IT'S TIME TO TAKE ANOTHER LOOK AT TORREFACTION

This article is an extended and more detailed version of an article of the same name to be published in Pellet Mill Magazine. It contains additional sections on the technological aspects of torrefaction utilizing essentially inert gas generated catalytically via

ATS TorreCat™ Catalytic Oxidation Technology

No one can argue that it has taken longer than expected for the wood-based torrefaction industry to develop. **But the benefits of torrefied wood pellets, when compared to white wood pellets, are simply too significant to be ignored**.

It is widely acknowledged that torrefied wood pellets (TWP) have physical characteristics superior to white wood pellets (WWP), including higher energy density, higher bulk density, improved grindability, and water resistance. It has generally been assumed, however, that TWP cost more than WWP. This article will provide a technical and financial analysis to illustrate that, when compared to WWP, TWP:

- **Reduce the cost-of-use for end users (power plants)**
- **Provide higher profits for pellet manufacturers**
- **Reduce the overall carbon footprint of the biofuel**

Torrefaction is a biomass pretreatment process that extracts the low value energy from the biomass, efficiently uses that energy in the torrefaction process, and concentrates the high value energy into a high quality renewable solid fuel!

Torrefaction improves every aspect of the use of a biomass solids fuel. It offers a consistently higher quality product, higher profits for the producer, lower cost-of-use for the end-user

AND A LOWER CARBON FOOTPRINT.

WHAT HAS CHANGED WITH TORREFACTION TECHNOLOGY?

Lignocellulosic biomass is comprised of mostly cellulose, hemicellulose, and lignin. Torrefaction is a mild pyrolysis process performed at temperatures between 220 C. and 300 C. During the torrefaction process most of the hemicellulose is volatilized, creating 'torrefaction gas.' Torrefaction gas is comprised of relatively low molecular weight condensable organic chemicals, non-condensable gases (carbon monoxide and carbon dioxide), and water. The organic chemicals include acetic acid, methanol, lactic acid, formic acid, furfural, and hydroxyacetone.

The difficulty of handling these concentrated and volatile gases has resulted in serious problems with both safety and operational sustainability for torrefaction developers. Fires and explosions have occurred, pyrolysis oils have leaked from ductwork and fittings, and plugged lines have frequently interrupted the process. To remedy these issues , torrefaction must be undertaken in an inert environment. The use of large volumes of inert gas allows for safe operations and significantly reduces the possibility of the formation of pyrolysis oils and plugged lines. Operationally, the inert gas is used to transfer thermal energy into the reactor, dilute the torrefaction gas as it is being generated, and carry the organic chemicals contained in the torrefaction gas out of the reactor, in very dilute concentration, for immediate oxidation. The inert gas is also used to safely cool the torrefied biomass as it exits the reactor and to recover its energy.

If this volatile torrefaction gas is allowed to exist in the process for any length of time, it will polymerize into liquids known as pyrolysis oils – this must not be permitted to happen.

This solution requires large volumes of inert gas. So where does this inert gas come from? Previous technological approaches had no built-in mechanism for providing inert gas, and purchasing it or installing equipment to produce it is cost prohibitive. Now, however, **catalytic oxidation** technology can be employed to produce the necessary inert gas as a natural, and essentially FREE, byproduct of the overall process. This is key to commercial torrefaction.

There are three 'keys' to successful commercial torrefaction. These include:

1. **Use of a catalyst flue gas as an essentially inert gas for use throughout the torrefaction process**
2. **Conversion and use of effectively 100% of the chemical energy contained in the torrefaction gas**
3. **Recovery and reuse of thermal energy from the torrefied solids exiting the reactor**

THE TORREFACTION PROCESS

In this article the author, utilizing a proprietary heat and material balance simulation program linked with a detailed financial model, examines the torrefaction of **Ponderosa Pine** feedstock. The analysis includes a comparison of a WWP plant and a TWP plant producing the same amount of energy. The following table shows assumptions used in calculations.

Example of 105,000 MT per year commercial torrefaction facility utilizing Ponderosa Pine feedstock.

Torrefaction System Feedstock Input	Kg per hour
Raw Wood to Dryer, at 50% moisture, w.b.	34,020
Dried Wood to Torrefier at 10% Moisture, w.b.	18,900
Bone-dry Feed to Torrefier	17,010

Torrefaction System Output	
Torrefier Solids Yield, 75% Bone-dry	12,757
Torrefier Solids Yield, 75% Solids + 3% Moisture, w.b.	13,151

What Happens to the Energy Contained in the Biomass During Torrefaction?

The Law of the Conservation of Energy states ***"...the total energy of an isolated system is constant; energy can be transformed from one form to another but can be neither created nor destroyed."*** The biomass heat content, high heating value (HHV), may be measured at input and at each step in the process. Torrefaction processing steps typically include grinding, drying, torrefaction, cooling, further grinding, and densification. During each step, other than torrefaction, there is little-to-no change in the HHV. But during torrefaction, the HHV is changed. With the volatilization of the hemicellulose, organic chemicals are created. These chemicals, as described earlier, contain a disproportionally high level of oxygen, and as they are removed as a part of the torrefaction gas, there is a dramatic improvement in the molecular ratio of carbon, hydrogen, and oxygen in the remaining solids. The overall effect of this transformation is to concentrate approximately 90% of the initial biomass heat content in the remaining solids. These changes can be seen in the ultimate analysis results for the biomass feedstock, torrefaction gas, and torrefied solids.

Many torrefaction developers have failed to properly account for, and take advantage of, the tremendous amount of relatively low value energy contained in the torrefaction gas.

Ultimate Analysis	Raw Wood Feedstock (1)	25% Torrefaction Gas	75% Torrefied Wood (2)
% Carbon	49.25	22.92	58.01
% Hydrogen	5.99	7.72	5.41
% Oxygen	44.36	69.30	36.05
% Nitrogen	0.06	<0.05	0.08
% Sulfur	0.03	<0.01	0.04
% Ash	0.31	0	0.41
Total	100	100	100
Energy Content, HHV MJ/kg	20.02	7.80	23.90(3)

(1) "Thermal Data for Natural and Synthetic Fuels", S. Gaur and T. Reed, Marcel Dekker, 1998

(2) Data obtained from torrefaction performed by **HM3 Energy, LLC**, Gresham, Oregon

(3) Note that the sum of 25% times 7.80 MJ/kg + 75% times 23.90 MJ/kg = 19.87 MJ/kg. In addition, the value of exothermic reaction occurring during torrefaction releases 0.15 MJ/kg into the reactor environment, bringing the total to 20.02 MJ/kg.

Because of the high moisture content of the torrefaction gas, conversion of the chemical energy contained in the organic chemicals can be difficult to achieve if undertaken by a conventional thermal oxidation approach.

The HHV of the biomass is mostly associated with its carbon content. Torrefaction results in a higher concentration of carbon in the torrefied biomass. During the process, the feedstock's HHV heat content is transformed into three unequal portions. First, the torrefaction reaction releases a portion of the heat content into the reactor environment. Secondly, the torrefaction gas itself contains a relatively small portion of the biomass' HHV. Although a poor quality fuel, cumulatively this stream contains a significant amount of energy and its beneficial use in the process is key to commercially viable torrefaction. Thirdly, the torrefied solids contain the balance of the initial heat content.

The table below illustrates what happens to the HHV during torrefaction. As can be seen, the biomass feedstock has a total HHV heat content of 340.54 GJ/hr. The torrefaction reaction generates 2.72 GJ/hr. of heat, and the torrefaction gas contains 32.87 GJ/hr. of chemical energy. The remaining energy, 304.94 GJ/hr., is concentrated into the 12,757 kg/hr. of torrefied solids with a heat content of 23.9 MJ/kg.

Raw Wood Feedstock	Kg/hr.	34,020	
Moisture Content	%, w.b.	50%	
Bone Dry Wood	Kg/hr.	17,010	
Wood Heat Content, HHV	MJ/kg	20.02	
Total Feedstock Heat Content	GJ/hr.	**340.54**	
Torrefaction EXOTHERMIC Reaction	GJ/hr.	2.72	
Torrefaction GAS (Torregas) Heat Content	GJ/hr.	32.87	**Heat Balance**
Sum of EXOTHERMIC Reaction and Torregas Heat Content	GJ/hr.	**35.59**	**10.45%**
Torrefied Wood, Heat Content	GJ/hr.	**304.94**	**89.55%**
Torrefied Wood	Kg/hr.	12,757	
Torrefied Wood Heat Content, **HHV**	MJ/kg	23.90	

To summarize, given a solids mass yield of 75%, the torrefied solids retain 89.55% of the original HHV energy of the feedstock. The chemical energy contained in the torrefaction gas plus the energy generated exothermically during the torrefaction process represents the remaining 10.45%.

The table below illustrates the sources and uses of the energy in the gases circulating in the system.

Follow the Energy!

There is a tremendous amount of energy contained in the feedstock and it must be accounted for at every step in the torrefaction process!

It is important to note that the energy value of the exothermic reaction increases dramatically with increasing torrefaction severity and solids yield loss until it will eventually become a dominant heat source in the reactor.

Energy SOURCES in the Torrefaction System	GJ/hr.
Energy Contained in the Torrefaction Gas	32.87
Energy RECOVERED from Cooling the Exiting Solids	4.76
Energy RELEASED into the System from the Exothermic Reaction of Torrefaction	2.72
Total Energy in the Torrefaction System	40.35
Energy USES in the Torrefaction System	
GROSS Energy Demand, Torrefaction Reactor	13.18
Energy EXPORTED to the DRYER System	25.34
Misc. Energy Losses	1.82
Total Energy USES in the Torrefaction System	40.35
Percentage of Total Energy which can be Exported for Drying	***63%***

Gas residence time in the reactor should be minimized!

The life expectancy of any organic chemical molecule, from creation to oxidation (destruction), should be measured in mere seconds!

Adequately cooling the torrefied solids is a safety issue. Recovering the thermal energy during the cooling process is an economic issue, and a distinct advantage. **The torrefaction system generates 63% more thermal energy than is needed in the process itself. This excess heat can be used to provide almost 50% of the energy required for drying a feedstock containing 50% moisture.**

How is Torrefaction Made Safe?

The safety risks associated with the torrefaction process involve two areas. First, the torrefaction gas is highly flammable. Secondly, the torrefied solids are produced well above their auto-ignition temperature. Both are areas of concern and can be addressed using inert gas.

TORREFACTION GAS. The torrefaction gas, absent free water from the incoming biomass, consists approximately of the following components (weight%/volume%): water vapor (41.0%/66.4%); **organic chemicals (44.0%/22.5%);** carbon dioxide (12.0%/8.0%); and carbon monoxide (3.0%/3.1%). These values may vary somewhat depending upon the type of biomass processed and the degree of torrefaction employed. **By using inert gas in the reactor, the concentration of the organic chemicals in the torrefaction gas is diluted to approximately 1% by volume in an atmosphere of carbon dioxide, nitrogen, and steam, thus significantly reducing the risk of fire or explosion**.

TORREFIED SOLIDS. Torrefied solids are processed at temperatures well above their auto-ignition point. To ensure auto-ignition does not occur as the torrefied biomass exits the reactor, inert gas is cooled and then used in direct contact with the hot torrefied solids to (1) terminate the torrefaction reaction, (2) strip away any remaining organic chemicals that may have condensed onto the surface of the solid torrefied wood, and (3) cool the solids to below their auto-ignition point. This allows for safe removal of the torrefied biomass from the reactor and recovery of the thermal energy for reuse in the system.

HOW ARE TORREFIED WOOD PELLETS COST COMPETITIVE WITH WHITE WOOD PELLETS?

TWP can be produced and delivered to the customer at a lower cost than WWP **because of the efficient use of the energy contained in the torrefaction gas.** To illustrate this fact, a side-by-side comparison of a WWP plant and a TWP plant, each producing the same amount of energy, is presented using the assumptions given earlier plus the additional assumptions shown below.

Additional Assumptions	WWP	TWP
Feedstock Cost, $/MT at 50% Moisture	33.00	33.00
Source of Supplemental Thermal Energy, same as Feedstock	Wood	Wood
Combustion Efficiency of Biomass Combustor for Supplemental Heat, %	75%	75%
Relative Electrical Power Consumption	EQUAL	EQUAL
Relative Size of Workforce	EQUAL	EQUAL
Annual Operating Hours	8,000	8,000

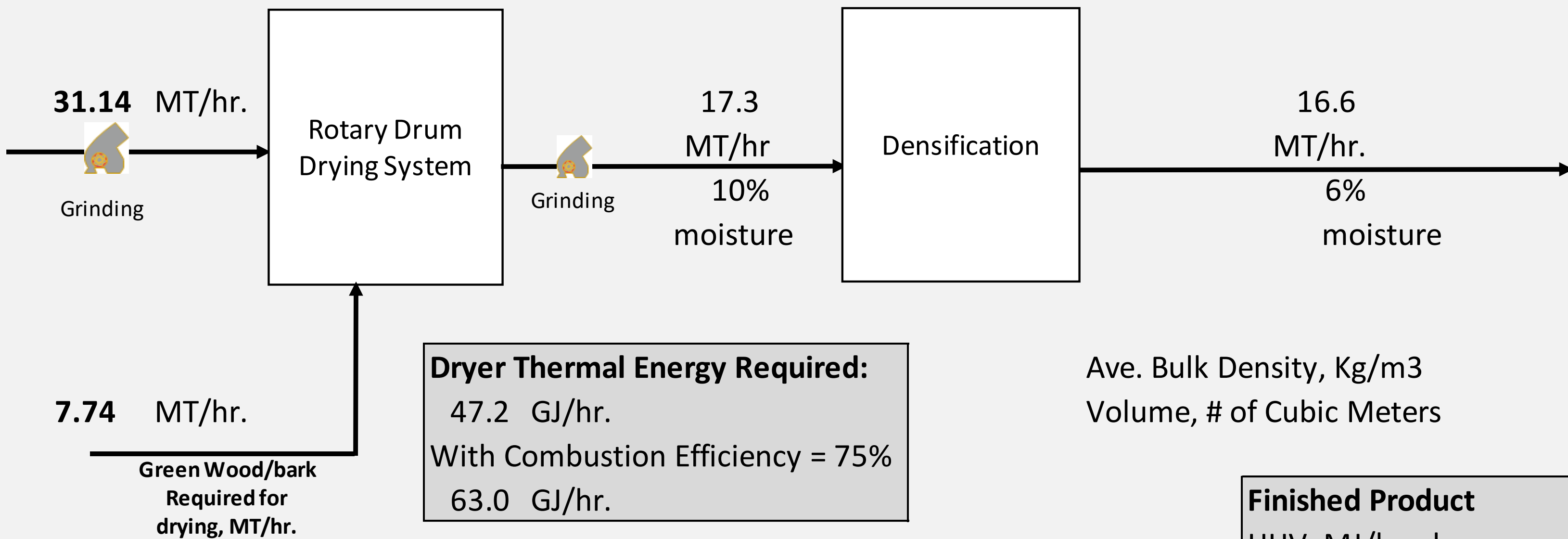
The two diagrams below contain, for the purpose of illustrating the differences, a basic process flow diagram for each process. The first illustrates a WWP facility with an annual capacity of 132,500 MT. The second illustrates a TWP facility with an annual capacity of 105,000 MT. From a production capacity, the WWP facility produces more weight and more volume **but exactly the same amount of energy** as the TWP facility. The TWP facility contains a torrefaction reactor, solids cooling and stripping system, and an ATS Torrefaction Gas Treatment system. The ATS Torrefaction Gas Treatment System contains all the components necessary to accept the diluted torrefaction gas from the reactor, oxidize this gas stream, and return a portion of the essentially INERT catalyst flue gas to the reactor thereby supplying the thermal energy necessary for continued operations. A detailed diagram of the ATS Torrefaction Gas Treatment System is provided later in this article.

It is oftentimes argued by some, including this writer, that one of the more significant benefits of torrefaction is its ability to process lower cost biomass feedstocks not customarily acceptable to conventional WWP facilities. In this comparison, the same feedstock and the same cost is utilized.

The ATS Torrefaction Gas Treatment System is of modular construction, fully assembled, instrumented, insulated, and delivered to the torrefaction site ready for placement on a foundation.

ATS TorreCAT™ Catalytic Oxidation Technology

White Wood Pellet Manufacturing



Dryer Thermal Energy Required:	
47.2	GJ/hr.
With Combustion Efficiency = 75%	
63.0	GJ/hr.

Ave. Bulk Density, Kg/m3	600
Volume, # of Cubic Meters	**220,873**

Finished Product	
HHV, MJ/kg, dry	20.02
LHV, MJ/kg	17.44
Annual Production	
Metric Tons	132,524
Annual Energy Produced	
LHV, GJ	2,311,215

Charge to System:

Total Biomass into system	38.88
Charge Rate, MT/hr.	31.14
Moisture Content, wb	50%
HHV, MJ/kg, dry	20.02
LHV, MJ/kg	8.13

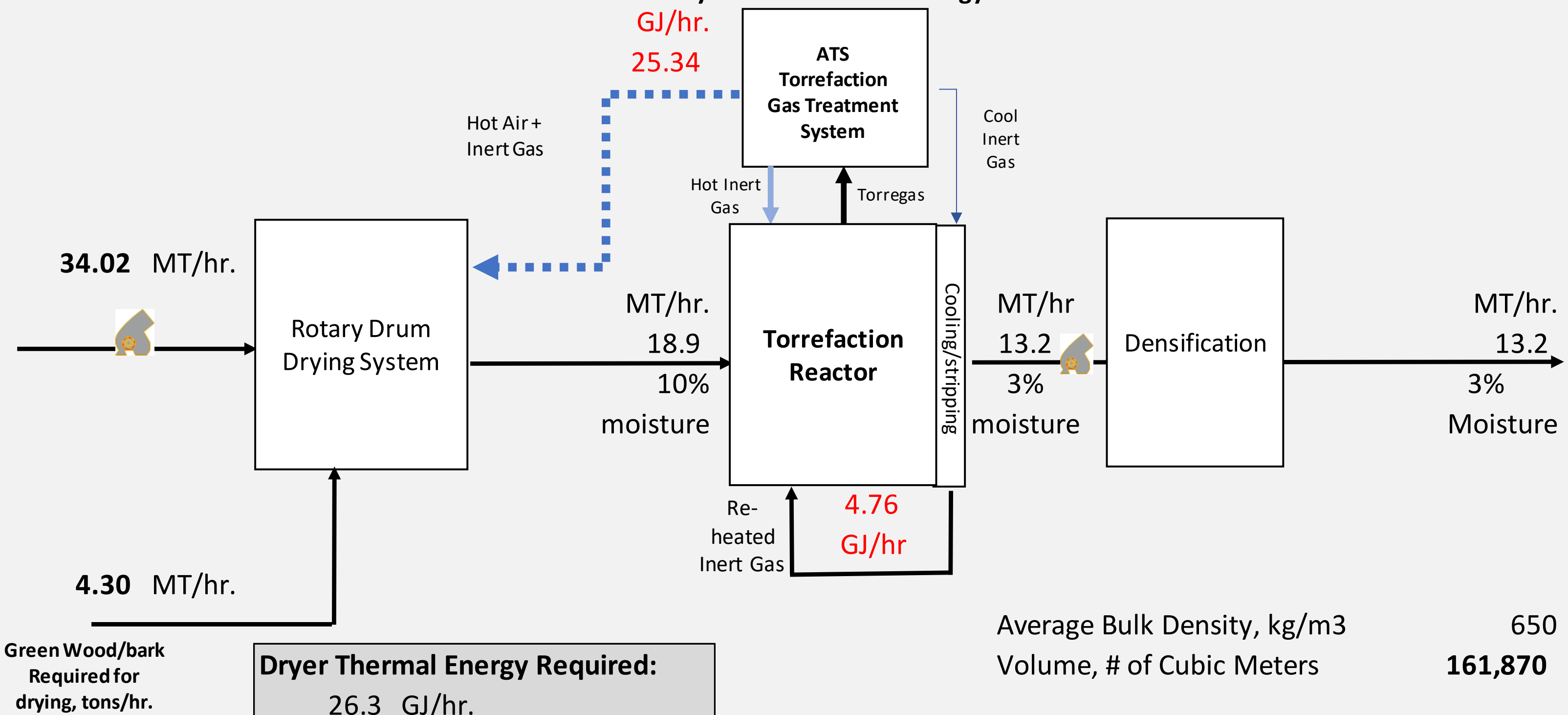
Both Input and Output

Ultimate Analysis Results, dry	
%C	49.25%
%H	5.99%
%O	44.36%
%N	0.06%
%S	0.03%
%Ash	0.31%
Total	100.0%

Feedstock: Ponderosa Pine

Torrefied Wood Pellet Manufacturing

ATS TorreCAT™ Catalytic Oxidation Technology



Average Bulk Density, kg/m3	650
Volume, # of Cubic Meters	**161,870**

Dryer Thermal Energy Required:

26.3 GJ/hr.

With Combustion Efficiency = 75%

35.0 GJ/hr.

Finished Product	
HHV, MJ/kg, dry	23.90
LHV, MJ/kg	21.961
Annual Production	
Metric Tons	105,215.8
Annual Energy Produced	
LHV, GJ	2,311,215

Charge to System:

Total Biomass into system	38.32
Charge Rate, MT/hr.	34.02
Moisture Content, wb	50%
HHV, MJ/kg, dry	20.02
LHV, MJ/kg	8.13

Ultimate Analysis Results, dry

	Input	**Output**
%C	49.25%	58.01%
%H	5.99%	5.41%
%O	44.36%	36.05%
%N	0.06%	0.08%
%S	0.03%	0.04%
%Ash	0.31%	0.41%
Total	100.00%	100.00%

Feedstock: Ponderosa Pine

The tables below show the operational and financial results of the comparison:

OPERATIONAL COMPARISON	UNITS	WWP	TWP	DIFFERENCE
Feedstock, into Process	MT/hr.	31.14	34.02	+9.2%
Feedstock, as Supplemental Fuel	MT/hr.	7.74	4.30	-44.4%
Feedstock, Total	MT/hr.	38.88	38.32	-1.4%
Finished Product, Weight	MT/hr.	16.57	13.15	-20.6%
Finished Product, Weight	MT/yr.	132,524	105,216	-20.6%
Finished Product, Heat Content, LHV	MJ/Kg	17.44	21.96	+25.9%
Finished Product, Heat Content, LHV	**GJ/yr.**	**2,311,215**	**2,311,215**	**EQUAL**
Finished Product, Bulk Density	Kg/m^3	600	650	+8.3%
Finished Product, Energy Density	GJ/m^3	10,464	14,274	+36.4%
Finished Product, Volume	m^3/year	220,873	161,870	-26.7%
Energy Shipped, 40,000 m^3 Vessel	GJ/shipment	418,560,000	570,974,481	+36.4%

FINANCIAL COMPARISON	WWP	WWP	TWP	TWP
	$/MT	**$/GJ**	**$/MT**	**$/GJ**
Sales, CIF (1)	192.00	**11.01**	241.89	**11.01**
Feedstock Cost (2)	62.17	3.56	85.54	3.90
Conversion Cost (3)	59.84	3.43	68.43	3.12
Total Cost, FOB plant	**122.01**	**6.99**	**153.97**	**7.02**
Shipping Cost, CIF (1) (4)	43.00	2.47	41.17	1.87
Total Delivered Cost	**165.01**	**9.46**	**195.14**	**8.89**
EBITDA	27.10	1.55	46.75	2.13
EBITDA Margin, %sales	14.1%		19.3%	

Note (1) CIF European Port from a port in Southeastern USA

Note (2) Biomass feedstock for the process only

Note (3) Contains the cost of biomass used as thermal energy in the dryer

Note (4) Shipping cost is lower for TWP because one can load a seagoing vessel by volume vs. weight

It's important to remember that it's always about producing and selling energy, not tonnes, <u>just energy!</u>

It's also about providing the customer with a high quality product that minimizes the cost to modify their process to enable its use!

Purchasing approximately the same amount of feedstock, extracting the low quality energy for use in the process, concentrating the high quality energy into the finished product, and shipping lower volumes but with the same energy content – that's the definition of success!

As can be seen, there are striking differences between the two biomass processing technologies. The use of inert gas throughout the torrefaction system plus the ability to beneficially use the energy from the torrefaction gas is paramount to torrefaction viability.

Operationally, the ability of the torrefaction facility to use relatively the same amount of feedstock, recover and recycle energy in an optimal manner, pack more energy into the finished product, and produce a product that has superior performance attributes, are all advantages offered by torrefaction.

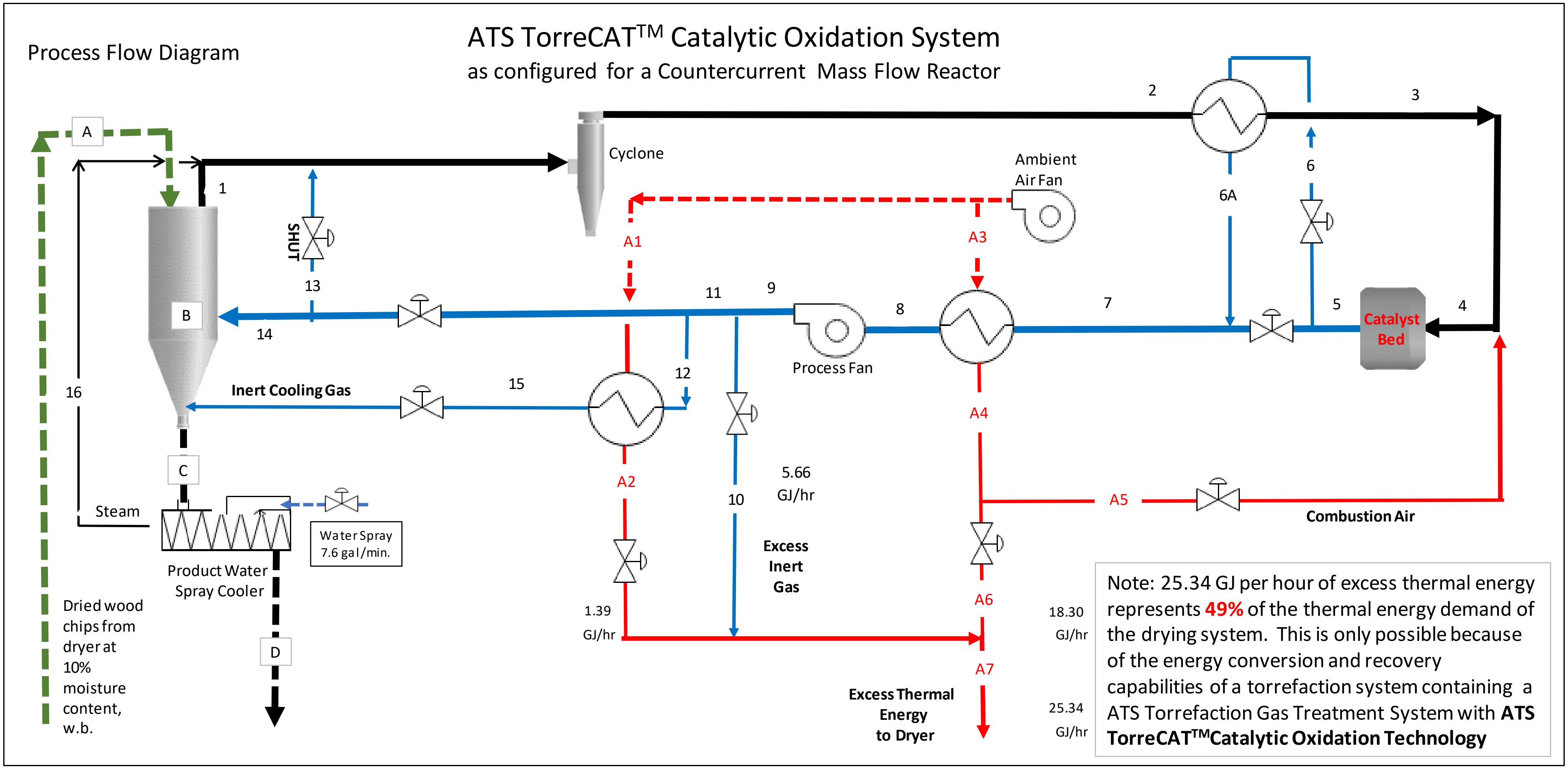
Financially, torrefaction presents pellet producers an opportunity to obtain greater returns. Torrefaction also allows end users to benefit not only from lower delivered cost, but also from a higher quality product, attributes which directly translate into a significantly lower cost-of-use renewable biofuel. In this analysis, the EBITDA, on a 'per MT' basis, is 72% higher for the TWP facility and 37% higher on a 'per GJ' basis.' Although beyond the scope of this article, it is estimated that the additional CAPEX needed for a 105,000 MT/yr. TWP plant, which would equal the energy output from a 132,500 WWP plant, is no more than 10%. The financial advantages offered by torrefaction are clear.

A lower carbon footprint is clearly one of the advantages of torrefaction. Achieving lower carbon emissions is the reason for the use of a carbon neutral or, more accurately, a near carbon neutral fuel.

Environmentally, torrefaction results in a lower carbon footprint. Since a significant portion of the carbon footprint of delivered biofuel is associated with transportation, the higher energy density, along with higher bulk density, allows for more energy to be shipped in a truck, railcar, or seagoing vessel. In addition, given its improved grindability which is similar to coal, torrefied biomass opens the door for use of densification technologies, such as cubing or briquetting, with lower electrical demand. These options all have the potential to further lower the carbon footprint of the biofuel.

HOW DOES THE TORREFACTION PROCESS OPERATE?

As stated earlier, safe, efficient and reliable commercial torrefaction is viable only with the use of large volumes of essentially inert gas. Purchasing an inert gas and heating it to torrefaction temperature is expensive and renders that approach economically infeasible. A different approach, involving the use of an oxidation catalyst, can generate the required essentially inert gas as a practically FREE BYPRODUCT of the catalytic combustion of the torrefaction gas. **ATS TorreCAT™ Catalytic Oxidation Technology** has been developed and patented specifically for this purpose. A process flow diagram of this technology and the temperatures and flow rates for the individual streams are shown below.



In the design shown, the torrefaction reactor is a direct contact, counter-current, vertical mass flow reactor but the overall concept is applicable to any torrefaction reactor design. Use of an essentially inert catalyst flue gas to drastically reduce the concentration of organic chemicals and carbon monoxide makes the process easy to control, allowing it to be sustained over long periods of time.

The torrefaction process, as shown above, is designed such that it will allow operations at both low severity and high severity and anywhere in between. The example shown here is of moderate severity.

	Process Gas Streams												
	Torregas	1	2	3	4	5	6	6A	7	8	9	10	11
Mass, lbs/hr.(1)	13,542	192,880	195,808	195,808	217,097	217,097	75,000	75,000	217,097	217,097	217,097	37,759	179,338
SCFM	3,493	48,972	49,999	49,999	54,669	55,059	19,019	19,019	55,054	55,054	55,054	9,575	45,479
ACFM	5,443	73,804	75,087	88,824	99,858	145,373	49,880	37,139	132,323	103,005	94,688	16,469	78,219
Temp., C.	177	177	175	254	262	495	495	295	426	271	271	271	271
Wgt% Volatiles, (2)	32.54%	2.28%	2.25%	2.25%	2.03%	trace	trace	trace	trace	trace	trace	trace	trace
Vol% Volatiles (2)	14.90%	1.06%	1.04%	1.04%	0.95%	trace	trace	trace	trace	trace	trace	trace	trace

	12	13	14	15	16
Mass, lbs/hr.(1)	13,111	-	166,227	13,111	2,928
SCFM	3,325	-	42,154	3,325	1,028
ACFM	5,718	-	73,413	3,960	1,310
Temp., C.	271	271	271	99	100
Wgt% Volatiles, (2)	trace	trace	trace	trace	trace
Vol% Volatiles (2)	trace	trace	trace	trace	trace

	Solids Flow			
	A	B	C	D
Mass, lbs/hr.	41,667	28,125	28,125	28,995
Temp. C.	25	270	200	25
% Moisture, w.b.	10%	0%	0%	3%

	Air Flows						
	A1	A2	A3	A4	A5	A6	A7
Mass, lbs/hr.	13,793	13,793	138,779	138,779	21,289	117,489	169,041
SCFM	3,025	3,025	30,438	30,438	4,669	25,768	38,369
Temp. C.	25	241	25	357	357	357	324

(1) Mass includes the free water from the feedstock entering the reactor

(2) Volatiles include carbon monoxide.

As stated earlier, the torrefaction reaction results in a gas mixture of reaction water, organic chemicals, carbon dioxide, and carbon monoxide. The organic chemicals (volatiles) represent approximately 22.5% of this mixture by volume. When including the free moisture contained in the feedstock, the concentration of organic chemicals plus carbon monoxide in the torrefaction gas is decreased to approximately 14.9%. But because the heat for the torrefaction process in the reactor is supplied by a hot, essentially inert catalyst flue gas, the concentration of these volatile gases is immediately reduced to approximately 1% by volume. At this concentration level, the stream is much less hazardous and much easier to work with than undiluted torrefaction gas. That diluted stream is then immediately oxidized in the catalyst bed creating an essentially inert catalyst flue gas. **A majority of the essentially inert catalyst flue gas is re-circulated back to the torrefaction reactor in a continuous process providing the energy**

required to maintain the torrefaction reaction. A slip-stream of the inert catalyst flue gas is cooled and then used to cool the solids and thereby recover available thermal energy. Given that catalytic oxidation operates at much lower temperatures than conventional thermal oxidation, the potential for formation of NOx is dramatically reduced. The system also produces excess inert gas which can be used elsewhere to purge the overall process or it can be used for drying as is shown in this configuration.

WHAT SHOULD BE THE NEXT STEP?

Armed with a better understanding of the potential benefits of torrefaction, industrial consumers of white wood pellets may consider facilitating the implementation of torrefaction technology by agreeing to permit the inclusion of torrefied biomass in the fuel mix at one of their power plants. This would create the support needed for torrefaction facilities to be constructed.

Over time, every industrial model undergoes technological innovation, sometimes merely incremental, but at other times transformational. This may well be a transformational moment for the WWP industry. Early adapters stand to benefit the most by capturing both market share and experience with the new technology. For many reasons, including both the opportunity for greater financial return and a profound improvement in environmental impact, producers should be interested in implementing torrefaction technology. Any WWP manufacturer interested in the next generation of advanced engineered biofuels might consider beginning with a relatively small (4-5 tons per hour) torrefaction system inserted into an existing WWP facility. Most of the torrefaction equipment required could be of modular construction and delivered to the site ready for final hookup.

LAST WORD

For pellet producers, torrefaction provides a tremendous opportunity to improve financial performance while delivering a much higher quality product. For end users, lower delivered cost plus plant-level benefits resulting from a biofuel that is similar to coal significantly reduce the product's overall 'cost-of-use.' In addition, significant value is rightly placed on reducing the biofuel's carbon footprint. It's time to move forward to create the "next generation" of solid biofuels.

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