

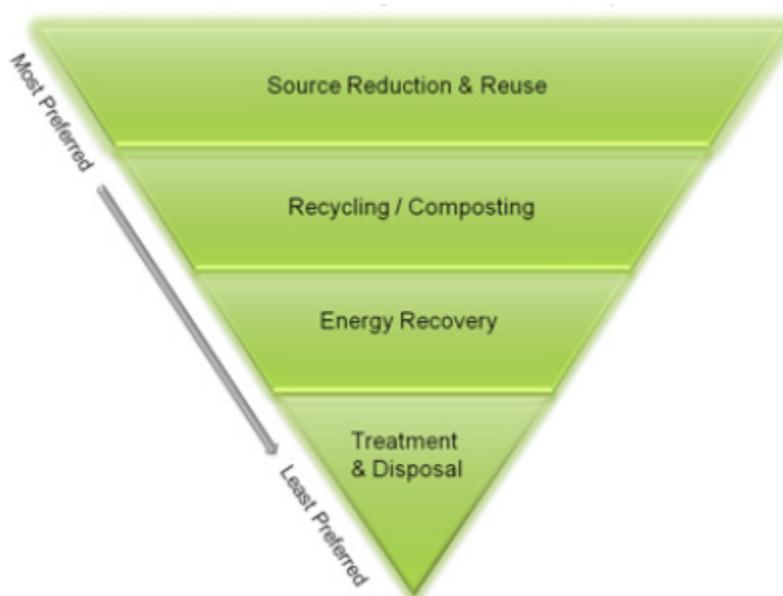
Bio-Based Products and Chemicals, Waste-to-Energy Scoping Analysis  
U.S. Environmental Protection Agency  
Office of Resource Conservation and Recovery  
April 2015

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**1.0 Background**

The U.S. Environmental Protection Agency (EPA) characterizes the generation and management of municipal solid waste (MSW) and other postconsumer wastes in their solid waste report<sup>1</sup> series. As part of this memorandum, EPA's contractor researched the major types of bio-based products and chemicals, including cellulosic and biomass-related materials, which are being used in waste-to-energy scenarios. EPA considers MSW combustion with energy recovery to be disposal for the purpose of calculating recycling rates, and promotes source reduction, reuse, recycling and composting over materials management for energy recovery.

**Figure 1. EPA Waste Management Hierarchy**



Specifically, this memorandum focuses on postconsumer MSW waste feedstocks that are being used to produce cellulosic biofuel, biomass-based diesel, advanced biofuel, renewable fuel, and cellulosic diesel. This memo defines each renewable fuel category shown below according to EPA's Renewable Fuel Standard (RFS) definitions at 40 CFR Part 80, Subpart M:

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<sup>1</sup> U.S. EPA. Advancing Sustainable Materials Management: Facts and Figures, formerly Municipal Solid Waste (MSW) in the United States: Facts and Figures report series located at <http://www.epa.gov/solidwaste/nonhaz/municipal/msw99.htm>

- **Cellulosic biofuel** is derived from feedstock with at least 75 percent cellulosic content (cellulose, hemicellulose, or lignin) and has lifecycle greenhouse gas emissions that are at least 60 percent less than the baseline lifecycle greenhouse gas emissions.
- **Biomass-based diesel** has lifecycle greenhouse gas emissions that are at least 50 percent less than baseline lifecycle greenhouse gas emissions, and 1) is a transportation fuel, transportation fuel additive, heating oil, or jet fuel; 2) meets the definition of either biodiesel or non-ester renewable diesel; and 3) is registered as a motor vehicle fuel or fuel additive under 40 CFR Part 79, if the fuel or fuel additive is intended for use in a motor vehicle.
- **Advanced biofuel** is a renewable fuel, other than ethanol derived from cornstarch that has lifecycle greenhouse gas emissions that are at least 50 percent less than baseline lifecycle greenhouse gas emissions.
- **Renewable fuel** is a fuel that is produced from renewable biomass; is used to replace or reduce the quantity of fossil fuel present in a transportation fuel, heating oil, or jet fuel; and has lifecycle greenhouse gas emission that are at least 20 percent less than baseline lifecycle greenhouse gas emissions.
- **Cellulosic diesel** is any renewable fuel that meets both the definition of cellulosic biofuel and biomass-based diesel. Cellulosic diesel includes heating oil and jet fuel made from cellulosic feedstocks.

The following sections provide an overview of domestic renewable energy consumption, present renewable fuel production under the RFS, and discuss the types and amounts (where possible) of waste feedstocks that are used to produce each category of renewable fuel, focusing on postconsumer MSW waste feedstocks. The research indicates that several existing facilities are capable of using MSW as feedstock, but few are using MSW to produce fuel at commercial scale.

EPA's contractor gathered information by reviewing scientific journals, EPA and U.S. Department of Energy (DOE) publications, renewable fuel trade association data and market reports, and other publicly available information. The National Biodiesel Board, the Advanced Biofuels Association, and the Renewable Fuels Association (RFA) were also contacted. Where data are available, EPA's contractor quantified the amount of waste feedstocks used in renewable fuel production.

This memorandum addresses the fuels listed above and does not include landfill gas or industrial wastes used as feedstocks for fuels. Additional research could be conducted to expand the scope of this memorandum to cover these waste-to-energy scenarios. Postconsumer food managed through anaerobic digesters is also excluded. EPA addressed food managed through anaerobic digestion in separate research efforts.

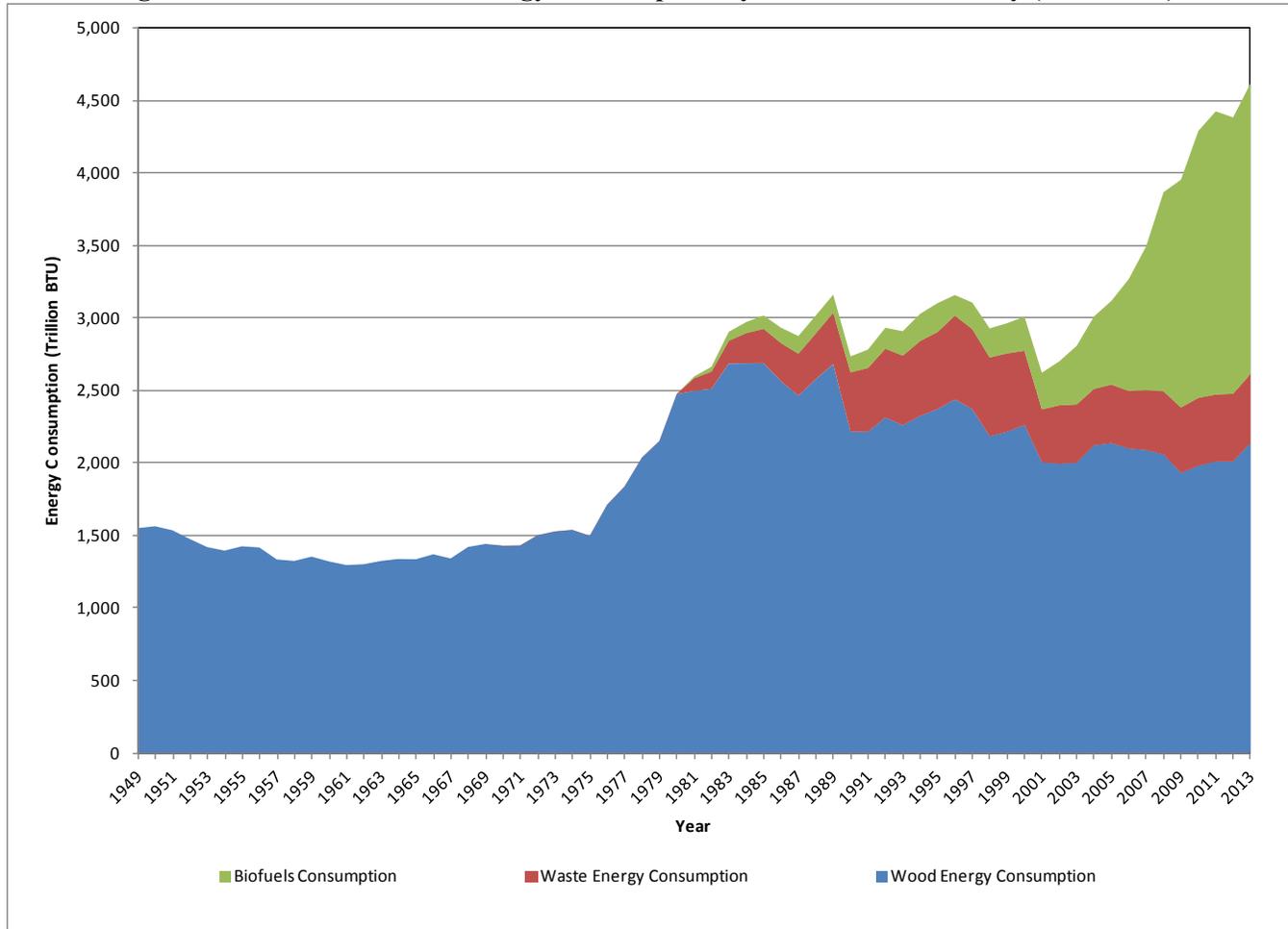
## ***2.0 Overall Renewable Energy Production and Consumption from Wastes Materials***

The U.S. Energy Information Administration (EIA) tracks domestic *renewable energy* production and consumption; Figure 2 presents energy consumption from biomass sources, based on EIA information. The waste energy consumption category includes MSW from biogenic sources, landfill gas, sludge waste, agricultural byproducts, and other biomass. EIA considers MSW consumption at combustion plants as renewable "waste energy." As shown in the figure, *renewable energy* consumption from waste sources (i.e. MSW combustion) was reported beginning in 1970, and has increased steadily since that time.

*Renewable fuel* (biofuel)<sup>2</sup> consumption was reported beginning in 1981, and has increased drastically since 2000. The data include consumption of renewable fuel from both virgin and waste feedstocks. Only a subset of this renewable fuel (i.e. those produced from waste feedstocks and shown in Section 1.0) is discussed in this memorandum.

The EIA waste energy data shown in Figure 2 includes additional waste-to-energy scenarios that are not covered in this memorandum, but provides general trend information on waste energy consumption and use.

**Figure 2. Annual Renewable Energy Consumption by Source, Biomass Only (1949–2013)**



Source: EIA, 2014a.

Biofuel—fuel ethanol (minus denaturant) and biodiesel consumption, plus losses and co-products from the production of fuel ethanol and biodiesel.

Waste—MSW from biogenic sources, landfill gas, sludge waste, agricultural byproducts, and other biomass. Through 2000, also includes non-renewable waste (MSW from non-biogenic sources and tire-derived fuels).

Wood—wood and wood-derived fuels.

<sup>2</sup> EIA data include biomass-based diesel (biodiesel) and renewable fuel (ethanol) only.

### **3.0 Renewable Fuel Production Under the RFS**

In addition to combustion for energy recovery, waste biomass and other materials are used in renewable fuel production. The RFS was created to establish renewable fuel volume mandates and to build a market for renewable fuels in the transportation sector. Created under the Energy Policy Act of 2005 and revised under the Energy Independence and Security Act of 2007, the RFS program (RFS2) requires 36 billion gallons of renewable fuel to be blended into transportation fuel by 2022.

EPA has been tasked with administering the RFS. The RFS sets separate mandates for each category of renewable fuel, allows U.S. producers and importers to generate Renewable Identification Numbers (RINs) to represent each gallon of renewable fuel produced under an EPA-approved pathway, and creates a market for trading RINs.

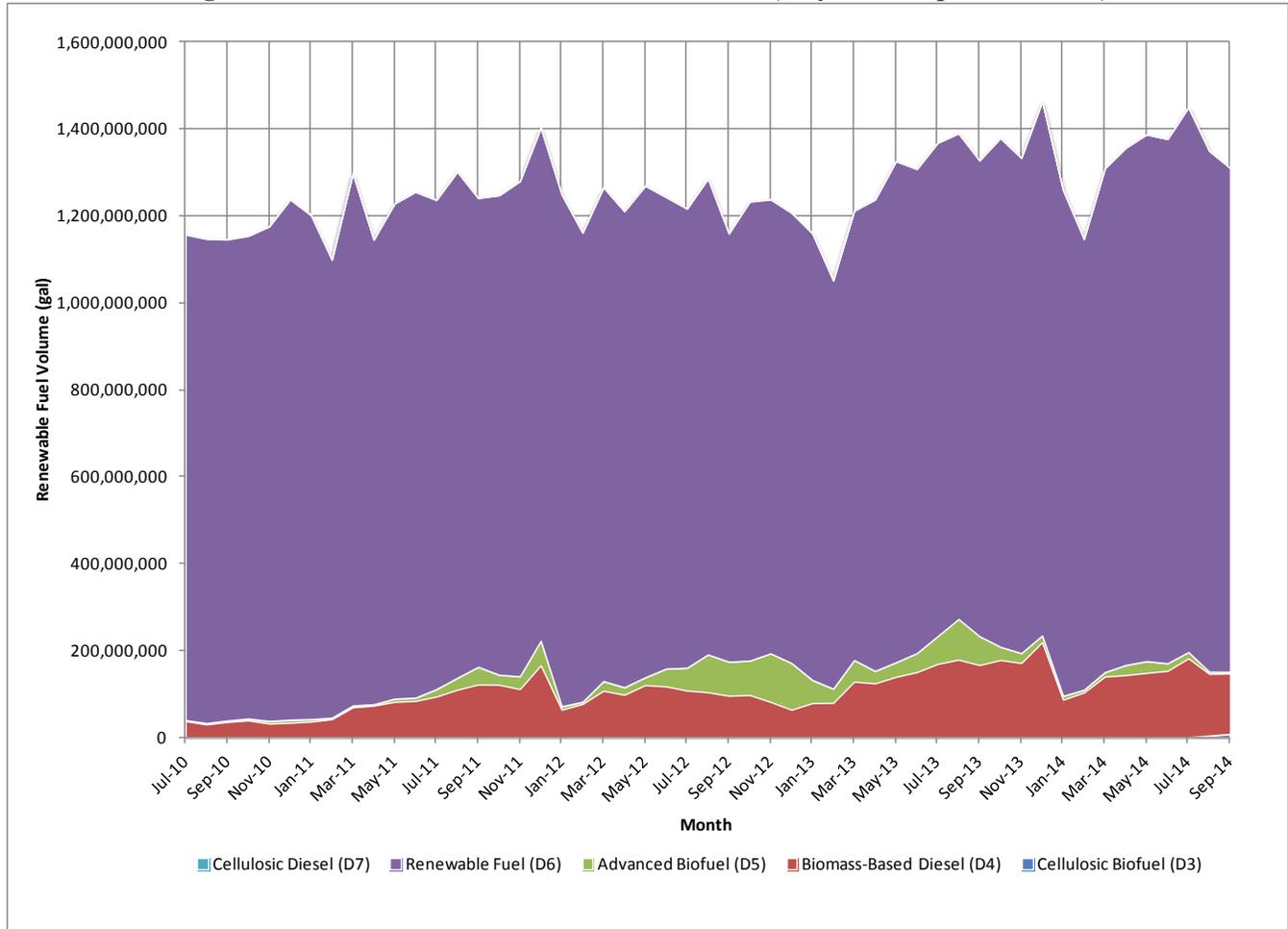
Figure 3 shows renewable fuel production under RFS2 based on RIN generation in EPA's Moderated Transaction System (EMTS), a system that manages RIN transactions and trades under the RFS. The data cover the period from July 2010 to September 2014 and include renewable fuel produced or imported into the United States. Table 1 presents the underlying data. Of these amounts, only a portion of renewable fuel was produced from waste sources. No RINs were generated for the cellulosic biofuel and cellulosic diesel categories until 2012; of the five categories reviewed in this memorandum, these two continue to remain a very small portion of the total renewable fuel production.

In August 2014, EPA modified regulatory provisions related to renewable fuel made from biogas (primarily a mixture of methane and carbon dioxide produced by anaerobic decomposition of organic material), including a new CNG/LNG (compressed natural gas/ liquid natural gas) cellulosic biofuel pathway, and adding a new cellulosic biofuel pathway for renewable electricity (used in electric vehicles) produced from biogas.

These policy changes will influence actions and data going forward. These pathways have the potential to provide notable volumes of cellulosic biofuel for use in complying with the RFS program. For example, the new rule could cause a flaring landfill to make a different choice between the CNG/LNG options versus making electricity, as a function of RIN price and environmental considerations such as lifecycle GHG emissions. The biogas that is cellulosic has a higher RIN value (Babson 2014).

Additional research of biofuel from these pathways is not included in this memorandum.

**Figure 3. Renewable Fuel Production under RFS (July 2010–September 2014)**



Source: EPA OTAQ RFS2 data, <http://www.epa.gov/otaq/fuels/rfsdata/2014emts.htm>. Downloaded November 10, 2014.

**Table 1. Renewable Fuel Production Quantity under RFS (July 2010–December 2013)**

RIN Year	EMTS Batch Volume (gal)				
	Cellulosic Biofuel (D3)	Biomass-Based Diesel (D4)	Advanced Biofuel (D5)	Renewable Fuel (D6)	Cellulosic Diesel (D7)
2010	0	215,402,913	19,233,282	6,789,828,018	0
2011	0	1,122,699,193	215,755,059	13,613,229,503	0
2012	20,069	1,146,899,177	618,671,889	12,987,396,467	1,024
2013	281,819	1,793,394,504	527,775,069	13,251,209,617	232,808

Source: EPA OTAQ RFS2 data, <http://www.epa.gov/otaq/fuels/rfsdata/2014emts.htm>.

EMTS also captures information on the types and amounts of feedstocks used in renewable fuel production, including waste cellulosic and biomass materials. According to EMTS data and publicly available information, current cellulosic biofuel, biomass-based diesel, advanced biofuel, renewable fuel, and renewable diesel production use waste materials including cellulosic materials, agricultural residue, biogas, wood residues, waste vegetable oil, and food.

Several facilities are capable of using the mixed MSW stream to produce renewable fuel; however, many of these facilities are not producing at commercial quantities. The sections below provide more information for each renewable fuel category of interest.

### **3.1 Renewable Fuel Category: Cellulosic Biofuel**

Fuels in the cellulosic biofuel category can include, but are not limited to, cellulosic ethanol, cellulosic renewable gasoline blendstock, renewable compressed natural gas (CNG), renewable liquefied natural gas (LNG), and renewable electricity produced from biogas.

Cellulosic biofuel was not produced at commercial quantities as of the last quarter of 2013 (AEC, 2013; Mufson, 2013). Under the RFS, only 281,819 gallons of cellulosic biofuel were produced during 2013. The Advanced Ethanol Council (AEC) describes “high capital risk from OPEC-induced price distortions, constrained blending markets and policy uncertainty” as causes of the delayed commercialization (AEC, 2013).

AEC’s report (2013) details existing and upcoming cellulosic biofuel facilities in the United States. The report also provides information on the feedstock used or planned for use at each facility for cellulosic biofuel production. Table 2 lists types of waste feedstock that are used or could be used at these facilities.

Table 3 lists the name and location of each facility as reported by AEC.

There is no publicly available information to quantify the amount of postconsumer wastes that was used in cellulosic biofuel production in 2013. Even though AEC suggests that several facilities are capable of using MSW as feedstock, the actual use quantity is likely low, based on low levels of cellulosic biofuel production, compared to other renewable fuel categories.

In 2014, most cellulosic biofuel consisted of renewable CNG and LNG produced from biogas. However, the quantity of postconsumer feedstock used to create the biogas used to produce the renewable CNG and LNG is not published.

**Table 2. Cellulosic Biofuel Waste Feedstock Types**

MSW Post-Consumer Wastes	Other Wastes
<p>Mixed MSW</p> <p>Separated food waste</p> <p>Vegetative and yard waste</p> <p>Wood and paper waste</p>	<p>Agricultural residue</p> <p>Bagasse</p> <p>Biogas from landfills, municipal wastewater treatment facility digesters, agricultural digesters, separated MSW and other waste digesters</p> <p>Corn crop residue and corn stover</p> <p>Forestry residue or other waste forestry biomass</p> <p>Other cellulosic waste</p> <p>Wood residue</p> <p>Wheat straw</p>

Source: AEC, 2013.

**Table 3. U.S. Cellulosic Biofuel Facility That Use or Plan to Use Waste Feedstock**

Facility Name	Location	Feedstock	Feedstock Capacity	Renewable Fuel Capacity	Status
Abengoa Bioenergy commercial site	Hugoton, KS	Agricultural residues, dedicated energy crops, prairie grasses	1,100 dry tons/day	25 MGY	Under construction; estimated completion in December 2013
BlueFire Renewables demonstration facility	Anaheim, CA	Various wood and paper wastes, MSW, bagasse	Unknown	200 lb/day (cellulosic sugar)	Used to produce cellulosic sugars for sale to companies developing processes to convert to bio-products
BlueFire Renewables commercial facility	Fulton, MS	Forestry residues, other cellulosic wastes	Unknown	19 MGY	Pending construction financing
Enerkem (commercial strategy)	Pontotoc, MS	MSW, wood residues	Unknown	10 MGY	Under development
Fiberight commercial facility	Lawrenceville, VA	MSW, commercial waste, energy crops	Unknown	1 MGY	Operations commenced in 2012
Fiberight commercial facility	Blairstown, IA	MSW, non-food wastes	1,000 ton/day MSW	6 MGY	Existing facility to be modified in 2013
Fulcrum commercial facility	McCarran, NV	MSW	Unknown	10 MGY	Pending construction financing; estimated completion in 2014
KL Process Design Group <sup>1</sup>	Upton, WY	Wood waste	Unknown	1.5 MGY	Operational
INEOS Bio commercial facility	Vero Beach, FL	Vegetative and yard waste, MSW	Unknown	8 MGY 6MW, gross (electricity generation)	Estimated startup in 2012
KiOR demonstration facility	Pasadena, TX	Forestry residuals	Unknown	15 bbl/day (cellulosic diesel, gasoline)	Began operation in 2010
KiOR commercial facility	Columbus, MS	Forestry residuals	Unknown	13 MGY (cellulosic gasoline/diesel)	Operational
KiOR commercial project	Natchez, MS	Forestry residuals	Unknown	40 MGY (cellulosic gasoline/diesel)	Estimated completion in 2014
LanzaTech commercial facility	Soperton, GA	Waste biomass from regional forest operations	Unknown	4 MGY	Estimated startup in 2014
POET demonstration facility	Scotland, SD	Corn crop residue	Unknown	20,000 GPY	Operational
POET commercial facility	Emmetsburg, IA	Corn crop residue	Unknown	20 MGY	Estimated completion in 2013; goal is to harvest 285,000 tons/year biomass

Sources: AEC, 2013; RFA, 2014.

<sup>1</sup> RFA, 2014.

bbl/day—barrels per day lb/day—pounds per day

MGY—million gallons per year GPY—gallons per year

### **3.2 Renewable Fuel Category: Biomass-Based Diesel**

The biomass-based diesel category consists predominantly of biodiesel, or fatty acid methyl esters produced from lipids (fats, oils, and greases) (NREL, 2013). Under the RFS program, nearly 1.8 billion gallons of biomass-based diesel were produced in or imported into the United States in 2013 (U.S. EPA, 2014). Of this amount, approximately 1.4 billion gallons were produced domestically (EIA, 2014b).

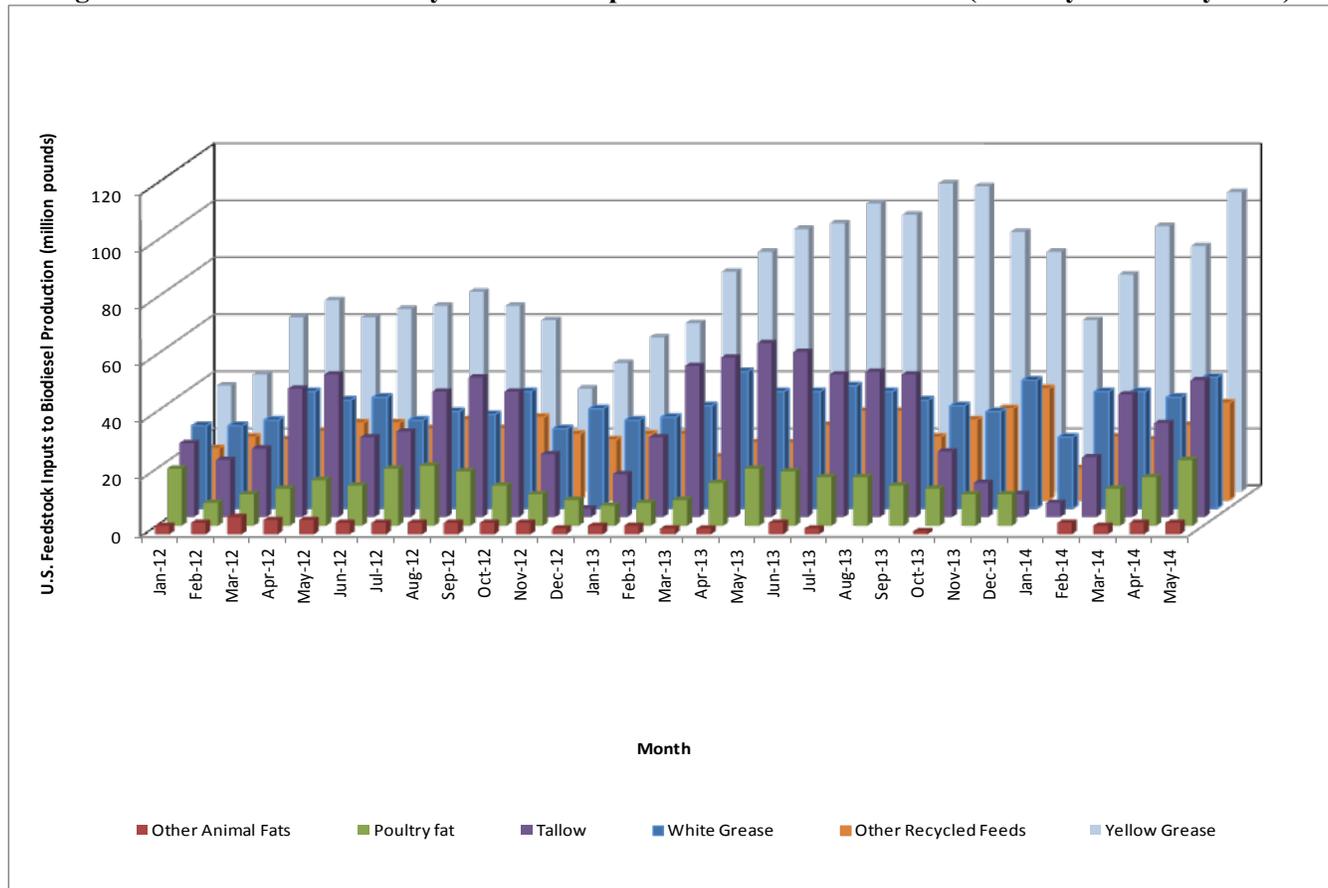
EPA approves the use of biogenic waste oils/fats/greases as feedstock for biodiesel production and RIN generation. Biogenic waste oils/fats/greases include animal fats (e.g. poultry fat, tallow, white grease) and waste vegetable oils (e.g., yellow grease, other recycled greases). Waste animal fats typically come from the rendering industry and are considered industrial wastes. Recycled feeds<sup>3</sup> such as yellow grease are usually waste restaurant cooking oils; however, some lower-quality yellow grease consists of fats from rendering plants.

EIA collects monthly data on U.S. feedstock usage and biodiesel production through the Form EIA-22M Monthly Biodiesel Production Survey, a mandatory reporting form under the Federal Energy Administration Act for any facility that produces biodiesel meeting ASTM D6751-07B specifications and used for commercial purposes. Figure 4 presents EIA data on monthly usage of animal fats and recycled feeds in biodiesel production from January 2012 to May 2014. Table 3 presents the same EIA data, tabulated on an annual basis, but includes all feedstock usage and corresponding biodiesel production. As shown in the data, animal fats and recycled feeds make up only a small portion of all biodiesel feedstock.

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<sup>3</sup> EIA defines “recycled feedstock” as material (biomass) used to produce biodiesel fuel that is not virgin, i.e. not produced for the first time or for the express purpose of making biodiesel.

**Figure 4. Animal Fats and Recycled Feeds Inputs to Biodiesel Production (January 2012–May 2014)**



Source: EIA, 2014b.

**Table 4. U.S. Feedstock Inputs and Biodiesel Production (January 2012–May 2014)**

Year	Vegetable Oils Input (MM lb)						Animal Fats (MM lb)				Recycled Feeds Input (MM lb)		Biodiesel Production (MM gal)
	Canola Oil	Corn Oil	Cottonseed Oil	Palm Oil	Soybean Oil	Other	Poultry	Tallow	White Grease	Other Animal Fats	Yellow Grease	Other Recycled Feeds	B100
2012	790	645	0	0	4,043	0	176	385	409	49	672	290	990
2013	646	1,066	0	442	5,508	6	161	465	466	17	1,048	310	1,358
2014 Partial January–May	221	357	0	0	1,621	4	53	150	192	15	420	114	442

Source: EIA, 2014b.

Definitions:

*White grease:* Inedible rendered pork fat.

*Yellow grease:* A term from the rendering industry that is generally assumed to include used frying oils from deep fryers and restaurants' grease traps. It can also refer to lower-quality grades of tallow from rendering plants.

*Brown grease:* A generic term that includes trap grease, sewage grease, black grease, and grease from all other sources whose free fatty acid content exceeds limits for animal feed.

*Poultry fat:* Poultry tissues obtained during the rendering process. It must contain less than 90% total fatty acids, not more than 2.5% unsaponifiables, and not more than 1% soluble matter.

*Recycled feedstock:* Material (biomass) used to produce biodiesel fuel that is not virgin, i.e., not produced for the first time or for the express purpose of making biodiesel. The "other recycled feeds" category includes brown grease.

*Tallow:* Solid fat extracted from the tissues and fatty deposits of cattle and sheep. Pure tallow is white, odorless, and tasteless; it consists chiefly of triglycerides of stearic, palmitic, and oleic acids. There is both inedible tallow, used to produce biodiesel, and edible tallow, used for food.

MM lb—million pounds

MM gal—million gallons

### 3.3 Renewable Fuel Category: Advanced Biofuel

In 2013, nearly 528 million gallons of advanced biofuel were produced or imported into the United States. The following types of waste feedstocks are approved for use in advanced biofuel production and RIN generation under the RFS:

- Biogenic waste oils/fats/greases
- Non-cellulosic portions of separated food waste
- Biogas from waste digesters

Biogenic waste oils/fats/greases (e.g., waste restaurant cooking oils) and separated food wastes are postconsumer wastes. Biogas could also come from digesters processing postconsumer wastes. Public RFS data do not include quantities of waste feedstock used in advanced biofuel production.

### 3.4 Renewable Fuel Category: Renewable Fuel

In 2013, 13 billion gallons of renewable fuel were produced or imported into the United States, more than 98 percent of which consisted of non-cellulosic ethanol. According to data published by RFA and BBI International, most non-cellulosic ethanol plants use corn or grain sorghum as feedstock. A negligible number use waste feedstock to produce ethanol. Table 5 lists the types of waste feedstocks that are being used in ethanol production. Table 6 lists the ethanol facilities that use these waste feedstocks. These facilities make up less than 1 percent of the domestic ethanol production capacity. The exact amount of waste feedstock processed at each facility is not known.

**Table 5. Renewable Fuel Waste Feedstock Types**

MSW PostConsumer Wastes	Other Wastes
Beverage waste <sup>1</sup>	Bagasse
Health and beauty items	Brewery waste
Waste beer	Cheese whey
	Waste sugars/starches
	Wood waste

Source: RFA, 2014.

<sup>1</sup> According to the company website, Parallel Products recycles unsaleable beverage products (packaged or bulk) and converts them into ethanol. Beverage products recycled include soda, water, juices, beer, wine, spirits, flavorings, ingredients, and line flush.

**Table 6. Biorefineries That Use Waste Feedstocks**

Company	Location	Feedstock	Nameplate Capacity (MGY) <sup>3</sup>	Operation Production (MGY)
BP Biofuels North America	Jennings, LA	Sugar cane bagasse	1.5	1.5
Dubay Biofuels Greenwood	Greenwood, WI	Cheese whey	NA (under construction, 5 MGY)	NA
Golden Cheese Company of California	Corona, CA	Cheese whey	5	0
KL Process Design Group <sup>1</sup>	Upton, WY	Wood waste	1.5	1.5
Land O' Lakes	Melrose, MN	Cheese whey	2.6	2.6
Merrick and Company	Aurora, CO	Waste beer	3	3
Parallel Products	Louisville, KY	Beverage waste; health and beauty items	5.4	5.4
Summit Natural Energy	Cornelius, OR	Waste sugars/starches <sup>2</sup>	1	1
Wind Gap Farms	Baconton, GA	Brewery waste	0.4	0.4

Sources: RFA, 2014; company websites.

<sup>1</sup> This facility produces cellulosic ethanol, which is also a type of cellulosic biofuel.

<sup>2</sup> Raw biomass byproducts from agricultural sources, food processing wastes, etc.

<sup>3</sup> RFA does not define "nameplate capacity"; however, this term typically refers to the maximum sustained output for a facility. The industry has 213 nameplate biorefineries (all feedstock types), with 14,932.4 MGY nameplate capacity.

MGY—million gallons per year

### 3.5 Renewable Fuel Category: Cellulosic Diesel

The cellulosic diesel category includes heating oil and jet fuel made from cellulosic feedstocks. The types of waste feedstocks that could be used to produce cellulosic diesel would be similar to those listed in Table 2. No additional information is available to quantify the amount of waste feedstocks used for this renewable fuel category.

### 4.0 Summary

Biomass-based diesel is currently produced from both postconsumer waste (restaurant waste oils and greases) and industrial wastes (animal fats from rendering). Data are available to quantify the amount of waste feedstock that is being diverted from the waste stream and used in biomass-based diesel production (see Figure 4 and Table 4).

Only limited data are available to quantify the amount of waste feedstock used to produce the other renewable fuel categories of interest. Existing renewable fuel facilities can use postconsumer waste feedstocks such as mixed MSW streams; beverage wastes; health and beauty items; and industrial waste feedstocks such as agricultural residues, various waste cellulosic materials, cheese whey, and brewery wastes. At this time, few MSW feedstocks are used for renewable fuel production at commercial scale.

This scoping analysis focused on identifying public data that quantifies postconsumer feedstocks used to create the renewable fuels of interest. With the exception of biomass-based diesel, limited feedstock data were identified. Gathering end-fuel production data and calculating backward to feedstock input could potentially provide more insight into postconsumer wastes used to create renewable fuels.

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