In the United States, current strategies to reduce dependency on imported energy and non-renewable energy include using biomass (generally plant derived material) as an energy source. One of the largest sources of non-food/feed biomass available is crop residues. These result from the harvest and/or processing of field grown crops such as corn, wheat, soybeans, cotton, grain sorghum and other grain crops. Other sources include fruit and vegetable residues left in the field at harvest, handling and processing wastes, and damaged crops such as moldy hay or fruit and vegetable culls. Currently, these crop residues remain in the field or are returned to the land to provide nutrients and organic matter for soil health and conservation. In some cases, residues are also used as livestock feed.

Many of these residues have been considered for conversion to energy by direct combustion (burning) for heat and for electricity, thermochemical conversion (pyrolysis, gasification, etc.) to various fuels, anaerobic digestion to biogas (methane, etc.) and more recently by a new technology referred to as “cellulosic” conversion to ethanol.

A survey of biomass residues and other potential bioenergy feedstocks in New Jersey was conducted in 2007 by the New Jersey Agricultural Experiment Station (NJAES) with support from the New Jersey Board of Public Utilities. Table 1 provides an estimate of various harvestable crop residues produced in New Jersey in recent years and their total potential energy value statewide.

<table>
<thead>
<tr>
<th>Crop/Residue</th>
<th>Tons (dry)</th>
<th>Total Energy (Million BTUs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweet Corn Residue</td>
<td>7,765</td>
<td>122,143</td>
</tr>
<tr>
<td>Rye Straw</td>
<td>38,087</td>
<td>594,157</td>
</tr>
<tr>
<td>Field Corn Residue</td>
<td>135,728</td>
<td>2,135,001</td>
</tr>
<tr>
<td>Wheat Straw</td>
<td>42,752</td>
<td>639,570</td>
</tr>
<tr>
<td>Non-Alfalfa Hay</td>
<td>129,549</td>
<td>2,020,964</td>
</tr>
<tr>
<td>Processing Residues</td>
<td>97,193</td>
<td>1,588,134</td>
</tr>
</tbody>
</table>

It is important to note that these are estimates of harvestable biomass residue, but some percentage, minimally 30%, should remain on the soil for conservation purposes (Table 1). It is also important to understand that these are potential energy values on a dry basis. Wet or field dry residues will have less net energy because water does not burn and, when such residue is burned for heat, some energy will be lost through the stack or lost by other means.

To evaluate the potential of crop residues for conversion to energy, it is important to consider the gross energy content. Table 2 and Figure 1 contain British Thermal Units (BTUs) per pound of material for various residues and other common energy sources.
Table 2. Gross Energy Content (BTUs/lb - dry basis) of Various Crop Residues at Harvest

<table>
<thead>
<tr>
<th>Crop/Residue</th>
<th>BTUs/lb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rye*</td>
<td>7,655</td>
</tr>
<tr>
<td>Oats*</td>
<td>7,544</td>
</tr>
<tr>
<td>Corn Stover**</td>
<td>7,524</td>
</tr>
<tr>
<td>Grain Sorghum Stover</td>
<td>7,242</td>
</tr>
<tr>
<td>Soybean Stover</td>
<td>7,466</td>
</tr>
<tr>
<td>Sorghum &amp; Sudangrass Hybrid***</td>
<td>7,230</td>
</tr>
</tbody>
</table>

**“Long straw,” i.e. early heading stage.**  
**Stover refers to stems, leaves and other harvestable material (except cobs) left behind after grain harvest.**  
***Hard dough stage, heads on.***

As apparent from these data, crop residues have a low energy density compared to traditional fossil fuels, i.e., about 1/2 to 2/3 of the energy value (BTU/lb) and 1/3 the energy density (BTU/cubic foot) of coal (Table 2 and Figure 1). Because crop residues are often in a form which may contain 15-70% or more moisture, this further lowers the “actual” energy value. The overall low energy density makes it uneconomical to transport crop residue very far (most economic analyses say less than 30 miles) because of high trucking/fuel costs. This suggests that conversion to energy will occur on or near the farm; otherwise, residues would need to be processed (densified) to allow for more distant transportation. As shown in Figure 1, it is of interest to note that corn (grain) has similar gross energy values as woody residues. Stoves and furnaces have been available for many years to burn corn grain when corn prices are low. Although not a field residue, spent cooking oil (typically soybean and other plant oils used for deep frying) has a very high energy value similar to the restaurant grease noted in Figure 1.

From a conservation and energy efficiency standpoint, direct combustion for heat generation is the most efficient way to convert plant biomass like crop residues into energy. Various cultures have, and still do, use wood and herbaceous plants and residues for heating and cooking. While dry plant material can be burned directly in a wood/coal stove or furnace, a current trend is to make pellets, briquettes, or other densified forms so that plant biomass can be transported farther and stoking can be mechanized. Such densification, however, reduces the positive energy balance of residues and increases the cost of using residues for energy. Growers and users of biomass can make some simple calculations to determine if using crop residues might be economical. To do so, a farmer should first estimate the amount of residue available per acre. For example, a 100 bu/A corn grain crop will generally result in about two tons of residue for harvest after leaving a sufficient amount of residue in the field for a 30% cover for soil conservation purposes, which the NRCS deems a minimum amount for conservation tillage/cover. Soybeans at 30 bu/A grain yields will result in less than a ton of residue and thus are not recommended for harvest. Wheat at 75 bu/A grain will produce about two tons of straw residue for harvest after accounting for 30% residue cover for soil conservation. A ton of well-dried corn stalks, for example, would contain almost the same amount of useable heat energy as 80-90 gallons of fuel oil. If growers have or can obtain appropriate equipment for harvesting, processing and burning the biomass and can determine their costs for using such equipment over a specified period, they can determine if it is economical to collect and utilize biomass for energy. The value of crop residue as a nutrient and organic matter source, along with the soil conservation value, should also be considered in the calculations. A ton of corn grain stalk residue can contain more than $30 of nutrients at today’s prices. Finally, as a note of caution on the use of residues for direct combustion: although problem gases (CO₂; NOₓ) are generally low compared to coal, particulate matter and ash are often higher. The ash that is removed from the combustion equipment can be re-applied to the field thereby recycling some of the plant nutrients.

Several relatively new methods of energy conversion include thermochemical conversion (pyrolysis, gasification, etc.) and fermentation processes such as cellulosic conversion to ethanol. Only a few processing facilities have been built to date, but most energy experts suggest that as the technology progresses they will be utilized commercially on a large scale similar to oil refineries. To be economical, these facilities will require more than 10,000 contiguous acres of biomass supply within 30 miles of the facility, a situation that no longer exists in a densely populated state like New Jersey, unless the facility can also utilize waste biomass from trash.

Many fruit and vegetable growers have plant residues, culls, and/or processing wastes in their operations. These materials tend to have very high moisture content (>70%), making them uneconomical to dry for eventual combustion to heat. Anaerobic digestion, a process frequently used with livestock manure, can convert wet wastes into biogas, a product that contains a significant amount of methane gas. The biomethane can be used for combustion heat or partially cleaned and used in low tech LP gas-type engines. Anaerobic digestion efficiency is dependent upon the actual crop material, carbon-to-nitrogen ratio, moisture, temperature and other factors that control digestion/fermentation. Current NJAES research is exploring anaerobic digestion processes, but no specific recommendations are yet available for the various crop material.
When considering the use of crop residues for biomass energy, it is not only important to consider economics and ultimate conversion processes, but also how the residue will be harvested and how much will be left behind for conservation and nutrient purposes.

Two important considerations for harvesting are:
* keeping the crop materials free of soil contamination (this keeps ash low; and
* field drying to harvest (bale) the material at a low moisture content (this gives higher heating value and more tons per package/bale).

Unlike hay used for feed, it does not matter as much if the residue gets wet from rain or is exposed to heavy dew (assuming minimal soil splash) as long as it is dry at harvest. In fact, while the total yield of residue may decrease after weathering, the remaining residue is often higher in energy value and lower in ash because potassium and other nutrients leach out into the soil. Storage of the baled crop residue must also be taken into consideration. While most farms will have enough land to accommodate the bales, they must be kept dry and away from flammable materials. Stacking and tarping the bales at the edge of the field until they are needed will work in most cases.

From a nutrient and conservation standpoint, the more residue left on the field the better for reducing soil and water erosion, returning nutrients (Table 3), and increasing soil organic matter (carbon sequestration). A farmer's conservation plan and the Natural Resources Conservation Service of USDA can provide recommendations to determine the proper amount of crop residue that needs to remain in the field to protect the soil from erosion and to provide an adequate nutrient replacement strategy. Normally, leaving a good stubble height (6-8 inches) and the small residues that fall to the soil surface will be

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**Figure 1. Comparison of As-Fired Energy Densities of Fuels Evaluated at Penn State**

*Figure used with permission of author.*
adequate for conservation purposes unless the field is considered highly erodible and/or it is on a steep slope. Cover crops and no-till crop production practices may also be needed where residues are removed.

**References**

1. [www.njaes.rutgers.edu/bioenergy](http://www.njaes.rutgers.edu/bioenergy)
4. Adapted from [www.nrcs.usda.gov/technical/ecs/nutrient/tbb2.html](http://www.nrcs.usda.gov/technical/ecs/nutrient/tbb2.html); values round to nearest pound; based on field dry moisture (10-25%); \( P \times 2.28 = P_{2}O_{5} \); \( K \times 1.2 = K_{2}O \)

### Table 3. Nutrient Content of Crop Residues and Hay (lbs/ton)

<table>
<thead>
<tr>
<th>Residue</th>
<th>( N )</th>
<th>( P )</th>
<th>( K )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn Stover</td>
<td>17</td>
<td>2</td>
<td>26</td>
</tr>
<tr>
<td>Soybean Stover</td>
<td>14</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>Sorghum Stover</td>
<td>14</td>
<td>2</td>
<td>19</td>
</tr>
<tr>
<td>Rye Straw</td>
<td>9</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td>Wheat Straw</td>
<td>11</td>
<td>1</td>
<td>21</td>
</tr>
<tr>
<td>Alfalfa-Timothy Hay</td>
<td>39</td>
<td>11</td>
<td>39</td>
</tr>
</tbody>
</table>