THE USE OF SWITCHGRASS BIOFUEL PELLETS AS A GREENHOUSE GAS OFFSET STRATEGY

R. Samson[1], M. Drisdelle[2], L. Mulkins[1], C. Lapointe, and P. Duxbury[1]

ABSTRACT

For more than 20 years, efforts have been made to grow dedicated biomass crops such as switchgrass, but no economically viable, energetically efficient transformation pathway has been described to convert this material into a usable energy form to displace fossil fuels. To meet this goal, it is proposed that warm season grasses such as switchgrass are used for heat related energy applications. This is considered to be the energy use with the highest comparative advantage for switchgrass, as the application requires little upgrading of the original energy quality of switchgrass, and it best matches the widespread production of the crop in North America. To improve combustion efficiency, the biomass quality of switchgrass can be upgraded through cultural management practices to reduce the chlorine, potassium and silica content of the fuel. Densification of the grass into a pellet form appears economically attractive and is essential to create highly controlled combustion for space heating applications.

Switchgrass pellets can be converted into usable heat at 82-84% efficiency in a close coupled gasifier pellet stove designed to handle moderately high ash fuels. Relative to oil and natural gas systems, switchgrass pellets have the potential to reduce fuel heating costs and greenhouse gas emissions in eastern Canada by approximately 30% and 90%, respectively. Compared to all other biofuel production and energy transformation pathways currently proposed, switchgrass pellet heating offers the highest net energy yield per hectare, the highest energy output to input ratio, the greatest economic advantage over fossil fuels, and the most significant potential to offset greenhouse gases.

Keywords: switchgrass, pellets, greenhouse gas emissions, energy transformation pathway

INTRODUCTION

Fast growing warm season perennial grasses have been identified as ideal candidates for biomass fuel production due to their high net energy yield per hectare and low cost of production. In particular, the C_4 grass switchgrass (Panicum virgatum) holds considerable promise as a biomass fuel in many agricultural regions in North America. Switchgrass is an ideal biomass energy source because of its moderate to high productivity, stand longevity, high moisture and nutrient use efficiency, low cost of production and adaptability to most agricultural regions in North America. Switchgrass has an energy output to input ratio of approximately 20:1, and typically can produce 185 GJ (175.5

MBtu) of energy per 10 tonnes of biomass from land that is often of marginal crop producing value. CO_2 emissions associated with fossil fuel use have produced a critical need to develop energy conversion pathways that efficiently transform renewable energy into a convenient and economical form. This paper overviews the opportunities and challenges associated with the transformation of switchgrass into a pelletized biofuel form, and its subsequent conversion to heat using a close coupled gasifier pellet stove. The economic, energetic and greenhouse gas implications of this strategy are compared to those of fossil fuels, and the net energy recovered/ha using switchgrass pellets is compared to alternative biofuel production/transformation pathways.

BIOMASS QUALITY OF SWITCHGRASS AS A COMBUSTIBLE BIOFUEL

A prerequisite to using switchgrass pellets as a biofuel to replace fossil fuels is to address some of the challenges associated with the combustion of herbaceous agricultural feedstock. One significant difficulty in the combustion of high ash fuels is clinker formation within the combustion unit, which occurs when high concentrations of chlorine and potassium in the ash melt at 600° C (1250 F) and fuse with silica. Clinker formation can be overcome in several ways. First, advances in equipment design help to minimize clinker. As discussed later in this paper, a pellet stove is now commercially available (http://www.pelletstove.com/) that is capable of burning some types of moderately high ash agricultural feedstocks. Second, the chemical composition of the feedstock can be improved for combustion through changing cultural practices. To limit clinker formation, Sander (1997) recommended 0.2% and 0.1% as maximum values for potassium and chlorine concentrations in the biomass, respectively. Strategies to reduce the concentrations of potassium, chlorine and silica in the biomass include avoiding the use of chlorine-containing fertilizers, growing water use efficient C_4 grasses (as silica is largely transported into the plant through silicic acid in water) and planting feedstocks on sandy soils (which contain lower levels of silicic acid) (Samson and Mehdi,1998; Sander, 1997). Additionally, since potassium and chlorine are highly water soluble elements, overwintering switchgrass enables nutrient leaching and results in K and Cl concentrations of 0.06% and 0.02%, respectively, which are well below the previously mentioned recommended limits. Combustion of spring harvested switchgrass is also facilitated by its ash content of approximately 3-3.5%, roughly 0.5-1% below that of fall harvested material. In contrast, western Canadian wheat straw has typical potassium and chlorine contents of 1.0% and 0.4%, respectively, and an ash content of 6.5-10%. The lower ash content of switchgrass also translates into a higher feedstock energy content of approximately 19.2 GJ/tonne (18.2 MBtu/tonne) for overwintered material and 18.5 GJ/tonne (17.6 MBtu/tonne) for fall harvested material in eastern Canada. The spring harvested energy value is only 3% lower than that of wood, at approximately 19.8 GJ/tonne (18.8 MBtu/tonne), and is 7% higher than that of wheat straw, at approximately 18 GJ/tonne (17.1 MBtu/tonne).

Another challenge associated with the combustion of herbaceous agricultural feedstocks is the bulky nature of the biomass, which makes it difficult to control the combustion process, obtain a high heat recovery and ensure clean combustion. Densification of the feedstock into a pelletized form eases these difficulties. With the support of Natural

Resources Canada, research on switchgrass pelleting and combustion was conducted to develop this opportunity (Samson et al., 2000), and the results are summarized in the following sections.

PRODUCTION AND ECONOMICS OF SWITCHGRASS PELLETS

Pilot plant studies on switchgrass pelleting were performed using a California Pellet Mill-CL Type 5 lab model pelleter and a 25 HP (9.3 MJ/hr) CPM Master Mill. As a feedstock, switchgrass behaved similarly to alfalfa, and was significantly easier to pellet than hardwood or softwood fibre sources. These feedstocks typically have throughput rates of 20 and 29 lbs./hr/HP (118.4 and 171.7 kg/hr/HP) respectively (Council of Great Lakes Governors, 1995). In comparison, monitored rates of production from western Canadian alfalfa producers are higher, ranging from 39.7-79.4 lbs./hr/HP (235.1-470.1kg/hr/MJ) (Hill and Pulkinen, 1988). The largest alfalfa pellet mill in Canada, with an installed capacity of 1250 HP (465.5 MJ/hr), reported an average production rate of 62 lbs./hr/HP (367.1 kg/hr/MJ) (Samson et al., 2000). Based on amperage draw and exit temperatures of pellets from the two CPM machines tested, it was predicted that production rates of 45-70 lbs./hr/HP (266.4-414.5 kg/hr/MJ) could be achieved in commercial pelleting of switchgrass. Pilot plant studies, a literature review and interviews with large commercial alfalfa pellet producers suggest that the necessary conditions to achieve high throughput and good switchgrass pellet durability include a fine length of chop (using a hammermill with a 7/64 or 2.8 mm screen), high temperature steam pretreatment of >110° C (250 F) (to release natural binders and lubricants in switchgrass) and selection of a die with a L/D (length/diameter) in the 9-10 range. Commercial scale trials are required to further improve pretreatment processes, die design and pelleting equipment technology to help achieve the higher throughput levels within this range.

The use of switchgrass as a pelleting material could considerably reduce pellet production costs by increasing the throughput of a 150 HP (55.86 MJ/hr) pellet machine to 6.9-10.9 tonnes per hour, compared to 3.1 and 4.5 tonnes per hour in the cases of hardwood and softwood sawdust, respectively. The economic analysis in Table 1 indicates that although switchgrass is currently more expensive than wood residues, it could be an economically more attractive feedstock as it requires minimal drying and has higher projected throughput rates. Moreover, since switchgrass pellets can be produced in closer proximity to more densely populated areas than can wood fuel pellets, there is potential to reduce transport costs. Ideally, switchgrass pellets could be locally handled in bulk, especially by farmers, who are accustomed to handling bulk agricultural materials. A bulk handled switchgrass pellet target price of \$100/tonne is a reasonable production objective, which could result in a delivered retail price of \$150/tonne prior to taxes.

Table 1. Summary of preliminary feedstock production costs (Canadian $ /tonne) [a]

	Wood pellet costs[b]	**Projected switchgrass pellet costs**

Feedstock	$ 34.35	$46-$68[c]
Drying	$11.93	$0
Direct Pelleting Costs	$59.00	$25.29-39.33
Bagging	$19.25	$19.25
Total cost	$124.53 (US$75.30/ton)	$90.54-$126.58 (US$54.87-$76.54/ton)

[a] Direct pelleting costs are based on 30 lbs./hr/HP (177.6 kg/hr/MJ) for wood residues and 45-70 lbs/hr/HP (266.40-414.5kg/hr.MJ) for switchgrass.
[b] Costs from survey of wood pellet producers, Council of Great lake Governors, 1995.
[c] Feedstock costs for switchgrass from Girouard et al., 1999

REDESIGNING COMBUSTION APPLIANCES FOR MODERATELY HIGH ASH FUELS

In the mid 1990's Dell-Point Technologies established a partnership with the Natural Resources Canada Advanced Combustion Laboratory with the goal of creating a high efficiency, low emission pellet stove capable of burning fuels with moderate ash levels, such as bark and switchgrass. The result was the 1998 licensing of a close coupled gasification technology pellet stove with an overall efficiency of 81-87%, which compares favorably to the more modest efficiencies of 35-69% of most pellet stoves on the market. The design of the close coupled gasifier technology is such that a lower operating temperature exists in the bottom of the gasifier where the first stage of the combustion occurs, allowing the ash to fall through the grate into the ash pan and reducing the production of clinker. The stove's efficient performance is largely due to its use of one-seventh of the excess air relative to current technology. A hydronic (providing combined heat and hot water) pellet furnace of 35 kWh (120,000 BTU/h) is currently under development and scheduled for field testing this year and commercial production in 2001.

COMBUSTION PERFORMANCE OF SWITCHGRASS FUEL PELLETS

Combustion of switchgrass pellets was evaluated by performing test burns in the Dell-Point stove at the Advanced Combustion Laboratory in Ottawa. The efficiency of the stove was assessed at medium and high output levels and was compared with values from combustion of hardwood fuel pellets. The laboratory trials indicated that switchgrass provided a relatively high combustion performance efficiency, with efficiencies of 82% and 84% at the medium output and high output range setting, respectively. These efficiencies were only about 2% lower than levels obtained with wood at each respective setting. This was considered to be a high level of performance, considering that the burner was not optimized for switchgrass pellet burning.

Particulate levels from switchgrass combustion were greater than those obtained for wood, with peak levels of 2.5 g/hour at the high range setting. This elevated particulate concentration is likely due to the plant's moderate ash content relative to wood. Nonetheless, even at the peak value of 2.5 g/hour, switchgrass particulate values were well below the 7.5 g/hour EPA limit for pellet stoves.

Switchgrass was found to be a slightly more challenging fuel to burn than wood in the Dell-Point stove. At the high range setting, switchgrass pellets formed weak bridges within the stove, causing some fuel accumulation above the grate. It is likely that programming the stove's grate cleaner to run more frequently than three times every 60 seconds would resolve this problem. Although more difficult to burn than wood, switchgrass is easier to burn relative to corn. Corn kernels were found to fuse and liquefy at high temperatures and eventually formed a hard cake-like layer over the grate. The Dell-Point close coupled gasifier furnace currently under development has an under-feed design that should minimize problems of grate obstructions and further widen the range of agricultural fuels that can be efficiently combusted.

ECONOMICS OF HEATING WITH PELLETED BIOFUELS

In North America, the adoption of biomass energy from switchgrass pellets could play an important role in reducing costs associated with fossil fuel use. Compared to electricity, oil and natural gas, switchgrass pellets offer a fuel savings of 46%, 28% and 30%, respectively (Figure 1). Fuels savings could be particularly striking in regions of North America where limited supplies of natural gas and oil create higher heating costs. For example, in Quebec, where approximately 50% of homes are heated with electricity, combustion of pelletized agricultural and forest residues using the new gasifier pellet stove technology could largely replace the use of electricity for heating purposes. This electricity could subsequently be exported out of province to displace the use of fossil fuel or nuclear power plants in other provinces or states. The rising prices of oil and natural gas will increasingly make the replacement of these fuels with biomass energy more financially attractive to consumers. In contrast, since the real dollar prices of agricultural commodities have historically followed a declining trend, the price of switchgrass pellets should remain relatively stable through time, as has been the case for wheat prices.

GREENHOUSE GAS EMISSIONS OF SWITCHGRASS FUEL PELLETS

There is considerable variation in the amount of $C0_2$ released from the use of different fuel sources for heating purposes (Figure 1). Emissions from the combustion of switchgrass pellets are considerably lower than those from fossil fuel sources. Pellet fuel heating reduces greenhouse gas emissions by 88%, 93% and 89% compared to electricity, oil and natural gas, respectively. However, the greatest potential to reduce $C0_2$ emissions is through the replacement of electrical heating with biomass energy in places such as Quebec, which are heavily reliant on electricity for heating applications. Quebec's unused electrical power could be exported, enabling the retirement of coal-generating energy plants in neighbouring provinces or states. This exchange could significantly reduce greenhouse gas emissions, as power generation by coal has a greenhouse gas loading factor of 245 kg $C0_2$/GJ (568 lbs. $C0_2$./MBtu), 4.7 times the $C0_2$ emissions of the Canadian electrical grid.

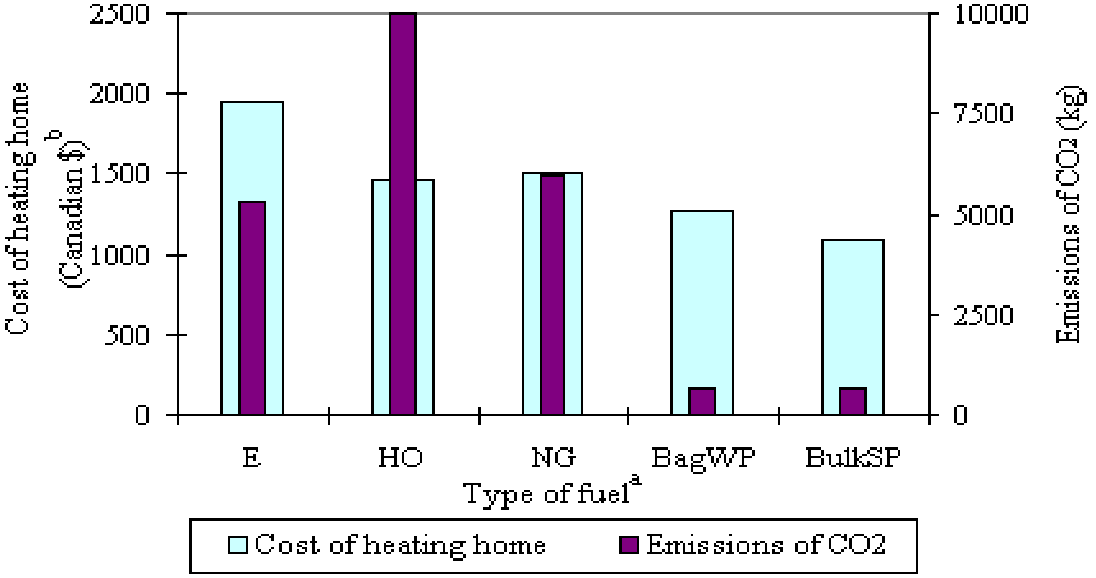

Figure 1. Fuel Costs and $C0_2$ emissions associated with home heating in SW Quebec

[a] Assumptions:

E= Electricity has an energy content of 3.6 MJ/kWh, a delivered fuel value of 6.87 cents/kWh, a $C0_2$ loading value of 52.2 kg $C0_2$/GJ and is converted at 98% efficiency, Approximate Canadian electrical mix: 63% hydro-power, 15% nuclear, 16.5% coal, 3% oil, 2% natural gas (Jaques, 1992).

HO= Heating Oil has an energy content of 0.0382 GJ/l, a delivered fuel value of 46.01 cents/l, a $C0_2$ loading value of 81.8 kg $C0_2$/GJ, and is converted at 82% efficiency

NG= Natural Gas has an energy content of 0.0375 GJ/m^3 ,a delivered fuel value of 47.85 cents/ m^3, a $C0_2$ loading value of 50.6 kg $C0_2$/GJ, and is converted at an average efficiency of 85%

BagWP= Bagged Wood Pellets have an energy content of 19.8 GJ/tonne, a delivered fuel value of $207/tonne, a $C0_2$ loading value of 5.3 kg $C0_2$/GJ, and are converted at 82% efficiency

BulkSP= Bulk Switchgrass Pellets have an energy content of 19.2 GJ/tonne, a delivered fuel value of $172/tonne, a $C0_2$ loading value of 5.3 kg $C0_2$/GJ, and are converted at 82% efficiency.

All delivered fuel values include taxes of 7% GST and 7.5% TVQ.

[b] Heat estimates made for a new detached 2000 sq. foot home with a heat requirement of 100 GJ (Natural Resources Canada, 1997). The analysis does not include capital costs associated with equipment.

Coal-derived electrical heating emits 38 times more $C0_2$ than switchgrass pellets in home heating applications. It is evident that substituting fossil fuel-based space heating applications with biofuel heating systems would be a highly effective strategy to reduce greenhouse gas emissions.

SWITCHGRASS PRODUCTION AND PELLETING: ENERGY ANALYSIS

The energy cost of switchgrass production for a large industrial user such as a pulp and paper or ethanol plant is estimated to be 0.91GJ/tonne , while that of a pellet plant is 0.79 GJ/tonne (Samson et al., 2000). The difference between energy costs is related to hauling distances to each facility. Because pellet conversion facilities are much smaller (200 tonne/day) than pulp and paper or ethanol plants (1500 tonne/day), pelleting plants can be situated in closer proximity to the site of switchgrass production. Assuming that 5% of the landscape is converted to switchgrass production and a harvestable yield of 10 tonne/ha is obtained, the switchgrass can be sourced within a 20 km radius of a pelleting plant, versus a 60 km radius for a large industrial user. This shorter radius would reduce the energy used in delivery from 0.177 GJ/tonne (19.5% of the total energy cost) to 0.059 GJ/tonne (7.5% of the total energy cost), and improve the energy output to input ratio for switchgrass production from 20 to 23:1.

Based on estimates from NOVEM (1996), King (1999) and Sokhansanj (2000), as well as actual power consumption data from wood pellet plant producers (Samson et al., 2000), the energy costs for the operation of a pellet plant are estimated to be 0.244 GJ/tonne, with the major costs associated with hammer milling and pelleting. Additional energy costs for pellet plant construction and materials and final delivery of the pellets brings the total pellet transformation costs to 0.48 GJ/tonne (Table 2). Adding the costs of switchgrass production, the total energy cost of the switchgrass fuel pellet production chain (from field to consumer) is estimated to be 1.27 GJ/tonne (1.2 MBtu/tonne). Surprisingly, production and delivery of switchgrass represents 62% of the energy required in the entire switchgrass fuel pellet production chain. This is largely due to the energy associated with fertilizer use and application, representing 36% of the total energy cost. Nonetheless, the net energy output to input ratio is 14.6:1 for the final pellet product, assuming a feedstock energy content of 18.5 GJ/tonne (17.5 MBtu/tonne).

Table 2. Energy inputs and outputs associated with of switchgrass as a pelleted biofuel.

Process	**GJ/tonne**
Switchgrass establishment[a]	0.028
Switchgrass fertilization and application	0.460
Switchgrass harvesting	0.231
Switchgrass transportation	0.072
Pellet mill construction[b]	0.043
Pellet mill operation	0.244
Management, sales, billing and delivery of pellets	0.193
Total Input Energy	**1.271**
Total Output Energy	**18.5**

Energy Output/Input Ratio	**14.6**

[a] Switchgrass information derived from Girouard et al., 1999 and Samson et al., 2000
[b] Pellet mill construction, operation, management sales, billing and delivery of pellets from King, 1999

SWITCHGRASS PELLET FUEL HEATING AS AN ENERGY PRODUCTION AND LAND USE STRATEGY

Relative to other biomass fuel initiatives, the production, pelletization and conversion of switchgrass into heat using the close coupled gasifier technology appears to be a promising energy production and transformation pathway (Table 3). For instance, a 10 tonne per hectare yield of switchgrass produces 185 GJ/ha of energy (assuming a feedstock energy content of 18.5 GJ). Five percent of this material is lost during the pelleting process, leaving 175.8 GJ of fuel pellets produced per hectare. Using the energy output to input ratio of 14.6:1, 163.1 GJ/ha of net energy are gained per hectare, a yield that favourably compares to other existing or demonstration level biomass energy transformation pathways. For example, power generation from co-firing switchgrass with coal produces a net energy gain of 47.2 GJ/ha, the production of switchgrass ethanol yields 57.1 GJ/ha and the production of corn-derived ethanol yields 21.4 GJ/ha. Thus, the use of pelletized switchgrass as a source of bioenergy is 3.5 times more land use efficient than the production of electricity from co-firing switchgrass with coal, 2.9 times more efficient than the production of cellulosic ethanol, and 7.6 times more efficient than grain corn ethanol production.

Table 3. Energy analysis of biomass fuel transformation pathways

	Switch-grass fuel pellets[a]	**Co-firing switch-grass with coal[b]**	**Switchgrass cellulosic ethanol and electricity[c]**	**Grain corn ethanol[d]**
Biomass yield per hectare (ODT)	10	10	10	6.5
Direct biomass energy yield (GJ/ha)	185	185	185	136.5
Energy yield after conversion	175.8	58.3	73.0 (67.2 ethanol + 5.8 electricity)	64.2+ coproducts

(GJ/ha)				
Energy consumedin production & conversion (GJ/ha)	12.7	11.1	15.9	42.8+ coproducts credits
Net energy gain (GJ/ha)[e]	**163.1**	**47.2**	**57.1**	**21.4**
Recovery of original biomass energy (%)	**88.2**	**25.5**	**30.9**	**15.7**

[a] Assumptions: Pelletization of switchgrass preserves 95% of the biomass energy and consumes 0.79 GJ/tonne in switchgrass production and 0.48 GJ/tonne in switchgrass pellet plant construction and materials, pellet processing and marketing.

[b] Assumptions: Switchgrass when co-fired with coal converts at 31.5% efficiency, switchgrass consumes 0.91 GJ/tonne in the production process and 0.2 GJ/tonne during its conversion at the existing coal plant

[c] Assumptions: Switchgrass cellulosic ethanol production is a cogeneration process that produces per tonne 320 l ethanol and 160 kwh electricity, the ethanol has an energy value of 0.021 GJ/l and the electricity 0.0036 GJ/kWh. Switchgrass production consumes 0.91GJ/tonne and processing consumes 0.68 GJ/tonne (adapted from Levelton, 2000 and Wang et al., 1999)

[d] Assumptions: Corn yields 6.5 ODT (120 bushels/acre) of grain which has an energy content of 21.0 GJ/tonne. Ethanol yields of 470 l/tonne are obtained, with all energy credits already assigned to coproducts. Corn production and ethanol processing consumes 0.14 GJ/l of ethanol (57,000 BTU/gallon), including coproduct credits. The ethanol has an energy value of 0.021 GJ/l (Wang et al., 1999)

[e] The net energy gain values for cellulosic and grain corn ethanol do not include energy costs of materials used in the construction of the processing facilities.

Expressed in terms of recovered energy, the conversion of switchgrass into fuel pellets is a highly energy conserving system, recovering 88% of the original energy stored in the switchgrass. Comparatively, the other biomass energy transformation pathways recover less than 1/3rd of the original plant energy in a final usable form. If the energy associated with the processing plant materials were included in the analysis, the energy efficiency of the coal co-firing and ethanol plants would appear even less favourable. Moreover, the corn ethanol chain is particularly inefficient given that high quality farmland is often used in its production. There is no doubt that ongoing improvements can be made in coal co-firing and ethanol plants, and that they produce a higher grade of energy than a fuel pellet. Nonetheless, using fuel pellets for heat related applications remains the most viable entry point to displace fossil fuels, as the original energy quality of the biomass best matches this end use, and little money or energy is dissipated through the transformation pathway.

CONCLUSIONS

Converting switchgrass pellets into heat using close coupled gasifier stoves and furnaces is proposed as the biofuel system with the greatest potential to displace fossil fuels at this time. It is a sustainable energy transformation pathway that is relatively environmentally benign. This system appears to accurately fit the definition of a ‘soft energy path,’ as described by Lovins (1977), due to its following characteristics:

1. It is powered by a renewable source of energy
2. It provides power sources which are multiple, small-scale and local, rather than few, large-scale and distant
3. It is a flexible and comparatively low technology system, facilitating its understanding and utilization

4. It is matched in terms of both scale and energy quality to its end-use application.

Further work is now required to commercially test and optimize the switchgrass pelleting and close-couple gasifier combustion systems. It is of paramount importance that policy makers are made aware of this energy transformation pathway, and that research and development budgets and tax credits, such as those currently oriented towards biofuel power generation and liquid fuel transformation pathways, are also provided to pelletized biofuel development.

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