



Designation: D6700 – 19

## Standard Guide for Use of Scrap Tires as Tire-Derived Fuel<sup>1</sup>

This standard is issued under the fixed designation D6700; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

### 1. Scope

1.1 This guide covers and provides guidance for the material recovery of scrap tires for their fuel value. The conversion of a whole scrap tire into a chipped form for use as a fuel produces a product called tire-derived fuel (TDF). This recovery guide has moved from a pioneering concept in the early 1980s to a proven and continuous use in the United States with industrial and utility applications.

1.2 Combustion units engineered to use solid fuels, such as coal or wood, or both, are fairly numerous throughout the U.S. Many of these units are now using TDF even though they were not specifically designed to burn TDF. It is clear that TDF has combustion characteristics similar to other carbon-based solid fuels. Similarities led to pragmatic testing in existing combustion units. Successful testing led to subsequent acceptance of TDF as a supplemental fuel when blended with conventional fuels in existing combustion devices. Changes required to modify appropriate existing combustion units to accommodate TDF range from none to relatively minor. The issues of proper applications and specifications are critical to successful utilization of this alternative energy resource.

1.3 This guide explains TDF's use when blended and combusted under normal operating conditions with originally specified fuels. Whole-tire combustion for energy recovery is not discussed herein, since whole-tire usage does not require tire processing to a defined fuel specification.

1.4 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

<sup>1</sup> This guide is under the jurisdiction of ASTM Committee D34 on Waste Management and is the direct responsibility of Subcommittee D34.03 on Treatment, Recovery and Reuse.

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1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

### 2. Referenced Documents

#### 2.1 ASTM Standards:<sup>2</sup>

- D2013/D2013M Practice for Preparing Coal Samples for Analysis
- D2361 Test Method for Chlorine in Coal (Withdrawn 2008)<sup>3</sup>
- D2795 Test Methods for Analysis of Coal and Coke Ash (Withdrawn 2001)<sup>3</sup>
- D3172 Practice for Proximate Analysis of Coal and Coke
- D3173/D3173M Test Method for Moisture in the Analysis Sample of Coal and Coke
- D3174 Test Method for Ash in the Analysis Sample of Coal and Coke from Coal
- D3175 Test Method for Volatile Matter in the Analysis Sample of Coal and Coke
- D3176 Practice for Ultimate Analysis of Coal and Coke
- D3177 Test Methods for Total Sulfur in the Analysis Sample of Coal and Coke (Withdrawn 2012)<sup>3</sup>
- D3178 Test Methods for Carbon and Hydrogen in the Analysis Sample of Coal and Coke (Withdrawn 2007)<sup>3</sup>
- D3179 Test Methods for Nitrogen in the Analysis Sample of Coal and Coke (Withdrawn 2008)<sup>3</sup>
- D3682 Test Method for Major and Minor Elements in Combustion Residues from Coal Utilization Processes
- D4239 Test Method for Sulfur in the Analysis Sample of Coal and Coke Using High-Temperature Tube Furnace Combustion
- D4326 Test Method for Major and Minor Elements in Coal and Coke Ash By X-Ray Fluorescence
- D4749 Test Method for Performing the Sieve Analysis of Coal and Designating Coal Size

<sup>2</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

<sup>3</sup> The last approved version of this historical standard is referenced on [www.astm.org](http://www.astm.org).



**D5468** Test Method for Gross Calorific and Ash Value of Waste Materials (Withdrawn 2016)<sup>3</sup>

**D5681** Terminology for Waste and Waste Management

**D5865** Test Method for Gross Calorific Value of Coal and Coke

**E873** Test Method for Bulk Density of Densified Particulate Biomass Fuels

**F538** Terminology Relating to the Characteristics and Performance of Tires

2.2 EPA Standards:<sup>4</sup>

**SW-846-5050** Bomb Preparation Method for Solid Waste

**SW-846-9056** Determination of Inorganic Anions by Ion Chromatography

### 3. Terminology

3.1 *Definitions*—For definitions of general terms used in this guide, refer to Terminologies **D5681** and **F538** on waste management and tires, respectively

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *bead wire, n*—a high-tensile steel wire, surrounded by rubber, which forms the bead of a tire that provides a firm contact to the rim.

3.2.2 *chip size, n*—the dimension of size-reduced rubber particles resulting from the processing of whole tires.

3.2.3 *combustion, n*—the chemical reaction of a material through rapid oxidation with the evolution of heat and light.

3.2.4 *combustion unit, n*—any number of devices to produce or release energy for the beneficial purpose of production by burning a fuel to include, but not limited to, units such as industrial power boilers, electrical utility generating boilers, and cement kilns.

3.2.5 *energy value, n*—the assignment of a value to the tire-derived fuel as measured in British thermal units per pound or calories per gram.

3.2.6 *fuel value, n*—the heat content, as measured in British thermal units (Btu)/lb or cal/g.

3.2.7 *new tire, n*—a tire that has never been mounted on a rim.

3.2.8 *relatively wire free, n*—TDF that has a bead wire content not greater than 1 % by weight, and a total wire content of 2 % or less by weight.

3.2.9 *rubber, n*—an elastomer, generally implying natural rubber, but used loosely to mean any elastomer, vulcanized and not vulcanized. By definition, rubber is a material that is capable of recovering from large deformations quickly and forcibly and can be, or already is, modified to a state in which it is essentially insoluble in a boiling solvent.

3.2.10 *scrap tire, n*—a rubber tire that is no longer used for its originally intended application.

3.2.11 *screen, n*—an apparatus for separating sizes of granules.

3.2.12 *standard size specification, n*—the size specifications with the broadest application when blending with other solid fuels and requiring minimal adjustments or retrofits to existing solid fuel combustion units.

3.2.13 *supplemental fuel, n*—a combustible material that displaces a portion of traditional fuel source. It refers to the product being used in conjunction with another conventional fuel but typically not as a sole fuel supply.

3.2.14 *tire-derived fuel (TDF), n*—a product made from scrap tires to exact specifications of a system designed to accept a tire-derived fuel as primary or supplemental fuel source.

3.2.15 *wire, n—in a tire*, high-tensile, brass-plated steel wire, coated with a special adhesion-promoting compound, used as tire reinforcement as belts, beads, or radial tire plies.

3.2.16 *wire free, n*—TDF that is free of all inherent wire.

3.2.17 *X minus, n*—a designation of sample particle size, with Dimension X indicating the upper limit or maximum size of particles passing through a sieve or screen opening upon which is cumulatively retained less than or equal to 1 % of the sample. For example, a sample designated as “2 in. (5 cm) minus” would pass a 2-in. screen opening with less than or equal to 1 % of the sample retained.

### 4. Significance and Use

4.1 When considering the specification of fuels for a boiler, issues to evaluate are the fuel's combustion characteristics, handling and feeding logistics, environmental concerns, and ash residue considerations. A thorough understanding of these issues is required to engineer the combustion unit for power and steam generation; however, TDF has demonstrated compatible characteristics allowing it to serve as a supplemental fuel in existing combustion units based on cumulative experience in many facilities originally designed for traditional fossil fuels, or wood wastes, or both. When used as a supplemental energy resource in existing units, TDF usage is generally limited to blend ratios in the 10 to 30 % range based on energy input. This limit is due to its high heat release rate and low moisture content, which differ significantly from other solid fuels such as wood, refuse-derived fuel, coal, and petroleum coke.

4.2 New combustion units dedicated to the use of TDF (or whole tires) as the sole fuel source are rare. The generation and availability of scrap tires are ultimately determined by market conditions for new tires and the depletion rate of scrap tire inventories (stockpiles). Scrap tires account for approximately 1 % of the municipal solid waste stream. Based on a national scrap tire generation rate, there are roughly 2.5 to 3 million tons (annually available for all uses to include fuel, crumb rubber, engineering projects, and so forth). Some dedicated combustion units have been built, however, competition for the scrap tires as other existing sources begin to use TDF will determine the ultimate viability of these facilities. Although most regions can supply TDF demand as a supplemental fuel, a dedicated boiler in the range of 500 000 lb/h (227 000 kg/h) steaming capacity would require over 66 000 scrap tires/day to meet its fuel demand. Such demand may strain a region's

<sup>4</sup> Available from United States Environmental Protection Agency (EPA), William Jefferson Clinton Bldg., 1200 Pennsylvania Ave., NW, Washington, DC 20460, <http://www.epa.gov>.



ability to supply and put the fuel supply at risk. Some design projects have incorporated TDF as a supplemental fuel with wood, coal, coke, sludge, or some combination of multiple fuels where demand is consistent with supply availability.

4.3 It is important to understand what objectives may lead to TDF's choice as a supplemental fuel in existing power units. Several model objectives may be as follows:

4.3.1 To increase boiler efficiency in a co-fired boiler using wood, sludge, and coal;

4.3.2 To procure a competitively priced fuel;

4.3.3 To supplement limited supplies of an existing fuel;

4.3.4 To use a high-quality fuel;

4.3.5 To achieve environmental benefits by using a fuel with a relatively low sulfur content in comparison to certain coals or petroleum coke, and;

4.3.6 To provide a public and social benefit that solves a regional solid waste problem.

4.4 Boilers generally are engineered around fuels that will be available through the amortized life of the power unit. Boiler design discussions here are limited as TDF standard size specifications have been developed to ensure TDF's performance in existing systems. TDF is mined from the solid waste stream as a whole tire, then engineered via processing techniques to fit a new or existing combustion unit. A major modification or re-engineering of the combustion unit to accommodate TDF normally would make its use uneconomical as a supplemental fuel. TDF's use is economically dependent on the following two issues:

4.4.1 A combustion unit's existing ability to use the fuel without modification (other than minor operational changes in oxygen grate speed adjustments, and feed/material handling) and,

4.4.2 The ability of a supplier to economically collect, process, and transport TDF to the combustion unit.

4.5 Once an economic decision has been made to develop TDF as a fuel source for a particular unit, issues of fuel specifications including size, proximate and ultimate analysis, combustion characteristics, and environmental concerns must be evaluated properly to determine whether TDF is an appropriate supplemental fuel resource without major system modification.

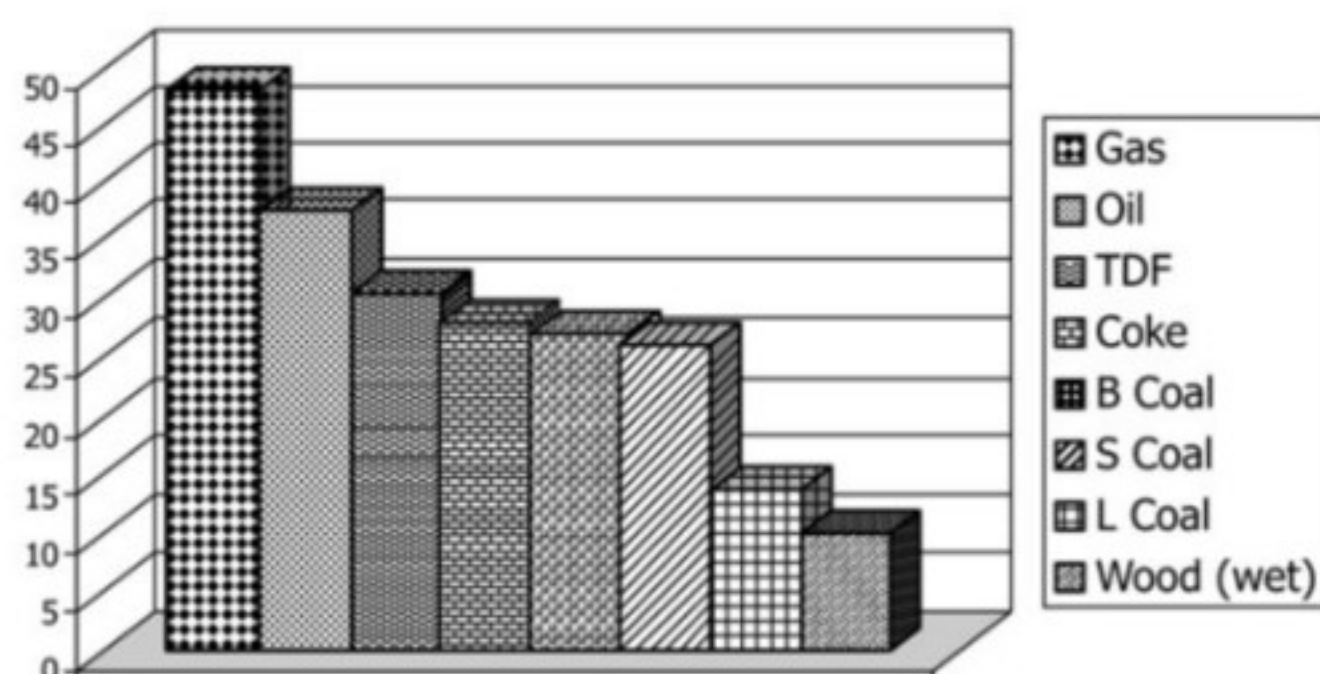


FIG. 1 Relative Energy Comparison of Fuels (Scale in Btu/ton)

## 5. Tire-Derived Fuel Analysis – General Description

5.1 TDF is defined as a fuel source derived from the processing of scrap tires into rubber chips with a range in size and metal content. Processing may include shredding, chopping, classification, recycling, granulation, wire/fabric separation, and other technologies. Size normally varies in a range from 1 in. (2.5 cm) to 4 in. (10.2 cm). Metal content ranges from wire free, to relatively wire free, to only bead wire removed, to no wire removed. TDF's tolerable wire content is determined by a combustion unit's design considerations. TDF's wire removal is determined by production process capabilities. Some combustion units such as cement kilns can tolerate all inherent wire, so no removal is necessary. In circumstances where no effort is made to remove wire, TDF must be cleanly cut with minimal exposed wire protrusion from the chips to facilitate mechanical handling.

5.2 Unless temperatures in a combustion unit are sufficient to oxidize the wire, the energy contribution from the wire is nominal and will account for a lower product energy value than that of either a wire-free or relatively wire-free TDF product. Cement kilns typically burn at sufficient temperatures to oxidize the wire and benefit from both the energy release from oxidation and the resultant iron oxide that becomes a critical component in cement chemistry. Depending on the amount of wire removed, the TDF has an energy content ranging from 14 000 to 15 500 Btu/lb (7770 to 8600 cal/g).

5.3 Combustion efficiency for TDF generally is understood to be in the 80 % range. TDF represents an ideal fuel source in that its moisture content is low (1 to 3 %), and its energy value is high. Low moisture content uses less energy for moisture vaporization and lowers combustion gas mass flow rate. TDF has a volatile content of roughly 66 %, which indicates rapid heat release. Relatively low ash content (3 to 5 %) maximizes heat absorption and decreases ash disposal costs. As rubber is non-absorbent, moisture swings during seasonal periods of rainfall in ambient weather conditions are limited to a range of 1 to 8 %. The smaller the TDF chip size, the greater the storage pile surface area and its concomitant ability to hold moisture on its surface. Table 1 identifies the energy content of common fuel types currently used singularly or in some combination.

5.4 The specifications for TDF are somewhat customer specific, as this material will be fed into an existing combustion unit. A highly refined product with the wire removed is more expensive to produce, but provides more energy per ton and fewer operating problems in many units. Problematic areas to

TABLE 1 Energy Value

Fuel Type	Energy Value in million Btu/short ton (MBTU/ton)
Tire-derived fuel (TDF)	28–3
Petroleum coke (PC)	26–28
Bituminous coal (BC)	18–27
Subbituminous coal (SC)	17–25
Lignite coal (LC)	12–14
Wood fuel (WF)	8–17
Relative Comparison of Non-Solid Fuels	
Oil	34–38
Gas	42–48



### Sampling Log TDF Size Specification - Testing

*Please complete the following and include with the sample shipped. Send additional copies to:*

Plant Location: \_\_\_\_\_

Name of Sampler: \_\_\_\_\_

Title of Sampler: \_\_\_\_\_

Time Samples Taken: \_\_\_\_\_

Date Samples Taken: \_\_\_\_\_

Total of nine (9) Samples Taken:

\_\_\_\_ Yes      \_\_\_\_ No

Total weight of sample sent, all nine (9) samples combined: \_\_\_\_\_ lbs.

Number of boxes shipped to make up complete sample: \_\_\_\_\_ boxes  
(preferably one)

Additional notes: \_\_\_\_\_

Signature: \_\_\_\_\_ Date: \_\_\_\_\_

**FIG. 2 Sampling Log**

**TABLE 2 Analysis of TDF (Relatively Wire Free)**

NOTE 1—TDF produced from scrap tires with 96 % plus wire removed.

Description	Percent by Weight as Received
<b>Proximate Analysis</b>	
Moisture	0.474
Ash	4.22
Volatile matter	65.34
Fixed carbon	29.966
	Total 100.00
<b>Ultimate Analysis</b>	
Moisture	0.47
Ash	4.22
Carbon	89.51
Hydrogen	7.59
Nitrogen	0.27
Sulfur	1.92
Oxygen	...
<b>Elemental Analysis</b>	
Zinc	1.52
Calcium	0.378
Iron	0.321
Chlorine	0.149
Chromium	0.0097
Fluoride	0.0010
Cadmium	0.0006
Lead	0.0065
Others below detectable levels to include mercury, barium, silver, and so forth	
Theoretical air	3.362 kg/10000 Btu (2520 Kcal)
Wet gas from fuel	0.266 kg/10000 Btu (2520 Kcal)
H <sub>2</sub> O from fuel	0.179 kg/10000 Btu (2520 Kcal)

evaluate to determine true specification requirements are fuel feed system, grate maintenance, ash circulation/handling, and ash disposal systems. Since roughly 10 to 15 % of a tire is comprised of radial ply wire and bead wire, any TDF that is not relatively wire free will have a fuel value 10 to 15 % less than the values reported for TDF in **Table 1**. TDF specified to have a lower wire content is more expensive to produce. The increased cost is attributable to further refinement expense and ultimate disposal, or recovery cost for the wire residue generated from TDF production, or both.

5.5 In addition to steel wire, nylon and polyester may be used in tire construction. Nylon and polyester plies are found in both steel radial and non-steel radial tires, passenger, and truck tires. Approximately 3 % of a tire is made up of these types of non-steel plies. When a tire is processed into TDF, these synthetic plies will typically stay in the TDF. Both nylon and polyester are petrochemical products with an energy content similar to that of rubber. Due to their low ash content and high energy content, the fuel value of plies is relatively consistent with that of the rubber.

5.6 A representative analysis of TDF is presented in **Table 2**. This table identifies key combustion issues. The high amount of fixed carbon (29.96 %) suggests particulate concerns and ash (4.22 %) suggests solid waste concerns. Other elements of concern include sulfur (1.92 %) and zinc (1.52 %).

## 6. Handling Considerations Conveying, Grate, and Ash

6.1 TDF can be produced with the wire left in or taken out. Either way, one must balance the trade-off(s). To remove a

greater percentage of inherent wire the chip size must ultimately be smaller, in the 5/8-in. (1.6 cm) to 2-in. (5.08 cm) size range. Both smaller chip size and increased wire removal will



add to the cost of producing TDF. Smaller chip requires increased mechanical production time. Wire residue may be landfilled or recovered, adding to production costs. Wire recovery potential is dependent on regional, market, and quality factors, but market value may not fully offset recovery costs.

## 6.2 *Wire Removal Precludes the Following Potential Problems:*

6.2.1 Wires protruding from TDF may cause chips to clump together, causing distribution problems. TDF is not as flowable when long strands of exposed wire are present.

6.2.2 Wires protruding from a rubber chip may catch on fuel conveying systems.

6.2.3 Wires may trip any metal detector used to protect the combustion unit from metal contamination.

6.2.4 Wires in rubber chips would either be captured or rejected by magnet(s) used to protect the combustion unit from metal contamination. Fixed magnets will require greater frequency of cleaning.

6.2.5 Significant amounts of wire may slag on the grate. There is a higher risk of this occurring on fixed-grate combustion units.

6.2.6 In the case of a moving grate, the wire may fall between the grate slats (posing a risk to grate keys), or lodge between the slats (potentially chipping the grate upon its return on the underside if caught in a pinch point), or both.

6.2.7 Wires may cause problems in ash handling systems by plugging conveying systems, or problems in storage bins by clumping or nesting.

6.2.8 Wires will add to the total volume of ash disposal and may complicate disposal opportunities such as land spreading.

6.2.9 In a fluid bed boiler, wires may compromise ash removal by plugging, bridging, nesting, or a combination thereof.

6.2.10 Significant amounts of wire may increase erosion in a circulating fluidized bed if wire becomes entrained in the circulating bed medium.

6.3 With the wire removed, the ash content of TDF is from 3 to 5 %, while the ash content if all the wire remains typically is 14 to 18 %. A TDF specification requiring all the bead wire and 50 % of the radial ply wire to be removed should preclude the problems identified in 6.2, and should achieve a standard size specification that is relatively wire free. Specific or unique boiler designs considered on a case-by-case basis to preclude problems as noted.

6.4 Tire wire consists of 99.9 % iron. Left in the TDF, bead wire will remain in its wire form with very little or no change, as its mass is too great and the grate or bed temperature is insufficient to cause oxidation. If significant quantities accumulate and temperatures are hot enough, partial oxidation may occur which can lead to agglomeration where contact points with other wire strands may fuse together.

6.5 All bead wire essentially becomes part of the grate ash. Iron's melting point is approximately 2800 °F (1537 °C). Radial ply wire has essentially the same iron content as bead wire, but has a much smaller diameter. This wire may or may not oxidize. Due to its low mass, rapid oxidation will occur if

sufficient temperature is achieved, normally above iron's kindling point of about 1500 °F (815 °C). In any event, it will remain on the grate as either wire or iron oxide unless under-fired air velocity through the grate is sufficient to entrain the fine wire with the air flow. Iron will not fume, but it will generate heat if converted to the iron oxide form, roughly 3000 Btu/lb (1665 cal/g). It is unlikely that grate temperatures in stoker boilers will exceed 1000 °F (538 °C) without other significant grate problems developing.

6.6 As a case study to illustrate potential problems with wire in a fluid bed combustor, a pilot facility tested a 100 % wire-in rubber chip for developmental evaluations. These tests were conducted for a large midwestern utility that currently is using a commercially scaled unit for power production and was seeking to introduce tire-derived fuel, wire in, as a standard fuel source. The pilot plant initially had been equipped with the standard sparge pipe/dual cone air distributor and bed cleansing system. When running with 100 % tire chips, it was discovered that the bed draw-down capabilities were impaired by the hang-up of wires in the holes of the inner cone. After two days of operation, all of the holes were plugged. Ultimately, retrofits made to the pilot plant to accommodate the wire-in material included a conical air distributor to keep everything in the conical section fluidized and remove restrictions to bed material flow where the wire could accumulate. Subsequently, long-term use of a relatively wire-free TDF has been developed in several fluid bed combustors without retrofits.

6.7 TDF in a size range of 2-in. (5.08 cm) minus is normally compatible with wood fuel and stoker coal in conveying to conventional stoker boilers, thus allowing for easy introduction onto an existing feeding system. Large pieces of rubber may be rejected or sent to a hammer mill for further size reduction via screening systems used to reject oversized coal or wood fuel, if such systems are in place. Oversized pieces should be avoided under these circumstances due to a hammer mill's or coal crusher's difficulty in processing tire chips.

6.8 A storage pile of TDF can mimic coal in appearance from a distance, but does not create dusting concerns when left in the open unprotected. TDF storage piles, if of sufficient size, may experience heating problems similar to coal piles. Storage management should be similar to that of coal to preclude heating problems.

## 7. Combustion

7.1 One way of optimizing combustion of TDF is to address the size of the tire pieces and ultimately its distribution on the grate. Even distribution on the grate will occur if the current solid fuel stoker is achieving even distribution with historical fuels and if TDF is close in size and bulk density to historical fuel(s) so that it mimics fuel handling characteristics. Free-flowing TDF has a bulk density in the range of 25 to 30 lb/ft<sup>3</sup> (4 to 4.8 g/cm<sup>3</sup>).

7.2 Although one could produce a rubber particle small enough to fire in a pulverized coal boiler with a blended mix of TDF/coal, the cost to process TDF to meet a pulverized coal specification would be prohibitive. For example, an electrical



utility (Otter Tail Power at Big Stone, SD) at one time fired a 2-in. (5.08 cm) TDF in a cyclone boiler specified for 0.25-in. (0.64 cm) coal. Cyclone boilers reach temperatures in excess of 2500 °F (1371 °C), which may allow for the oxidation of all remaining steel wire in the TDF. Significant increases in iron oxide may cause operating problems. A bead wire-free TDF appears to succeed in keeping concentrations below the boiler's threshold limit.

7.3 Smaller-sized TDF consists of an aggregate of odd-shaped pieces, many of which have significant flat surfaces. Little or no segregation has been noted in its blending and conveying with conventional fuels. One concern has been that on occasion, dense angular TDF chips may bounce off the side walls of the boiler and land near the dump end of the grate, thus precluding complete combustion before entering the ash handling system. This is more of an issue with traveling grate boilers as the grate movement will dump the unburned, burning, or partially burnt rubber into the ash collection and handling system. Concerns here may be addressed by adjusting the stoker's projection of solid fuel into the boiler. This correction may not always be possible. Smaller sizing of the TDF also may correct the problem. As TDF's mass is reduced, ambient conditions in the boiler may exert greater influence as TDF's own inertia generated by the stoker system may not be great enough to overcome the air turbulence in the boiler. These fuel feed issues are not applicable to fluid bed combustors.

7.4 In the case of traveling grates, larger pieces of TDF may need a longer residence time on the grate to achieve complete combustion, requiring adjustment of grate speed. Larger pieces of rubber chips (greater than 2 in. (5.08 cm)) may lack sufficient inertia from the stoker to achieve proper distribution. In some cases, it has been observed that larger pieces of TDF prematurely fall to one area on the grate and may cause hot spots on the grate or slagging. Again, a smaller TDF size specification will provide for shorter combustion times and reduce or preclude the need for grate speed adjustments other than to maintain an adequate ash layer on the grate for insulation purposes. Grate insulating issues are more important where TDF replaces higher ash content coal, thus reducing the volume of ash. Although grate temperature variation from traditional fuel burning has been minimal when adding TDF, it remains important to maintain under fire air flow as the highly volatile, low moisture content of the TDF will increase radiant heat transfer back to the grate. It is this radiant heat from combustion of TDF and its highly volatile fraction within the combustion zone that assist in the combustion of high-moisture fuels, such as sludge.

7.5 Recent operating experience with TDF in fluid bed combustors has enhanced our understanding of TDF use in these units. The following considerations are important to note. (7.5.1 and 7.5.2 also would have application to stoker boilers.)

7.5.1 *Air Distributor and Bed Letdown/Cleansing System*—Wire from TDF will accumulate in the lower portion of the bed. Large accumulations may lead to bed defluidization and clinker formation. Design features to preferentially remove wire from the bed would include sloped air distributors, sparge pipes, and directional nozzles. A specification requiring wire-

free or relatively wire-free TDF would preclude the need for a system to remove the wire.

7.5.2 *Heat Transfer Surface Allocation*—If TDF is being considered as a supplemental fuel to blend with a lower-Btu fuel such as wood waste, the quantity will be limited by the surface area of the combustor relative to the heating value and moisture content of the fuel for which the unit was designed. This is similar to the grate heat release limitations in a stoker boiler. The effective heat transfer surface in the bed or furnace is fixed. Thus, a constant amount of heat absorption occurs at a given bed temperature regardless of the fuel. As certain combustors have most of their surface allocated in the convection pass or heat recovery area, this would limit the amount of tire fuel that could be fired without exceeding limits on bed temperature. Changing bed depth or bed density may allow for a greater feed rate of TDF by increasing the amount of bed or furnace heat absorption.

7.5.3 *Gas and Particle Residence Time*—Units designed with long furnace gas residence times, overfire or secondary air systems and fly ash reinjection are better suited to completely combust TDF.

## 8. Sampling and Analysis

8.1 A typical, multiple-use size specification for TDF that currently is fed to many of the power units, alluded to in the overview as 2 in. (5.08 cm) minus, is identified in Table 3. This size specification also has been successfully applied to pneumatic conveyance into lime and cement kilns while maintaining complete combustion and kiln product quality. Applications in lime kilns are end product quality specific.

8.2 The determination of TDF size distribution is well defined through the analysis performed via modified Test Method D4749. The analysis to perform for wire content has been developed as follows:

8.2.1 Collect a random No. 5 sample of TDF (see Test Method E873).

8.2.2 Send to a lab with the ability to grind the entire sample into at least 0.25 in. (0.635 cm) particle size. This additional refinement will liberate (separate) remaining inherent wire from rubber particles.

8.2.3 Qualified laboratories will separate wire from rubber magnetically.

8.2.4 Each product will be weighed and reporting will include total weight of wire and rubber and wire weight reported as a percentage of total.

**TABLE 3 Sieve Analysis – Random Sample of 2-in. Minus TDF**

NOTE 1—Analysis performed to Test Method D4749.

Percent Passing Sieve Analysis	Sieve Opening	
	(in.)	(cm)
not reported	3	7.6
not reported	2	5.4
96	1½	3.8
62	1	2.5
32	¾	1.9
20	⅝	1.6
10	½	1.3
2.1	⅜	0.5



8.3 Historically, TDF wire content analysis was conducted in the laboratory by taking a sample, burning the rubber, magnetically separating the wire, and then conducting a weight analysis described in 8.2 – 8.2.4. Problems associated with this guide are as follows:

8.3.1 Combustion of a No. 5 sample created concern for resultant air quality issues.

8.3.2 Fine radial ply wire may oxidize and lose mass, which would affect the accuracy of residual wire weight and reporting.

8.3.3 A typical, multiple-use, relatively wire-free specification for TDF that currently is fed to several power units, alluded to in the overview wire content, is identified in Table 4. This wire content analysis evaluates compliance with a relatively wire-free specification. The wire extraction process for scrap tires is mechanical. Historical test results show a normal variability of TDF wire content up to approximately 1 % of the relatively wire-free standard.

## 9. Fuel Analysis

9.1 Routine fuel analysis reporting is a requirement by some combustion unit operators or their compliance agencies; however, due to the consistent chemistry of scrap tires, frequent analysis has been rare. Most requests have been limited to the initial air quality permit addendum phase for a combustion unit to include TDF as a normally permitted fuel. Evolving permit compliance strategies may increase the frequency of fuel analysis. Evolving tire chemistry also may increase the frequency of analysis. Several methods of fuel analysis exist. Some significant differences exist that can produce misleading results. If oxygen is of concern, it should be measured directly. Laboratories typically calculate oxygen as the difference between the total sample mass and that of the other major elements. To establish consistency in reporting, especially if changing laboratories for analysis, the methods are recommended in Table 5.

9.2 A critical component of accurate analysis is the initial sample collection and preparation. A scrap tire, although appearing homogeneous, has differences in chemistry makeup specific to its sections, for example, tread, sidewall, or tire interior liner (bladder) rubber.

9.3 When collecting and preparing a sample for analysis, it is important that the sample represent an appropriate aggregate of the whole tire's chemistry, and subsequently, that the laboratory analyze that aggregate. To accomplish this goal, sample preparation for the lab should be similar to that for wire analysis. By processing the TDF sample into a 0.25-in. (0.64 cm) minus, the small particle size ensures a well-mixed sample for laboratory analysis. This effort precludes a lab from selecting only one or two larger chips to process (mill) and analyze, representing only one or two components of the tire rather than its entire makeup. A better opportunity also exists to include a representative mix of tire types, that is, passenger, truck, or off road within the analysis.

TABLE 4 Wire Analysis – Random Sample of 2-in. Minus TDF

Wire Content, %	0.91
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TABLE 5 Methods and Units for Fuel Characterization

	Coal Standards
Bulk density, lb/cf (kg/m <sup>3</sup> )	Test Method E873
Calorific value	
Btu/lb, MJ/kg	Test Method D5865, Test Method D5468
Proximate composition	Practice D3172
Moisture	Practice D2013/D2013M, Test Method D3173/D3173M
Ash	D3174, D5468
Volatiles	D3175
Fixed carbon	By difference
Ultimate analysis	
C, H	D3176, D3178
N	D3179
S	D4239, D3177, SW-846-5050, SW-846-9056
Cl	D2361 (chromatography and X-ray fluorescence can also be used), SW-846-5050
Ash elemental (Si, Al, Ti, Fe, Ca, Mg, Na, K, P, Zn)	D3682, D2795 (X-ray fluorescence and ICP can also be used), D5468 (Ash), D4326 (Metals analysis)

## 10. Random Sampling

10.1 Protocol is critical to ensure a representative sample of current TDF production. A representative sample will minimize variability due to individual tire chemistry, tire types, and product size through a normal production day. Once collected, the sample will be sent for sieve analysis. The sample also will be used to extract a sub-sample for any proximate, ultimate, and wire analysis after the sieve analysis. The following is an outline sampling protocol for TDF, pulling the sample from current day's production inventory that is typically a cone-shaped pile accumulated at the end of the production discharge conveyor.

## 11. Protocol Outline for TDF Sampling Based on Test Method E873

11.1 The TDF pile should be selected as required and labeled for data sampling.

11.2 Identify nine points on the pile.

11.3 The pile should be sampled at nine points as follows.

11.3.1 The pile is roughly quartered (visually) so that eight samples are taken at equal intervals around the perimeter of the pile.

11.3.2 After the points are marked with a flag, the sampler will walk into the pile for 5 ft (1.5 m) from the edge and excavate down 1 ft (0.3 m).

11.3.3 Approximately 5 lb (2.3 kg) of sample will be removed and placed in a clean container (cardboard box). This procedure will be done for all eight points. The final 5-lb (2.3 kg) sample (No. 9) will be taken from roughly the center of the pile at a 2-ft (0.6 m) depth. All sample containers are to be labeled according to sample location and date sampler.

11.3.4 The approximately 45 lb (20.4 kg) of total sample will be composited at the laboratory. Samples may be combined prior to shipping for convenience.

11.3.5 A sample record and chain-of-custody form must be completed.

11.3.6 Samples should be packaged securely and delivered to either a delivery service or directly to the laboratory if nearby on the same day of the sampling event.



NOTE 1—If rainy weather exists, care should be taken that samples are not dripping wet. If necessary, the depth at which samples are secured may be increased and a notation should be made on the sampling log.

11.4 Once this sample has been composited by the laboratory, sieve analysis can be conducted. After the completion of the sieve analysis, the sample should be composited again. From this 45-lb (20.4 kg) sample, the laboratory can again create two more random 5-lb (2.3 kg) samples. One sample then would be designated for wire content analysis and the other for proximate, ultimate, and energy content analysis.

## 12. Model Sampling Log Form

### 12.1 Summary:

12.1.1 Tire-derived fuel utility as a high-quality energy resource is represented by its fuel characterization analysis. Proper and accurate analysis is critical to define TDF quality. Consistent sampling and analysis protocols will ensure accurate and objective comparative analysis between fuel suppliers and provide customer assurances as to quality and composition. For both new and existing units, TDF specifications should be directed at proper sizing and handling to ensure compatibility with the handling of conventional solid fuels. With the proper specification for TDF, current use and past testing have determined TDF to be a viable fuel for traveling grate boilers, vibrating grate boilers, bubbling bed combustors, cyclone boilers, circulating fluidized boilers, stage combustors, cement kilns, and lime kilns. Operators may have to adjust for a higher heat release fuel, which may burn more efficiently than other solid fuels.

12.1.2 Some important issues to keep in mind when specifying TDF are as follows:

12.1.2.1 Size for combustion and handling considerations. One standard size specification may not be appropriate for all

applications. Variations in size specification may present trade-offs that will affect cost, material handling, combustion, ash disposal, and handling and energy value.

12.1.2.2 Wire removal, although not required for all combustion units, can decrease ash disposal, improve ash handling/conveying, and eliminate associated erosion or slagging problems. Although a wire-free material is not essential for most boiler applications, a relatively wire-free product eliminates many of the operational concerns noted herein. Wire removal for most kilns is not an issue. Clean-cut chips to reduce exposed wire is an issue in that it eliminates handling problems.

12.1.2.3 A significant fraction of TDF is used in cement kilns, where many of the concerns regarding inclusion of wires do not apply. In cement kilns, included wires are beneficially incorporated into the cement clinker product, providing iron that might otherwise be added from other sources.

12.1.2.4 Sulfur and zinc must be evaluated to address air permitting and ash disposal issues.

12.1.2.5 Actual size specification with broadest acceptance in conventional and fluid bed boilers, based on current consumption, is a 2-in. (5.08 cm) minus standard size specification.

12.1.2.6 The more refined the TDF, the lower the cost to use it from an operation and maintenance standpoint. The cost to produce the chip will go up proportionately to its size reduction and wire removal requirement.

## 13. Keywords

13.1 ash; Btu content; chip size; combustion; conveying; minus; moisture; passenger tire equivalent (PTE); quality control; sulfur; tire-derived fuel (TDF); wire; zinc

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