedstock as plastic lumber.

For those plastics that are not recycled or are not recyclable for one reason or another, a simple process was invented at Pennsylvania State University to densify these products into fuel, shown in Figure 1. Called Plastofuel, the process forces waste plastic through a heated die, melting a thin jacket which encapsulates dirt and debris within. This forms a dense fuel nugget that can be easily produced, conveyed, stored and shipped.



Figure 1. Plastofuel made from various waste thermoplastics.

### **Previous Penn State Plastic and Coal Combustion Research**

Plastofuel was originally developed to be burned with coal in a coal-fired boiler. In 2002, combustion tests were conducted at Penn State's Energy Institute when burning the nuggets with coal in a laboratory stoker simulator (Miller, et al; 2002). Tests evaluated emissions of 1) criteria pollutants, namely carbon monoxide, sulfur dioxide, and nitrogen oxides; 2) polycyclic aromatic hydrocarbons (PAHs); and 3) dioxin toxic equivalents (TEQ). Baseline tests were run burning coal alone, while additional testing entailed burning the baseline coal blended with nuggets made from discarded watermelon mulch films. Samples were obtained from growers in California, Pennsylvania, and Florida. The plastic nuggets comprised 5% and 10% of the thermal input of the fuel blend.

Regarding criteria pollutants, tests revealed that SO<sub>2</sub> and NO<sub>x</sub> emissions using the nugget/coal blends were similar to those when coal alone was burned. CO emissions were very variable, which is a deficiency of batch-type tests.

Regarding PAH and dioxin TEQs, the addition of plastic nuggets to the fuel blend did result in elevated emissions for two of the three plastics used. The emissions from the California plastic tests were similar to those observed when firing only the baseline coal. Complex PAHs and dioxin TEQ emissions were elevated when firing the Pennsylvania and Florida plastics, with the Florida plastic tests exhibiting the highest level of PAHs/dioxin TEQ emissions. The emissions from the Florida plastic tests contained the greatest quantity of the more toxic compounds.

### **High-temperature Plastic Combustion**

In 2004, a unique hot water boiler system was imported to the United States from Korea, shown in Figure 2. This heating unit is designed to burn pea-sized pellets made from waste plastic. (On a side note, this system is currently being modified to burn the larger-sized Plastofuel nuggets.) The burner preheats using fuel oil to elevate the combustion chamber to an operating temperature of 900-1100 °C (1652-2012 °F), then automatically switches to the pellet fuel. Costs will be \$12,000-\$15,000 for a unit that generates a nominal 100,000 kcal/hr. (396,850 Btu/hr.) on 9-15 kg/hr. (20-33 lb/hr.) with 11,000 kcal/kg (19,787 Btu/lb) plastic fuel pellets. The manufacturer, GR Technologies Company, Inc., is using test data gathered in a field setting at the Penn State Horticulture Research Farm to help determine commercial viability in the U.S. Hot water generated from the boiler will be used to heat a high tunnel greenhouse and eventually other buildings at the site. While emissions conform to Korean air quality standards, the unit was tested again in May, 2005 to assure conformance with U.S. Environmental Protection Agency standards. Results of these air emissions tests are the subject of this paper.



Figure 2. The GR Technologies, Inc. burner fueled on plastic pellets (inset) made from waste agricultural mulch

film. The burner is shown pulled out of the hot water boiler, shown on the left.

Emissions testing was conducted to demonstrate that the combustion of waste agricultural plastics is a clean, safe source of energy. The GR Technologies unit had been previously tested by the Korean Testing Laboratory (Ko and Kim; 2002) and found to not only conform to but exceed Korean air standards. Although these standards mimic U.S. Environmental Protection Agency (EPA) standards, emissions needed to be verified in a field setting. Testing conformed to EPA guidelines, administered by TEST, Inc. from Poca, West Virginia (Chinuntdet and Maxwell; 2005).



Figure 3. The two fuels consumed during air emissions testing, l to r, Korean LDPE pellets made from waste agricultural mulch film, and HDPE granulated barrels.

### **Materials Tested**

Figure 3 shows the two fuels tested in the GR Technologies burner. As a baseline for testing and in an effort to duplicate the Korea Testing Laboratory results of 2002, low-density polyethylene film was used, having a high heat value (HHV) of 10,945 kcal/h (19,689 Btu/lb.). From Pennsylvania, scrap high-density polyethylene barrels were granulated for use, with an HHV of 11,081 kcal/kg (19,933 Btu/lb.).

Plastofuel, previously tested cofired with coal (and shown in Figure 1) was not tested for air emissions because the fuel nugget size is too large to be fed into the existing burner. This GR Technologies system is being modified to accept the larger Plastofuel, however the design was not developed in sufficient time to test air emissions in this study.

### **Emissions Testing Procedure**

Continuous emissions monitoring and stack testing extending over a four-day period. Field testing was performed on the boiler at the Horticulture Research Farm. Three sets of tests for particulate matter, sulfur dioxide, oxides of nitrogen, carbon monoxide, and

total hydrocarbons and dioxins/furans were performed for each of two different operating conditions. The first condition entailed baseline data collection while burning plastic pellets made in Korea. The second condition entailed burning granulated plastic drums recovered locally. Testing was performed according to the procedures outlined in 40 CFR Part 60, Methods 1, 2, 3A, 4, 5, 6C, 7E, 10, 23, and 25A. Each test for particulate matter, sculpture dioxide, oxides of nitrogen, carbon monoxide, and total hydrocarbons was a minimum of 60 minutes, while tests for dioxins / furans was a minimum of 240 minutes in length.

## Results

The emissions measured during the stack testing are summarized in Table A. Three sets of tests were performed for each plastic fuel and the average of the three sets is presented in Table A. The results of the dioxin and furan testing are reported as 2,3,7,8 and total tetrachlorodibenzodioxin (TCDD) and 2,3,7,8 and total tetrachlorodibenzofuran (TCDF).

Table A. Average (of three sets) emissions from LDPE Korean pellets and HDPE plastic granules.

<b>Pollutant</b>	<b>LDPE Korean Pellets</b>	<b>HDPE Plastic Granules</b>
<b>Particulate Matter</b>		
gr/dscf <sup>a</sup>	0.0026	0.0017
lb/h <sup>b</sup>	0.0064	0.0043
<b>Sulfur Dioxide (SO<sub>2</sub>)</b>		
ppm	2.29	0.56
lb/h	0.006	0.0017
<b>Nitrogen Oxides (NO<sub>x</sub>)</b>		
ppm	48.53	14.44
lb/h	0.101	0.031
<b>Carbon Monoxide (CO)</b>		
ppm	13.11	44.15
lb/h	0.017	0.058
<b>Total Hydrocarbons</b>		
ppm	2.12	2.82
lb/h	0.004	0.006
<b>TCDD</b>		
2,3,7,8 (lb/h)	<1.37 E-12	<4.75 E-13
Total (lb/h)	2.33 E-11	N.D. <sup>c</sup>
<b>TCDF</b>		
2,3,7,8 (lb/h)	1.46 E-11	<1.26 E-12
Total (lb/h)	2.33 E-10	2.98 E-11

<sup>a</sup> grains per dry standard cubic foot

<sup>b</sup> pounds per hour

<sup>c</sup> not detected

## Conclusions

The Pennsylvania Department of Environmental Protection (DEP) does not have emissions regulations for boilers under 2.5 million Btu/h. The Korean boiler, with a firing

rate of 100,000 kcal/hr.(396,850 Btu/hr.), falls into this category; hence, there are no DEP emissions limits for this boiler. Consequently, in the ensuing paragraphs a comparison is made between the Penn State testing and two other tests or test conditions, namely 1) Lafarge North America plastic-derived fuel (PDF) cofired in a cement kiln with coal (Martin; 2004); and 2) the U.S. Environmental Protection Agency (EPA) regulations for a new municipal solid waste (MSW) plant.

### **Penn State Results Compared to Cement Kiln Emissions**

Lafarge North America performed testing in one of their cement kilns located in Whitehall Township, Pennsylvania, where they cofired PDF with coal. The substitution ratio was 1:1.3 based on heat input. The average PDF feed rate during the test was 2.14 metric tons per hour.

The particulate matter emissions during the Lafarge tests were 1.64 and 2.15 lb/h for the baseline period and PDF test period, respectively. Although there was a slight increase in the particulate matter emissions, this difference resulted in less than 10% of the New Source Review threshold of 25 tons per year; therefore Lafarge would not trigger regulatory action or installation of new pollution control equipment.

The SO<sub>2</sub> emissions during the Lafarge tests were 166 and 77 lb/h for the baseline period and PDF test period, respectively. These are significantly less than their emission limit of 362 lb/h.

The NO<sub>x</sub> emissions during the Lafarge tests were 162 lb/h during the baseline period firing coal and 101 lb/h when cofiring PDF and coal. These emission rates are less than their emission limit of 260.5 lb/h.

The CO emissions during the Lafarge tests were 915 lb/h during the baseline period firing coal and 330 lb/h when cofiring PDF and coal. The facility did not report a CO emissions limit.

The dioxin/furan emissions during the Lafarge tests were  $1.21 \times 10^{-11}$  gr/dscf TEQ for the baseline period and  $4.94 \times 10^{-12}$  gr/dscf TEQ when cofiring PDF and coal. The dioxin/furan emissions limit for Lafarge's unit is  $8.7 \times 10^{-11}$  gr/dscf TEQ.

Penn State's emissions of particulate matter, SO<sub>2</sub>, NO<sub>x</sub>, and CO are all significantly less than Lafarge's emissions and emission limits. Similarly, Penn State's TCDD total emissions for the LDPE and HDPE fuel samples and TCDF total emissions for the HDPE fuel sample were significantly less than Lafarge's emission limits. The concentration of total TCDF for the LDPE fuel, however, was greater than that observed by Lafarge and was greater than their emission limit.

### **Penn State Results Compared to a Municipal Solid Waste (MSW) Incineration Emissions**

Penn State's emissions were also compared to the regulations for a new MSW plant with a capacity greater than 35 metric tons per day, which has the most stringent EPA regulations for dioxin/furan emissions.

Emission limits for such a plant are 15 mg/dscm particulate matter, 30 ppm SO<sub>2</sub>, 180 ppm NO<sub>x</sub>, 50 ppm CO, and 13 ng total dioxin/furan emissions/dscm @ 7% O<sub>2</sub>. By comparison, Penn State's total dioxin/furan emissions (*i.e.*, addition of TCDD total and TCDF total emissions) for the LDPE fuel sample was 0.45 ng/dscm @ 12% O<sub>2</sub> while the total dioxin/furan emissions (*i.e.*, addition of TCDD total and TCDF total emissions) for the HDPE fuel sample was 0.03 ng/dscm @ 15% O<sub>2</sub>. When converted to 7% O<sub>2</sub>, these emissions are substantially less than the EPA regulations.

The SO<sub>2</sub>, NO<sub>x</sub>, and CO emissions from the Penn State testing are much lower than the EPA regulations. Similarly, Penn State's particulate emissions are 5.9 and 3.89 mg/dscm for the LDPE and HDPE fuel samples, respectively, which are well below the limit of 15 mg/dscm.

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