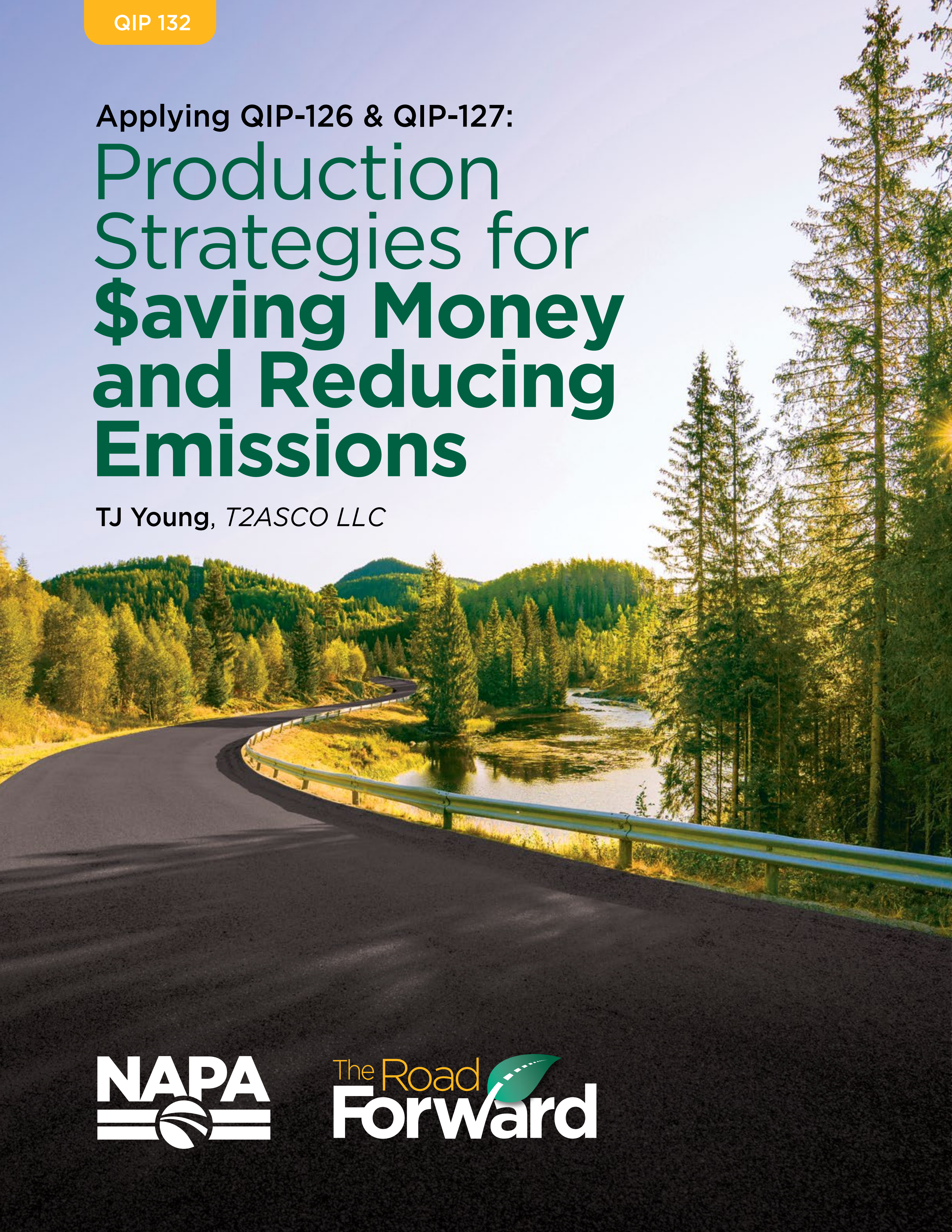
QIP 132



Applying QIP-126 & QIP-127:

Production Strategies for **$aving Money and Reducing Emissions**

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The Road Forward is an initiative of the asphalt pavement industry, with the committed support of NAPA members, partners, and staff, to achieve net zero carbon emissions by 2050.

Learn more about the initiative and find additional resources at AsphaltPavement.org/Forward.

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ACKNOWLEDGMENTS

Thanks to The Road Forward Partners, whose contributions helped fund this project, and to the Committee for Engineering Application & Practice Plant Operations Subcommittee for their assistance in finalizing this publication.

Contents

Introduction

Energy use in the asphalt mix production process, and therefore energy reduction opportunities, fall into three distinct areas in the plant facility.

1. Energy consumed in drying and heating the aggregate.
2. Energy consumed keeping the plant and liquid asphalt binder at operatable temperatures—keeping the liquid asphalt binder at pumpable temperatures, keeping the transfer pipes hot enough so the liquid asphalt binder does not cool off en route to the mixing area, keeping the mixing area and plant transfer equipment hot enough so the final product does not cool off en route to the storage silos, and keeping the mix warm enough in the storage silos prior to shipping to the job site.
3. Energy consumed operating the electrical motors on the plant facility.

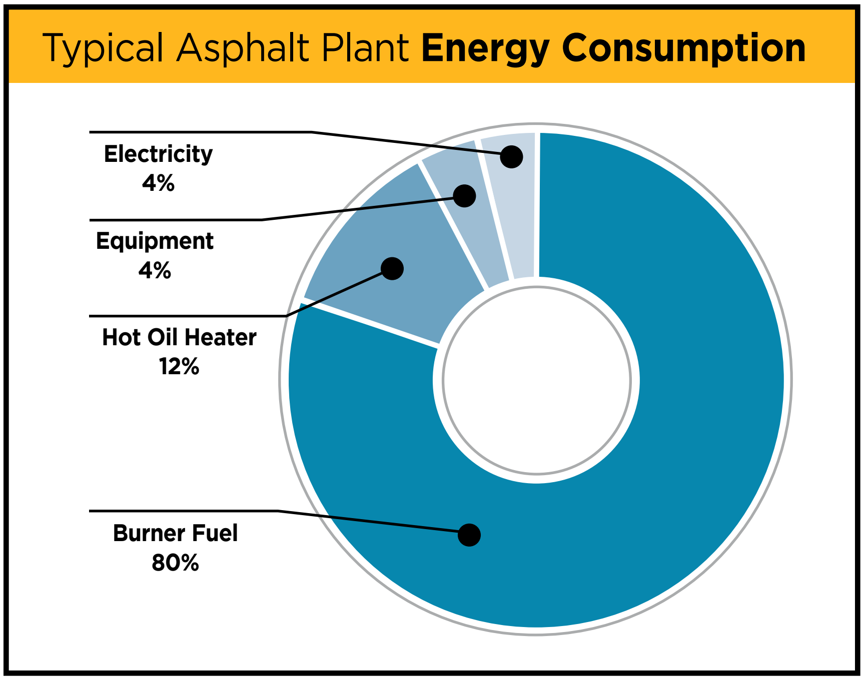


Figure 1. Energy consumption for a typical ashpalt plant

Separating energy requirements into these distinct areas allows us to:

1. Focus on opportunities for energy reduction in each stage of the process.
2. Identify the energy used and costs consumed by function.

Naturally, energy use and costs incurred will vary regionally based on local climates, moisture and humidity characteristics of that area, aggregates used in that geography, and local energy costs. Trying to establish a national average or create a national standard for energy used in the mix production process is a risky thought process, since regions vary dramatically.

As shown in Figure 1, the greatest amount of energy—80% of total plant energy consumption—is consumed drying and heating the aggregate. Keeping the asphalt binder and the plant equipment hot enough to transport the liquid asphalt and then keeping the plant equipment hot enough so that the mix is not prematurely cooled accounts for 12% of the total energy footprint. Electricity used for running the plant equipment consumes another 4% of the total energy, while running the loader and miscellaneous plant equipment like a skid steer loader or forklift accounts for another 4%.

Figure 2 shows a typical breakdown of energy costs, which will vary based on local energy rates, availability, and usage.

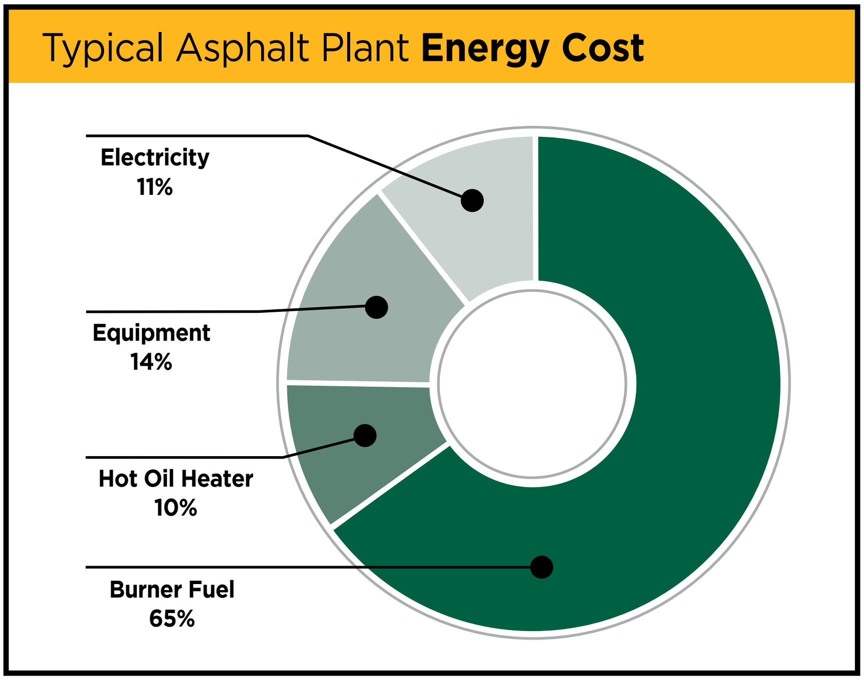


Figure 2. Energy cost for a typical asphalt plant

Figure 2 confirms that the cost associated with drying and heating the aggregate is substantial, and the costs associated with keeping the asphalt binder and plant equipment hot starts to balance with the expense of the diesel fuel used to run the plant equipment and the electricity to run the motors.

This breakdown is useful, as it helps prioritize where to focus energy reduction efforts.

These charts are based on very rough estimates; climate, precipitation, and aggregate type vary wildly across the country. Aggregates characterized by higher moisture content and binder absorption are more difficult and costly to dry and are more dramatically affected by climate conditions. For example, in dry, sunny climates, the relative percentage of energy used for drying and thermal storage will be less and the percentage of electrical energy will be higher; for cool, damp climates, the relative percentage of energy used for drying and thermal storage will be more and the relative percentage of electrical energy will be less.

Comparing plants against each other in the same region or geography, however, provides valid comparative data. An owner of multiple plants, or a local agency, can compare relative efficiency between producing units.

Fortunately for plant operators, energy improvement is based on engineering principles and physics. NAPA has tackled this topic multiple times over the years, starting in the early 1970s with *The Fundamentals of the Operation and Maintenance of the Exhaust Gas System in a Hot Mix Asphalt Facility* (IS-52), revising that document in the late 1980s, continuing in the 1990s with *Applying IS-52: Performance Expectations From Your Facility* (TAS-22), in 2000 with *Best Management Practices To Minimize Emissions During HMA Construction* (EC-101), and in 2008 with *Energy Conservation in Hot-Mix Asphalt Production* (QIP-126) and *101 Ideas to Reduce Costs and Enhance Revenue* (QIP-127).

The opportunities for improvement that lead to both energy conservation and cost reduction, along with what we have learned since publishing QIP-126 and QIP-127 and implementing the ideas outlined in them, are detailed in this document. Rather than rewrite and update QIP-126 and QIP-127, we have elected to create a resource that builds on the knowledge outlined in these publications and create a practical field guide that NAPA producer members and those interested in the process can use to easily compare different plants, identify opportunities for improvement, and move toward making each facility as energy efficient as possible. Links and references to original publications are provided throughout this document for those wanting to dive deeper into the engineering principles. New self-audit worksheets are included as Appendices to make it easy to evaluate individual facilities.

Opportunities for Energy Conservation in the Drying and Heating Process

A high percentage of the energy consumed in the mix production process is related to drying and heating aggregate materials. Since asphalt binder (or the glue in this production process) operates more effectively with dry aggregate, we need to dry the aggregates.

Historically, drying and heating have been most cost-effective when using the convective heat transfer of a fossil fuel-fired burner embedded in a rotary drying kiln (aggregate dryer). Other heat transfer techniques have been tried and do work, but the higher production rates of fossil fuel-fired rotary drying kilns have always won the cost-effectiveness competition. Selecting the most cost-effective fuel, together with managing the following items, allows one to run as cost-effectively and energy-efficiently as possible with this type of equipment.

Reducing Final Mix Temperature

Every 10°F reduction in final mix temperature results in a 2-3% reduction in BTUs required for drying and heating (depending on which energy model you want to embrace).

A 40-50° reduction in final mix temperature, therefore, results in a fuel savings range of 8-15% depending on which energy model you want to embrace and what your target final mix temperature reduction is (40° at 2% savings or 50° at 3% savings).

12% fuel savings are easily achievable.

How to Achieve

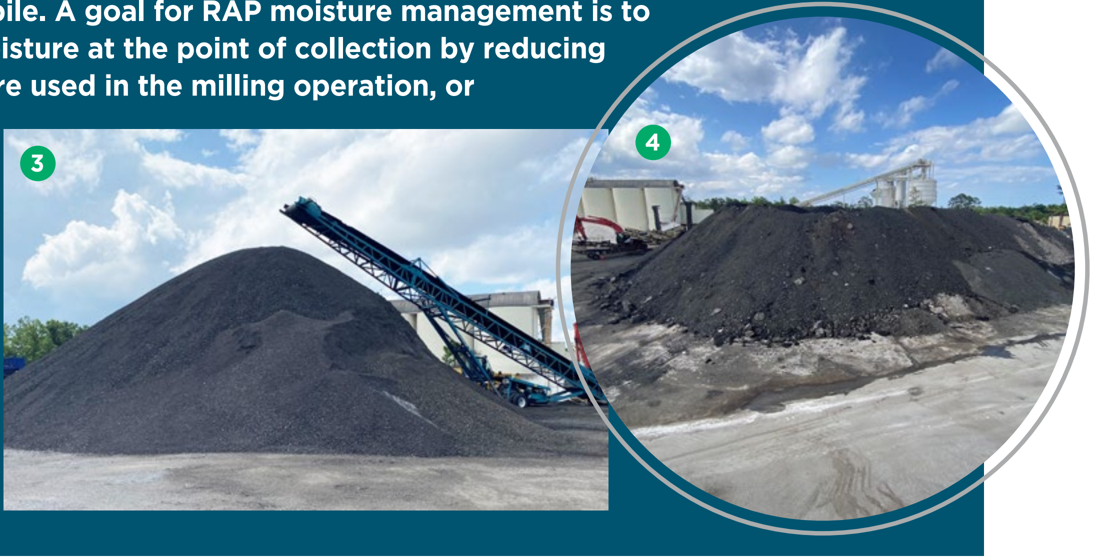
Warm-mix technology allows us to lower final mix temperature while still achieving the desired mixture and asphalt binder characteristics that allow us to successfully complete placement and achieve final mat density.

Warm-mix technology is achieved through either 'foaming' the asphalt binder (injecting small amounts of water droplets into the asphalt binder during mix production in a variety of different techniques) or introducing additives into the asphalt binder at either the terminal prior to transport or in the plant during mix production.

Table 1. BTUs required for drying and heating for varying temperatures and moisture contents
(Based on 25% excess air conditions in the burner) (Generated from data published in NAPA IS-52)

		270°F	280°F	290°F	300°F	310°F	320°F
Percent Moisture	3%	203,600	207,800	212,000	217,300	221,700	226,000
	4%	230,100	234,800	239,600	244,400	249,300	254,200
	5%	255,700	260,900	266,200	271,600	277,000	282,500
	6%	281,200	286,900	292,800	298,800	304,800	310,800
	7%	306,700	313,000	319,400	325,900	332,400	338,900
	8%	332,100	338,900	345,900	353,000	360,000	367,100

It is very difficult to get RAP (reclaimed asphalt pavement) to dry once it is placed in a stockpile. A goal for RAP moisture management is to attempt to reduce moisture at the point of collection by reducing the amount of moisture used in the milling operation, or stockpiling material at the plant in a way that prevents rain from easily entering the pile; with a conical pile, water will run off the surface, while using ramps provides a downhill runway for water to run off.



Figures 3 and 4. **RAP stockpiles built using ramps help reduce moisture accumulation prior to processing RAP**
Processed RAP stockpiles built in conical shape help reduce moisture accumulation from rain events as moisture runs off the sloped face and the slightly hardened “crust” of the RAP stockpile sloping the base under the stockpiles helps the material drain. paving under sloped stockpiles facilitates even better drainage.

Reducing Aggregate Moisture

Every 1% overall aggregate moisture results in 10% reduction in BTU consumption. (Refer to Table 1.)

Larger aggregates drain freely, but fine aggregates tend to hold moisture, and, worse yet, actually ‘wick up’ moisture if placed in an area that does not freely drain. For this reason, focusing on fine aggregate moisture management should be a higher priority.

Calculating the impact of stockpile moisture management techniques requires a ‘weighed average calculation’ of moisture reduction opportunities against typical mix formula percentages. Examples were provided in QIP-126 *(Example 1 and Example 2 on pages 10 and 11)*, while another example is shown below (Table 2). If a moisture reduction of 2% can be achieved in fine aggregates and 0.5% can be achieved in coarse aggregates with the mix formula shown below, the overall BTU/fuel savings potential in drying is 6%, a significant yet achievable goal.

Table 2. **Moisture savings potential by aggregate type**

Aggregate Type	Mix %	Moisture Savings Potential	Savings Impact (mix % x savings %)	BTU Savings (at 10% per 1% H_2O)
Sand	10%	2%	0.2%	2%
Stone Screenings	30%	2%	0.2%	2%
3/8” Stone	20%	0.5%	0.1%	1%
1/2” Stone	10%	0.5%	0.1%	1%
RAP	30%	0%	0%	0%
TOTAL	100%	N/A	0.6%	6%

A practical target for reducing moisture is 1% overall, resulting in 10% fuel savings for drying and heating. As Table 2 shows, even modest gains in moisture reduction can be significant.

How to Achieve

To reduce aggregate moisture, avoid feeding wet or fresh material directly into the plant. Instead, allow the material to drain and dry before using it. This can be accomplished by:

- Load driest material possible at the quarry for transport at the plant. (Can washed material be allowed to dry before loading into transport railcars or trucks?)
- Create a front side/back side or left side/right side stockpile plan, allowing new material to dry before feeding it to the plant. Wetter new material can be placed on one side, giving it a chance to drain, while the loader extracts material from the drier side of the pile. This technique allows an added benefit: verifying that material gradation is consistent with expectation before using it.
- Have the loader feeding the plant keep the bucket up 12" as they extract material so drier material can be fed into the plant. The wettest material will be on the bottom of the pile. (See Appendix F for a discussion and specific example of how elevation differences in stockpiles affect moisture levels.)
- Slope stockpiles away from the feeding face, allowing moisture to drain out the back and away from the area where the loader is extracting material. Any slope angle above 2% is useful, but 4-6% will drain more quickly.
- Stabilize the base or pave under the stockpile to allow moisture to drain more rapidly. Added benefits are less material loss into the stockpile 'floor' and the reduced possibility of subgrade contamination into the stockpile.
- Cover fine aggregates that don't drain easily to keep them from accumulating precipitation.

Try it: **Estimate the benefit from paving the stockpile floor. Calculate your payback period by paving a pad with your desired slope and checking moisture changes over time. Moisture from precipitation during the test can complicate your calculations; consider adding a loose tarp over the test pile supported by used tires so it does not 'sweat' under the tarp. You will get a fairly representative idea of the benefit of paving under the stockpile and reducing moisture accumulation from precipitation using a covering. If your stockpile turnover is faster than the effective drying time period, however, the cost effectiveness could be compromised.**

Adjusting Dryer Flights

Every 10° reduction in exit gas temperature results in a 1% reduction in BTUs required for drying and heating.

This rule of thumb is established based on several NAPA Associate member energy models for the theoretical BTUs required to heat and dry aggregate.

The reduction may not sound significant, but reducing exit gas temperature by 30-50°F, which is often easily achievable, results in a fuel reduction of 3-5%, which *is* significant.

Field experience has shown that 5% fuel savings is a practical and achievable target.

How to Achieve

Overall exit gas temperatures are reduced by adjusting the 'dryer flights'—the steel shapes that lift and drop material across the 'cross-sectional' area of the drum.

Flighting adjustment is made with different shapes and patterns, by changing the rotation speed of the drying drum, or both.

As flights dig through aggregate materials, they wear and lose their effectiveness, so constant inspection of their condition is important to maximize energy efficiency.


https://youtu.be/lk_6vjM7mbU

Figure 5. **Video of aggregate veil inside a rotary dryer drum**

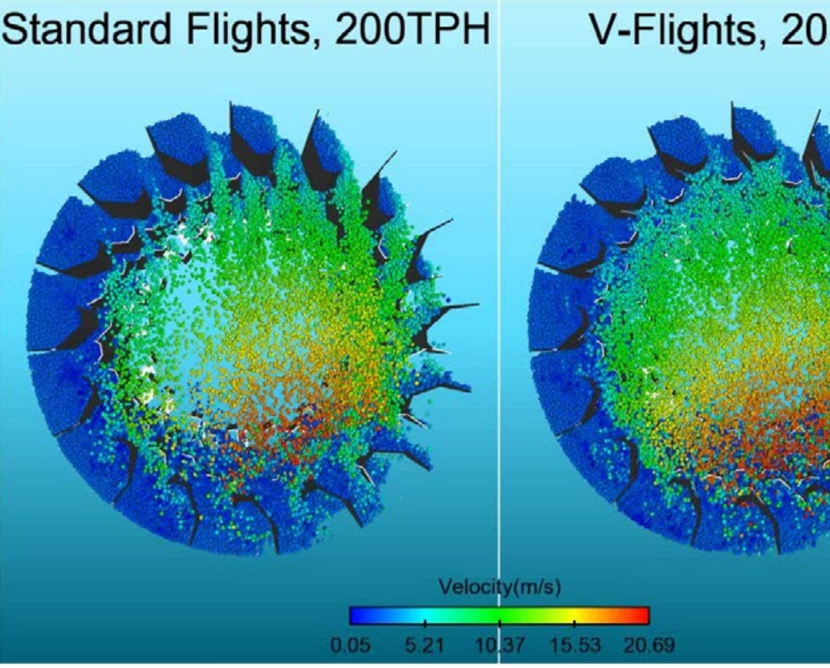
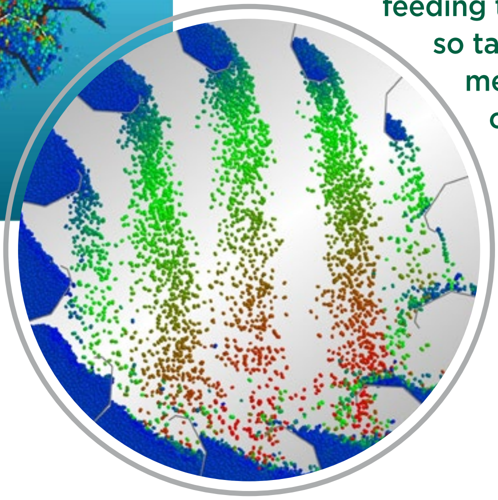


Figure 6. **Computer modeled veiling with different flights inside a rotary dryer drum** (courtesy Astec)

An indication of the effectiveness of flight design and wear condition can be made by comparing the exit gas temperature in the exhaust gas housing on the 'uphill' side of the drum (drum is rotating upward) and the 'downhill' side of the drum (drum is rotating downward). This can either be done by drilling a hole in the exhaust gas housing and measuring the temperature directly, or by waiting until the dryer operates about an hour and taking a temperature reading of the ductwork with an infrared thermometer in the same spot on both sides of the duct. Appendix B includes a worksheet for recording these readings. You will discover that the highest and most representative reading of the exhaust gas temperature differential will be approximately 12-16" away from the seal on the exhaust housing and in the spot about 2/3 up the drum cylinder, because the exhaust gases and steam are rising out of the drum shell. Taking readings below this point may not provide a valid reading of exit gas temperatures. Temperatures can also be affected by 'tramp air'—excess outside air being drawn down an inlet chute or around the opening of the slinger conveyor feeding the drum—so take these measurements carefully.



Side-to-Side Exit Gas Temperature Differential should be 75° or less (100° pass/fail)

Gases will always be hotter in direction of rotation. Test to see if they are 100°F or more to find worn flights.

Figure 7. **Measuring exit gas differential**

If the differential between the uphill and downhill side exit gas is greater than 100°F, flight adjustment, rotational speed adjustment, or both are indicated to improve efficiency. Using 100°F as a pass/fail metric of heat transfer efficiency is practical, valid, and noncontroversial.

Field experience has shown that closing the exit gas temperature differential to 50°F or less can save 1-2% on energy consumption, and the overall exit gas temperature will drop as you adjust the veiling effectiveness of your dryer.

Temperature profile of counter-flow dryer drying virgin aggregates

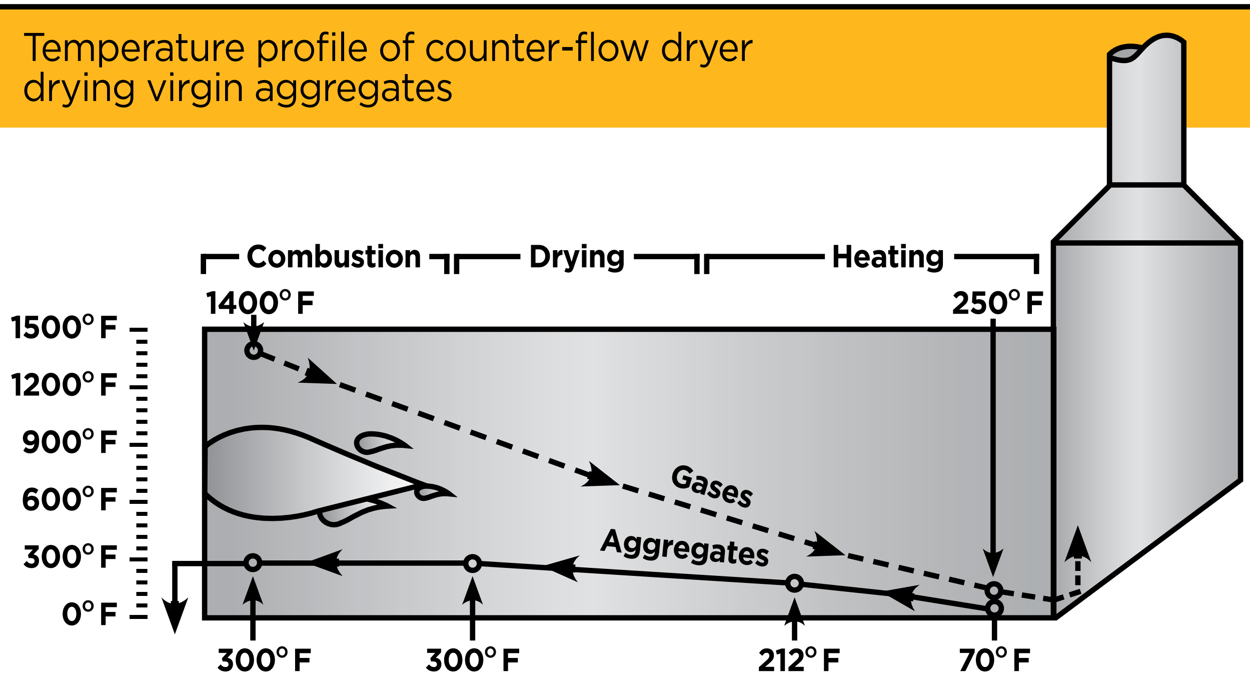


Figure 8. **Illustration of counter-flow dryer showing typical gas/material temperatures**

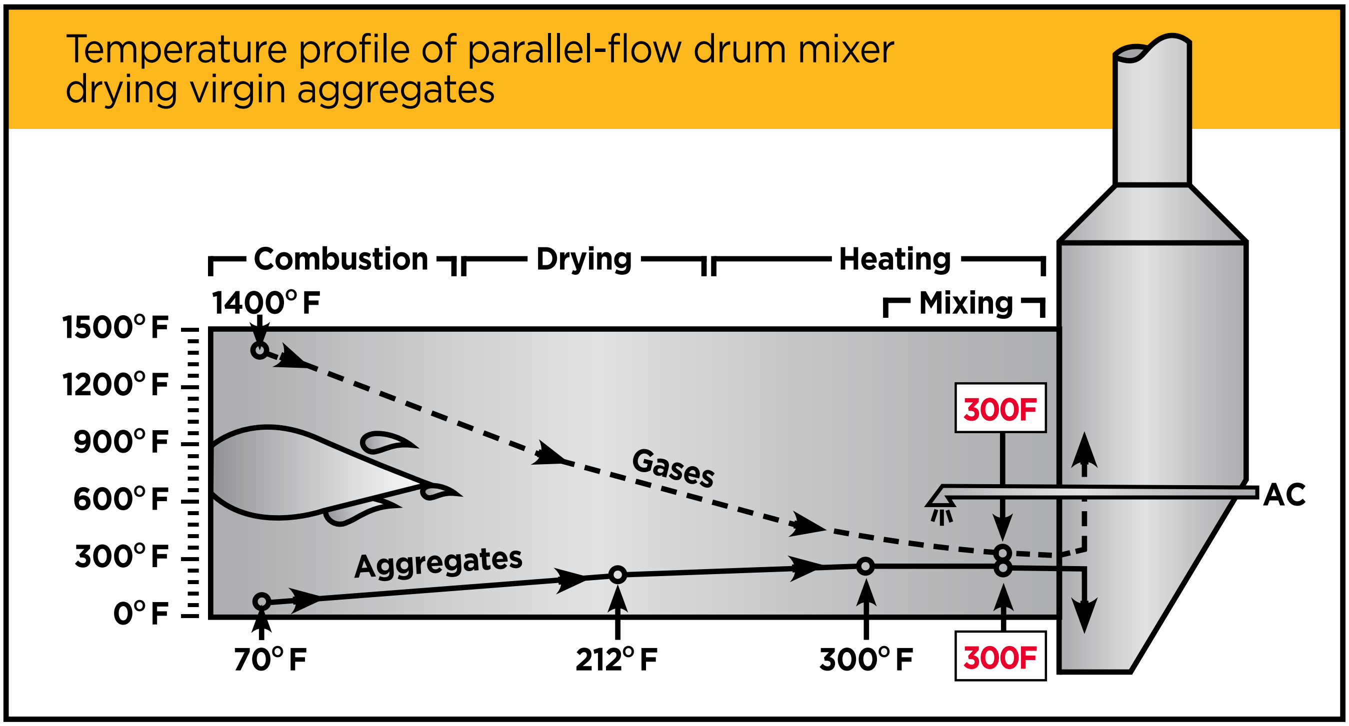


Figure 9. Illustration of parallel-flow dryer showing typical gas/material temperatures

<u>A note about efficiency differences in 'parallel-flow' and 'counter-flow' drying:</u>

An excellent discussion about the difference between parallel-flow and counter-flow drying can be found on pages 13-14 in QIP-126. The figures from this section are provided for a brief treatise.

When North American drum-mixer type continuous flow plants—those that dried, heated, and mixed in the same drying cylinder—were first developed in the 1970s, they were essentially all parallel-flow dryers. The burner was positioned on the entry end of the dryer and aggregates were dried and heated as they moved away from the burner and downward toward the mixing area. Combustion byproducts and steam from the aggregate were being drawn out of the dryer in the same direction as the flow of the aggregate, hence the term 'parallel-flow' drying. Typical batch type plants at the time had counter-flow dryers, where aggregate entered the end opposite the burner and flowed toward the burner, drying and heating as it went. Combustion byproducts and steam from the aggregate were evacuated from the dryer at the same end where the aggregate was entering. The process gas and steam flow were running 'counter' the flow of the aggregate, explaining the term counter-flow' drying.

Counter-flow dryers are inherently more energy efficient than parallel-flow dryers because the drying flights can be adjusted to use as much heat as possible from the process gas stream and steam, as long as the exit gas temperatures can keep the baghouse above 'dewpoint'—the temperature at which steam turns back into water, which hampers the effectiveness of the baghouse to keep captured and returned dust dry. Exit gas temperatures can be, and typically are, significantly lower than the dried product temperature.

On the other hand, parallel-flow dryers cannot, by their nature, have exit gas temperatures lower than final product temperatures unless there is leakage air around the dryer seals and housings artificially pulling the gas temperature down. Exit gas temperatures must be the same as the final product temperature, because the process gas is heating the material.

Parallel-flow drum mixers allowed binder introduction in the cooler end of the drum, with the gas temperature approximately at the same temperature of the final mix. This, however, released a considerable amount of hydrocarbon 'vapor' or 'fume' from the liquid asphalt binder into the process gas stream.

In the late 1980s, it was discovered that the burner could be inserted up into the main body of a counter-flow drum, RAP could be introduced in the vicinity of the burner without damaging it, and the asphalt binder could be introduced behind the burner outside of the process gas stream, which essentially starts at the point of combustion in a convective dryer. Several patents were issued on different designs, many have expired, and today most North American continuous flow drum-mix manufacturers use a variation of this design. Asphalt fume/vapor is not introduced into the process gas and exiting steam with these types of dryer designs and any hydrocarbon emissions or odors associated with mix production are drastically reduced, if not eliminated. These dryers, since they are counter-flow in configuration, are more energy efficient than their parallel-flow cousins. The difference depends on your approach to final mix temperature; for example, for a final mix at 300°F, you should be able to easily flight a counter-flow dryer for an exit gas temperature of 240°F while maintaining the baghouse above dewpoint and realize a 6% fuel savings over operating a parallel-flow plant with an exit gas of 300°F, which is the lowest a parallel-flow aggregate dryer can be with a 300°F final product temperature. (Every 10°F exit gas reduction results in a 1% BTU reduction as noted previously, thus 60° exit gas reduction indicates a 6% fuel savings.)

Operating a counter-flow drum mixer will be more energy efficient than operating a parallel-flow drum design because the exit gasses will be lower, indicating more effective convective heat transfer and use of the BTUs available in the fuel.

Insulating the Dryer Shell

Studies show that insulating the dryer shell can reduce overall BTU consumption by 5-10%. Multiple contractor case studies have demonstrated a 7% fuel reduction AFTER the dryer flights have been improved for efficiency.

How to Achieve

Several commercial insulation companies specialize in insulating drying kilns. Special insulation is required as shell can be excessive, especially when running high percentages of RAP. Ceramic fiber insulation is typically used. Reach out to these kiln insulation companies or contact one of the dryer manufacturers for suggestions. They may be able to provide a kit for your drum. DO NOT insulate a dryer shell until you have made dryer flight adjustments to get your dryer shell temperature as low as possible, as shell warpage can occur if you 'hold' this elevated temperature below shell insulation. Contact dryer manufacturer first. Adjust flights second. Insulate last.

Keeping the Dryer Burner Tuned

A universally accepted best practice is to tune burners annually at a minimum. Some firms suggest that burners be checked and tuned twice per year. Checking the state of burner tune is not difficult. Affordable exhaust gas analyzers are available that read carbon monoxide (CO), carbon dioxide (CO_2), and excess oxygen (O_2) in the system using pre-calibrated sensors—information that is required to adjust a burner. Taking measurements is as easy as drilling a hole in the exhaust duct, turning the instrument on, inserting it in the hole, and taking readings while the plant is running. When you make a burner adjustment, you can immediately see your results. Fuel savings of 3% or more are typical from simply fine-tuning your burner.

Figure 10. Example of an affordable exhaust gas analyzer

Figure 11. A burner technician measuring exhaust gases through a pre-drilled hole to ensure proper burner tuning

While taking readings to find out how efficiently your burner is operating is easy, for adjusting the burner you will want to call a burner technician or learn how to make your own adjustments by attending one of the schools offered by NAPA-member burner manufacturers. You will learn how to adjust primary air, secondary air, fuel pressure, and fuel/air ratio at different firing rates for effective operation throughout the entire firing rate of the burner.

Scan the QR code to learn about asphalt plant and other industry training opportunities. https://www.asphaltpavement.org/expertise/engineering/training-education

Using Alternate Fuels

Costs vary significantly for different fuel types, and while this may not affect the actual BTUs consumed in the drying and heating process, it will affect the overall cost of the operation, which is a primary concern in a low bid environment.

Most burners on modern mix facilities are designed to burn either gaseous fuel or liquid fuel as a standard feature, making changes from gaseous fuels to liquid fuels relatively easy—typically only the fuel manifold needs to be modified. Natural gas, liquified natural gas (LNG), propane (LPG), reclaimed fuel oil (RFO—used motor oil and other lubricating oils processed and converted into a burner fuel oil product), heavy oil (virgin refined oil of higher viscosities), and diesel fuel are all common fuel types.

From an availability standpoint, alternate fuel choices can be limited. Regionally, natural gas lines, LNG terminals, and refined heavy oils may be limited in supply. RFO is typically available everywhere, and the mix production industry is a significant user of this type of fuel. Portable plants that move from remote rural project to remote rural project typically burn liquid type fuels, primarily RFO when available.

The most common types of fuels used currently, by order of preference and overall cost per BTU, are natural gas, RFO, LNG, Bunker C or No. 6 oil (both refined heavy oils), and diesel fuel. There are a few plants located in close proximity to coal sources (adjacent to power plants or large industrial boilers using coal) that have been fitted with coal grinders and special burners that can burn coal, but they are relatively rare. Plants co-firing on landfill gas (methane) together with another fossil fuel are sometimes found when plants are located adjacent to large landfills, but are also relatively rare. The mix production industry has put a great deal of effort into using alternate fuels, and in some cases environmentally positive fuels, in its goal to lower drying costs.

From a cost standpoint, natural gas typically has the lowest cost per BTU, and is the fuel type of preference, but natural gas is not available in all markets, and even if it is, the plant facility is often not located close to a gas pipeline; the capital investment required to establish a gas line to the plant can be cost-prohibitive. Dryers fired with RFO typically are the next most desirable from a cost standpoint, and in some locales the price and availability of RFO can competitively challenge natural gas. As already mentioned, portable plants typically are fired with liquid fuels, but in some locales the price and availability of LNG, LPG, or even butane may be competitive with liquid fuels.

Essentially, the quantity of BTUs required for a given set of field conditions remains the same for any fuel type, but gaseous and liquid fuels are sold by different types of units (gallons, cubic feet, etc.) and have different BTU values per unit of sale. Once adequate supply availability is established, comparing optional fuel types is just a matter of comparing the cost per BTU for the different type fuels. Since there is often a capital cost associated with switching fuels (installing a natural gas ‘train’ or adding RFO tanks and pumps, for instance), you can establish the payback associated with switching to that alternate fuel by calculating the fuel cost savings per ton and the number of tons required to pay for those savings.

While there are slight differences in the effective heat values of different types of fuels (RFO creates a higher radiant heat value than LNG, for instance), the industry generally regards a BTU as a BTU for the drying and heating process, so calculating fuel cost savings is generally accomplished simply by comparing the cost per BTU for different fuel types.

QIP-126 includes a simple table for comparing the savings potential using different fuels, adjusting unit prices for the BTU equivalents. Appendix D provides these tables for simplified comparison. From an emissions standpoint, all fuels can be adjusted to burn effectively and efficiently.

What We Have Learned About Dryer Efficiency Since Originally Publishing QIP-126

Using the energy models previously referenced and creating a metric to analyze plant performance of actual fuel consumption against theoretical consumption based on these models (which allows multiple plants to be compared against each other even though moisture removal and final mix temperature vary), we have discovered the following things.

The Effect of Multiple Starts and Stops on Energy Consumption

Plants that start and stop more than three times in a given shift see their actual fuel consumption rise by 20-35% compared to theoretical ‘steady run’ requirements, depending on the number of starts and stops and the timeframe between these starts and stops.

The requirement for starts and stops can be the result of inadequate project planning forcing the plant to restart multiple times, lack of proper truck planning (resulting in all projects and trucks trying to ship at the same time and putting a truck gap in the return trips and forcing a plant shutdown when the silos are full), not having enough silo storage to remain in continuous production as the trucks get out of sequence for the return trips, interruptions of the paving process due to equipment breakdown in the field, interruptions in return truck flow due to traffic problems, or the lack of the production planning by the plant operator as they view the day's requirements. Guidance could be written on this topic in itself... but contractors that have created metrics to track actual vs. theoretical fuel requirements have discovered this fact as they dig deeper into why some plants burn more fuel than they should. This suggests that tracking the number of starts and stops per day is valuable.

The Effect of Running at Reduced Rates to Energy Efficiency

Generally, the industry installs larger plants than are required for average day-to-day operations. There are good reasons for this.

- If upset conditions arise due to scheduling problems, return truck flow, or field equipment problems, this gives the plant an opportunity to catch up quickly and restore field productivity.
- If scheduling forces the plant to start up early and 'silo-up' product so multiple crews can have mix shipped to them at the same time, having increased production capacity and multiple silos is useful and allows these silos to be recharged at high rates to accommodate the paving speed of all the crews.
- The competitive bidding environment forces the contractor to have increased production capability a few days per season for those jobs where they can make good daily production. The producer with the capability to produce and pave at a higher rate while maintaining mix and paving quality typically wins that bid.
- Larger plants allow a producer to maintain desired production in high moisture conditions (during the rainy season or after an intense rain event) as dryer diameter, burner size, exhaust fan size, and dust collector size all affect drying and heating capability—every 1% additional moisture requires an additional 10-12% BTUs and 13-14% airflow (see IS-52 and TAS-22).

All these factors put competitive pressure on the producer to have larger plants and more silos than are typically required on an average day.

Producers that closely track their actual BTU consumption against theoretical requirements have discovered that operating a dryer significantly below rated capacity pushes BTU consumption up about 10% because the convective drying process becomes less efficient than filling the dryer to its rated capacity.

While there is no published data on this point, many NAPA members have discovered it as they have worked to make their operations as efficient as possible. One can conduct an experiment on this point. If you have adequate silo storage, and when project and traffic conditions allow, run the plant close to rated capacity for an extended period of time, filling the silos and recording the BTUs consumed. Make sure there are no starts and stops in the run. Do the same on a day running at two-thirds of rated capacity (which is normal for our industry). Again, make sure there are no starts and stops in the run. Compare the BTUs per ton against the theoretical requirements for the moisture removal and final mix temperature of the runs. You should notice that the BTUs per ton required for the full-capacity run are lower.

There are a lot of opinions on why this is: BTUs lost due to excess air being heated and not effectively used in the heat transfer process, the relative loss of more heat to the drying shell and duct, or the slightly higher exhaust gas temperature compared to running with a full veil in the dryer. Variable speed motors on the drying drum might mitigate some of these discrepancies as the cross-sectional veil of the aggregate in the dryer can be adjusted for the moisture removed and production rate. This phenomenon suggests that tracking the run rate against the BTUs consumed in addition to moisture removed and final temperature is not a bad idea. For producers attempting to tighten their performance as much as possible, being aware of this possibility is helpful.

Because of this variance, some have suggested always trying to run the plant close to capacity. While this is a logical idea, it requires that all jobs know exactly how many tons they will take each day, one has enough silos for the different mixes required for that day, no traffic interruptions happen and trucks cycle back according to plan, and everything runs according to plan in the field. Having all those factors line up perfectly is unlikely, which means that starts and stops are likely in the real world, thus choosing an 8-10% BTU penalty from not running the plant to rated capacity is preferable over facing a 20-35% penalty due to multiple starts on stops. Recording the number of starts and stops in a given shift is a good metric to track, and working to minimize that number is a worthy objective.

As we continue to track plant performance metrics in actual vs. theoretical BTUs, we will undoubtedly learn even more about minimizing energy consumption. Tracking the factors that can negatively impact energy consumption is logical.

Opportunities Related to Maintaining Adequate Storage Temperatures

Since the characteristics of asphalt binder allow it to flow and pump at elevated temperatures yet become rigid at ambient temperatures—therefore making it an excellent binder material—we find ourselves needing to store these binder materials at elevated, pumpable temperatures.

A significant amount of energy is consumed keeping liquid asphalt tanks at usable storage temperatures, keeping asphalt transfer pipes hot so liquid asphalt does not cool appreciably en route to the mixing area, keeping asphalt pumps at operating temperatures, keeping the mixing area of the plant warm, and keeping the final product transfer conveyors and storage silos at usable temperatures. Heat transfer oil is typically used for this purpose, although other systems exist. This oil is typically heated and pumped around the asphalt lines and pumps;

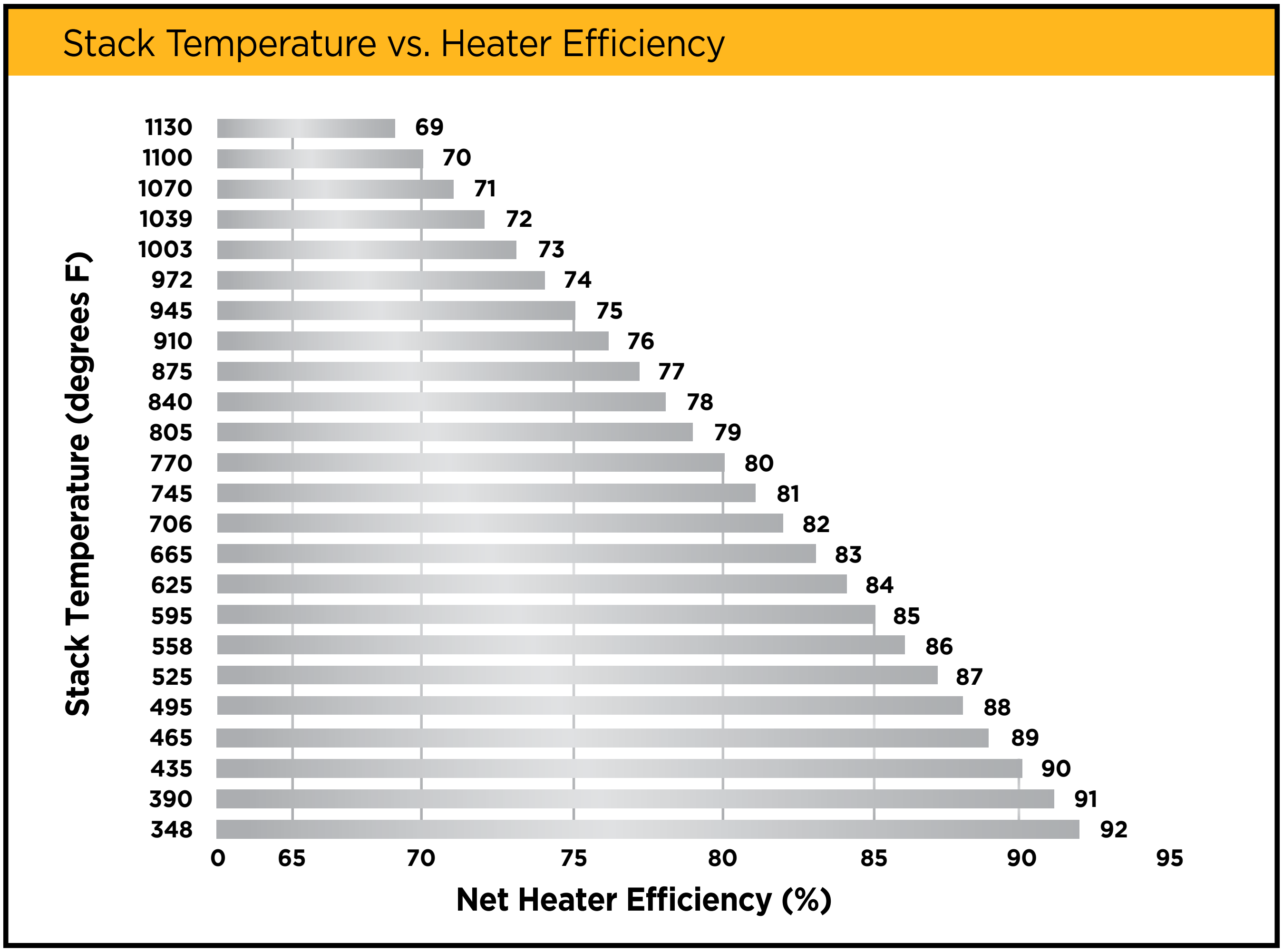


Figure 12. Simplified chart correlating heater efficiency to exhaust gas temperatures (courtesy Astec)

Table 3. **Effect of hot-oil heater efficiency on costs for No. 2 fuel oil, assuming a heating requirement of 1,000,000 BTU/hr** (courtesy Astec)

Heater Efficiency	Cost Per Hour
50 Percent	$\frac{1,000,000 \text{ BTU per hour}}{132,000 \text{ BTU per gallon}} \text{ X } \frac{1}{0.50} \text{ X } \$1.00 = \$15.15$
60 Percent	$\frac{1,000,000 \text{ BTU per hour}}{132,000 \text{ BTU per gallon}} \text{ X } \frac{1}{0.60} \text{ X } \$1.00 = \$12.63$
70 Percent	$\frac{1,000,000 \text{ BTU per hour}}{132,000 \text{ BTU per gallon}} \text{ X } \frac{1}{0.70} \text{ X } \$1.00 = \$10.82$
80 Percent	$\frac{1,000,000 \text{ BTU per hour}}{132,000 \text{ BTU per gallon}} \text{ X } \frac{1}{0.80} \text{ X } \$1.00 = \$9.47$
85 Percent	$\frac{1,000,000 \text{ BTU per hour}}{132,000 \text{ BTU per gallon}} \text{ X } \frac{1}{0.85} \text{ X } \$1.00 = \$8.91$

Heating load = 1,000,000 BTU per hour. No. 2 fuel oil LHV (low heating value) = 132,000 BTU/gallon. No. 2 fuel oil cost = $1.00 per gallon

coiled pipes that contain this fluid are used inside the asphalt tanks, mixing area, transfer conveyors, and storage silos to keep the asphalt tanks and plant equipment at proper temperature.

The information in QIP-126 in this area remains valid; the key points to focus on when judging thermal efficiency and looking at energy conservation and cost-saving opportunities, detailed as follows, likewise remain the same. Some of the key Illustrations, charts, and tables from QIP-126 are included, and we've added new appendices to function as a quick field guide for finding your conservation and cost-saving opportunities.

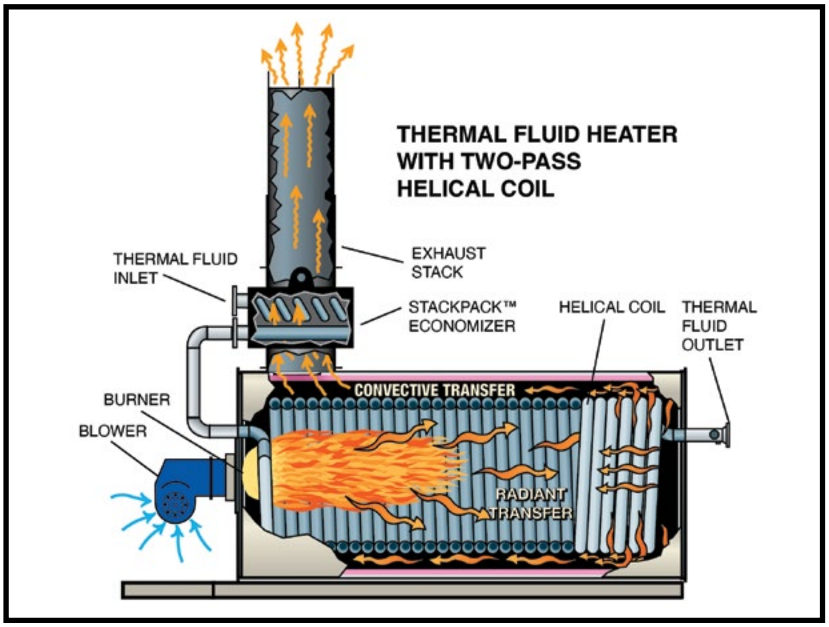


Figure 13. **Cutaway drawing of hot-oil heater** (courtesy Astec)

Hot Oil Heater Design

Hot oil heaters produced in the last 20-30 years are more efficient than older styles, with a longer heat transfer chamber and better insulation. They transfer the energy from the fossil fuel fired burner into the heat transfer liquid (used to heat the asphalt tanks, pipes, pumps, mixing area, slat conveyors, and storage silos) more effectively. This effectiveness can easily be judged by measuring the exit gas temperature of the heater, illustrated in Figure 12. Most modern heaters perform at close to 90% efficiency. Many heaters have preheaters installed in the exhaust stack where the return hot oil from the plant is first run through these preheater coils, capturing as much of the exit gas heat as possible, before circulating down to the heat chamber of the heater. These preheaters help lower the exhaust temperature even more and make the whole system more energy efficient. Older heaters with excessively high gas temperatures should be replaced. Table 3 illustrates both the BTU-saving potential and the cost-saving potential of a more effective heater, using $1.00 per gallon as a benchmark. Simply multiply the current cost of diesel fuel by the values in Table 4 to obtain the cost-saving potential of converting to a more effective heater.

Figure 14. **Hot-oil heater** (courtesy Astec)

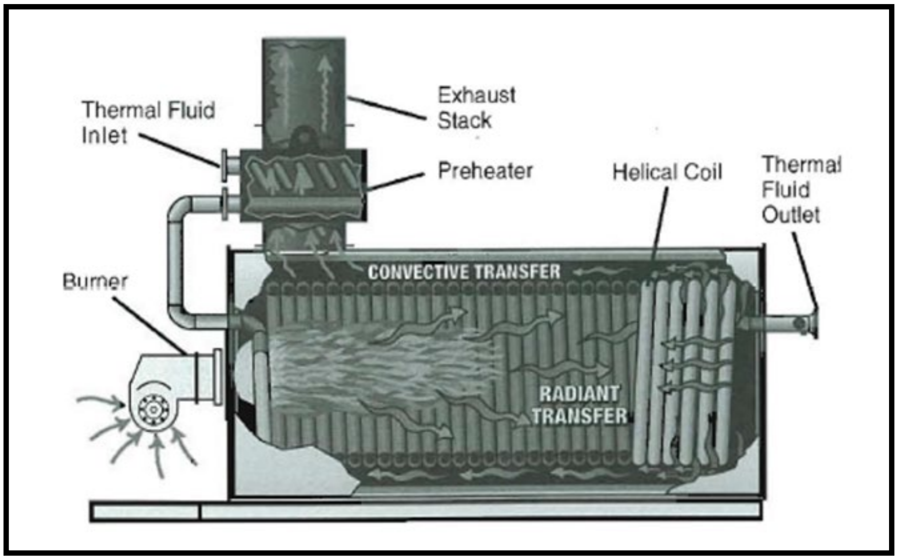


Figure 15. **Cutaway illustration of 2-pass helical coil style hot-oil heater** (courtesy Astec)

Alternate Fuels for Hot Oil Heaters

Like aggregate dryers, the burners on hot oil heaters can typically burn other fuels. A gas/oil burner is common. If natural gas is available, it is usually less expensive than diesel fuel. By comparing the cost per BTU of natural gas to the cost per BTU of diesel fuel, you can easily calculate fuel savings potential.

If propane is a cost-effective alternate fuel per BTU, you can explore (a) installing a vaporizer on the propane system so the propane is burned as a gas in your existing burner or (b) changing to a propane fired burner. Compared to the burners for the aggregate dryer, these burners are not expensive. The payback for a new burner could be rapid.

RFO and heavier fuel oils are typically not burned in these types of burners. Natural gas is the favored fuel if it is available because it is typically less expensive per BTU and provides more trouble-free combustion.

Combustion Efficiency of Hot Oil Heaters

Like the burners on aggregate dryers, the burner of the hot oil heater should be checked for combustion efficiency at least annually. Twice per year is a good idea.

The burners on hot oil heaters typically burn very efficiently. Very low CO levels (typically less than 100 PPM or parts per million) at oxygen levels below 7% are normal. If your burner does not yield numbers in these areas, the burner needs attention. Like an aggregate dryer, you will either call a burner technician for this service or attend one of the burner manufacturer's schools to learn how to do this yourself.

The same type of exhaust gas analyzer used in checking the combustion efficiency of an aggregate dryer burner is used for a hot oil heater. Measurements are typically taken in the exhaust stack. These burners cycle on and off, so you want to take the readings after the burner starts and moves to 'high fire' and has a chance to stabilize, which only takes a few seconds.

Since most hot oil burners burn very efficiently, the focus here is on thermal efficiency.

Figure 16. Hot-oil heat exchanger added to heater exhaust stack (courtesy Astec)

Figure 17. Electrically heated hot-oil heater (courtesy Astec)

Electrically Heated Hot Oil Systems and Electrically Heated Tanks

There are several reasons to consider electrically heated hot oil systems, as well as electrically heated tanks. Absolutely no fossil fuels are burned at the plant facility. They are generally more trouble-free. They do not require annual or bi-annual tuning. Their operation may, however, be more expensive depending on the local cost of a kWh and the demand or 'power factor' charge being assigned to the plant facility. (Electrical costs are covered in the next section.)

The adjacent figures show an electrically heated hot oil heater (Figure 17) and an electrically heated horizontal asphalt storage tank (Figure 18). Vertical asphalt storage tanks are heated similarly.

Often electric heat is used on the plant equipment components instead of hot oil heat, which eliminates running hot oil lines and simplifies plant layout. Electrical heat is commonly used on silo cones and discharge gates, and often on the slat conveyors feeding the silos or the transfer conveyors on top of the silos.

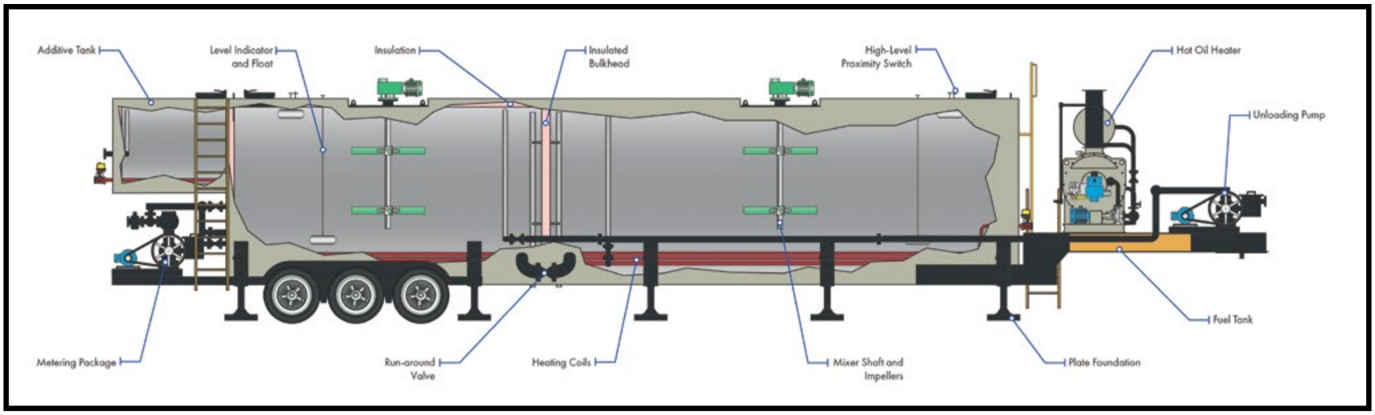


Figure 18. Illustration of heated asphalt tank (courtesy Astec)

Direct-Fired Tanks

Direct-fired tanks (Figure 19) have burners fitted directly inside them. A refractory lined combustion chamber is installed in the tank and the exhaust gases from burner exit through a lengthy exhaust pipe installed in the tank.

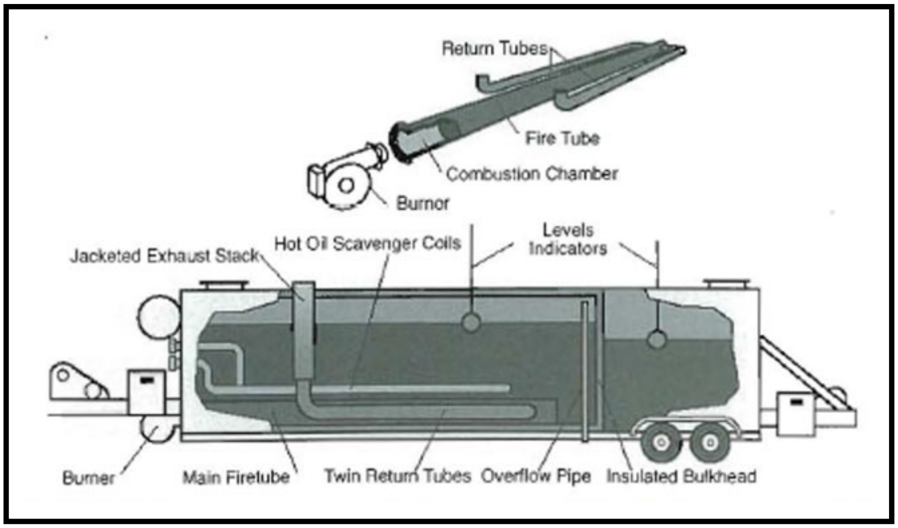


Figure 19. Schematic of direct-fired asphalt tank (courtesy Astec)

Although most of these tanks are portable, horizontal and vertical stationary models exist.

The exit gas temperatures of these tanks are usually very low, while combustion efficiency, due to the lengthy combustion chamber, is very good.

Thermal Efficiency of the Storage Tanks and Plant Equipment

Thermal efficiency of the tank system and plant equipment is judged by these factors:

- For fossil fuel fired hot oil heaters, the efficient transfer of heat from burning the fuel by looking at the exhaust gas temperature of the stack.
- The number of BTUs consumed heating the storage tanks and plant equipment. (A common metric like BTUs per 30,000 is useful for this purpose when comparing one plant facility against another. See Appendix D.)
- Measuring the surface temperature of the tanks in several places to verify the insulation is functioning correctly. (Surface temperature should be below 100°F but can be affected by the radiant heat of the sun, especially if the tanks are painted black to take advantage of this solar energy.)
- Measuring the surface temperature of the heated plant equipment to make sure it has adequate insulation.
- Measuring the surface temperature of the insulated asphalt pipes and hot oil lines to make sure that insulation is functioning correctly.
- Making sure all asphalt pipes, hot oil lines, valves, and exposed steel inspection doors are insulated. Failure to do this will require extra BTUs/kWh to replace heat loss to atmosphere.
- Monitoring inlet oil temperatures and exit oil temperatures for each tank and plant component as an indication of the heat transfer oil functioning. No temperature drop, together with a loss of storage temperature, indicates that piece of equipment has buildup around the heating elements, insulating them and rendering them ineffective.

Appendix D includes a useful field guide for taking these measurements and suggests a metric for comparing plants to a common value.

Tanks and plant equipment should be inspected internally on an annual basis to ensure that buildup around the heating elements is not rendering the heat transfer system ineffective. An indication of this is significant temperature loss to stored asphalt binder when the plant is not operating (for example, over a weekend). If the tanks are electrically heated, you might find kilowatt consumption high while struggling to keep the tanks hot. Monitoring each tank's actual temperature to set point is useful. If your hot oil system for the tanks cycles based on return hot oil temperature, you may find the hot oil heater rarely runs but the tanks still lose heat.

Since you cannot view inside tanks or plant equipment without emptying it and opening it up, learn to identify efficiency signals by monitoring different metrics in your operation.

Effective Insulation for Pipes and Valves

Heat loss is significant for exposed pipes, valves, pumps, and solid steel inspection doors on asphalt tanks. Unfortunately, most asphalt plant facilities have some uninsulated components, often the result of needed repairs and pressure to get back on-line that cause operators to postpone replacing insulation. New priorities push insulation repair to the back burner. Most plants can use some improvement in this area.

Insulating pipes, valves, pumps, and other exposed surfaces has one of the most rapid payback periods of any other plant improvement. Sometimes it can be measured in weeks.

Crushed insulation (stepping on pipes?) is evidenced with higher skin temperatures than the 80°F that is typical for a properly insulated set of pipes, valves, and pumps.

Inspection and analysis require simply taking temperatures with a reliable infrared thermometer. Thermal cameras are also useful and have come down drastically in price.

Outside commercial insulation firms will perform a thermal audit on your piping and tank system and provide you with a quote to improve your insulation.

Table 4 and Appendix D allow you to calculate the potential BTU savings you can realize from improving insulation.

Table 4. Theoretical energy losses from un-insulated and insulated pipe (courtesy Astec)

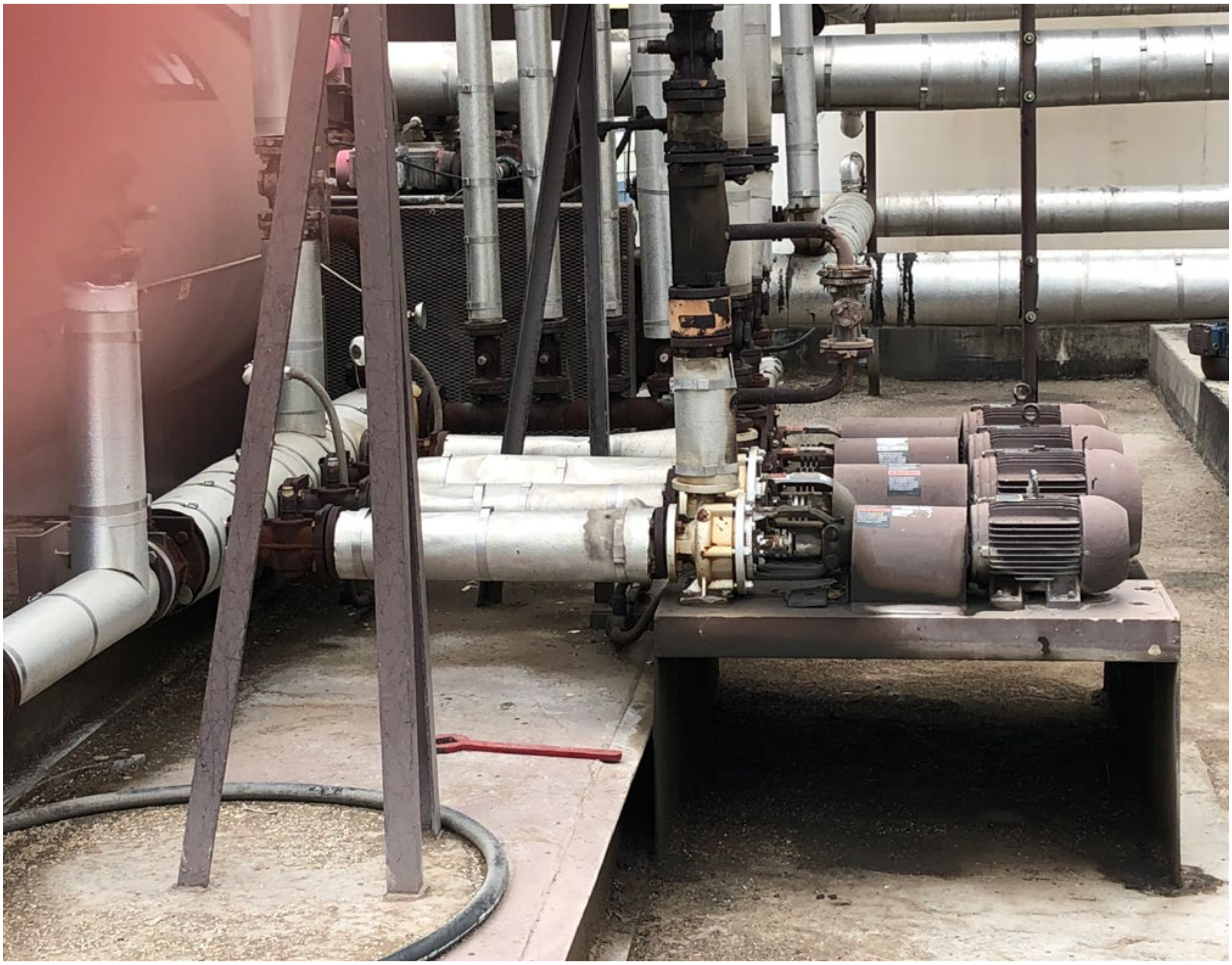
Jacketed Asphalt Piping					
Asphalt Pipe Nominal Size	Hot-Oil Jacket Nominal Size	Loss Per Linear Foot BTU Per Hour		Loss Per Flange BTU Per Hour	
		Un-insulated Jacket	Insulated Jacket	Un-insulated	Insulated
3 inches	4 inches	1598	86	1890	120
4 inches	6 inches	2349	122	2600	134
5 inches	8 inches	3057	148	3240	178

Hot Oil Piping				
Pipe Diameter	Loss Per Linear Foot BTU Per Hour		Loss Per Flange BTU Per Hour	
	Un-insulated	Insulated	Un-insulated	Insulated
1-1/2 inches	676	47	1205	97
2 inches	846	54	1660	115
2-1/2 inches	1024	55	2155	125
3 inches	1243	72	2485	130

Asphalt temperature = 300° F. Hot-oil temperature = 350° F. Pipe insulation = 1-1/2 inches.

Table 5. **Recommended pipe insulation thickness** (from Astec T-140 and *Thermal Insulation Handbook* by Turner and Malloy)

Insulation Thickness for Various Operating Temperatures						
Pipe Diameter	**150°F**	**200°F**	**300°F**	**400°F**	**500°F**	**600°F**
1 inch	1 inch	1 inch	1 inch	1-½ inches	1-½ inches	2 inches
1-¼ inches	1 inch	1 inch	1 inch	1-½ inches	1-½ inches	2 inches
1-½ inches	1 inch	1 inch	1 inch	1-½ inches	2 inches	2 inches
2 inches	1 inch	1 inch	1 inch	1-½ inches	2 inches	2-½ inches
3 inches	1 inch	1 inch	1 inch	1-½ inches	2 inches	2-½ inches
3-½ inches	1 inch	1 inch	1 inch	1-½ inches	2 inches	2-½ inches
4 inches	1 inch	1 inch	1 inch	1-½ inches	2 inches	2-½ inches
5 inches	1 inch	1 inch	1 inch	1-½ inches	2-½ inches	2-½ inches
6 inches	1-½ inches	1-½ inches	1-½ inches	2 inches	2-½ inches	3 inches
8 inches	1-½ inches	1-½ inches	1-½ inches	2 inches	2-½ inches	3 inches



Opportunities Related to Reducing Electrical Energy Use

There are two cost charges associated with electrical energy consumption. One is for every kilowatt (kW) of electrical energy used or consumed. The industry typically refers to this as the ‘use charge.’ Another charge, established for the maximum amount of electrical energy you *might* need for the plant facility on any given shift, goes by different names, but the industry typically refers to this as a ‘demand’ or ‘power factor’ charge.

To complicate things, every utility seems to have different names for these two charges, along with different billing formats. There can also be a sliding scale of both the ‘use’ rate and the ‘demand’ rate depending on the time of day or season. Some utilities, particularly in northern climates, charge a penalty if you start up the plant before an agreed upon time, ostensibly to save the power demand on their grid during the winter season.

Electrical charges can also vary widely within a geographic region. When you move from one utility to another, even a few miles away, you can find different rates in both kW use and demand rates.

For these reasons, it can be difficult to compare electrical costs between plants. You may have to sit down with the rate personnel for your utility, but rest assured that somewhere in your utility bill both of these rate calculations exist. You may also find that your utility links the two rates; if you reduce your overall potential peak demand, you may have a different kW use rate. Similarly, heavy kW users may be charged a higher use rate because of their excess demand on the system.

Demand charges are calculated in several different ways. The utility may perform an annual audit, where they bring equipment and connect it to your system. They may just monitor use remotely, and when use rises above a certain amount, your operation triggers an additional charge. It makes sense from a utility’s standpoint to charge for potential demand. They are essentially reserving capacity on their grid if you run your plant at full capacity. If everyone on the grid ran their plants at full capacity at the same time, it could overtax the system, forcing the utility to buy energy from the grid they are connected to for the extra kilowatts (at higher rates than it costs them to produce) or force them to make decisions on who they will take offline. Someone has to pay for holding that power capacity in reserve.

The following electrical energy conservation ideas fall into two areas: one that reduces actual kilowatt use when the plant runs and another reducing the demand charge. If equipment or operating practices can be put in place that reduce peak demand, then the demand or power factor charge can be minimized. When auditing your facilities, you will notice that this charge is significant. Opening a dialogue with your utility is paramount as you explore reducing your energy requirements. Your plant and utility both benefit from such a discussion and implementing the ideas outlined in this section. The utility may even be interested in helping pay for some of the equipment that will reduce both kilowatt consumption and overall demand.

Ways to Reduce Peak Load, Peak Demand, and Demand Charges

Sequencing Motor Starts

Electrical motors surge when they start. They consume a tremendous amount of power initially, then settle down to less kilowatt consumption as they run. Simply starting large motors one at a time by waiting 10-15 seconds before starting the next large motor in sequence will reduce the overall amp draw on the system.

Minimizing Hot Starts

As you can imagine, 'hot stops' and 'hot starts'—also called system stops and system starts or mid-stream stops and mid-stream starts—are extremely hard on peak demand because a hot start initiates all plant motors at once. Some operators find it more convenient to hot stop and hot start a plant than sequentially shutting it down and sequentially restarting it when silos are full and trucks haven't made it back to the plant to empty them so they can run continuously. The most common reason for this practice is that it protects the integrity of the mix (no waste on out-of-spec mix or cleaning the plant out and recharging it). However, this practice can have a seriously negative impact on your demand charge, resulting in a permanent ongoing expense as your demand charge is raised.

Realistically, emergency shutdowns are occasionally required, but it doesn't mean that a hot start is required. If the plant has to shut down for an emergency, it can be emptied out sequentially by turning on only the silo feed or batch tower feed conveyor first and then the drum to empty the plant. Exploring the impact of one or more of these events on your demand charge each month is worth the exercise. It is likely that your demand charge or power factor charge has already been impacted by this. Your utility should be able to help you calculate the cost already incurred, or the potential cost savings of establishing a policy to limit these type of restarts. This estimate might be easy to establish by creating a short-term policy of eliminating hot starts and employing other ideas outlined in this section as you partner with your utility to monitor your power factor over a specified period (say, two to three months). A new demand charge could theoretically be calculated.

Power Factor Reducing Capacitors

A 'power factor reducing capacitor' is an old-school way of reducing the power required to bring the plant online. They are typically added to the large motors only.

Power factor reducing capacitors use capacitors added to the circuitry to draw some of the energy off the motor circuit and charge the capacitor as the motor is running. When the motor is started, it drains the stored energy in the capacitor before using utility power, reducing the surge of power required on restart. Consequently, this reduces the demand charge imposed by the utility since it is seeing a lower spike in power required to bring the motor online.

With the reduction in cost for 'soft starts' and VFDs (variable frequency drives), which can be configured for soft start characteristics, power factor reducing capacitors have fallen into less common usage. They are mentioned here to be thorough in our discussion and because they are still available.

Soft Starts

A 'soft start' is a type of motor starter that reduces the amount of power consumed when the motor comes online, which also reduces the momentary power required from the utility. Since they are expensive, they are typically only applied to larger motors. It is easy to see how soft starts, in addition to the delayed sequencing of bringing the plant motors online, would reduce the surge in power the utility records and therefore also reduce the demand charge.

Variable Frequency Drives

VFDs replace traditional motor starters, reduced voltage starters, and soft starts as a motor starter but have the additional advantage of turning a constant speed motor into a variable speed motor. In recent years, prices have fallen dramatically and VFDs have become extremely popular because they reduce power consumption and are easier on the equipment. If modulation is required, most engineers now look at a VFD on the drive motor to see if it is cost-beneficial to apply.

VFDs on cold feed and RAP feed bin motors were an easy decision. Varying the speed of the motor to achieve different flow rates was simpler, less expensive, and more trouble-free than trying to achieve flow rate differences with variable speed transmissions for the feeder belt or motorized gates on the bin openings. As prices have plummeted, the industry has added VFDs to:

- exhaust fans to replace motorized dampers to regulate exhaust gas air flow,
- burner blowers to replace motorized dampers to regulate the intake air for the burners,
- dryers to change rotational speed and improve veiling efficiency and reduce drying costs, and
- slat conveyors to lower costs by improving the wear life of the chain and slats.

VFDs can be adjusted to ramp motors up slowly, reducing power consumption on startup just like soft starts and obtaining the same net effect as power factor reducing capacitors, thereby reducing demand charge calculations. They also reduce overall power usage during operation. It is not uncommon for power companies and utilities to participate in the cost of their installation because the power company also benefits from their use; essentially their existing power grid can serve more customers.

It is wise to reach out to the power company and let their engineers assist in a power evaluation of your facility. They can help quantify your cost-saving potential and may have grants and rebates to defray some of the costs associated with converting to new equipment.

Ways to Reduce Kilowatt Consumption and Use Charges

More on VFDs – Their Benefit in Reducing Power Consumption

VFDs help in reducing costs in two ways: by reducing the power surge used by motors on startup, thereby reducing demand charges, and by reducing overall power consumption during operation, reducing kilowatt use. Although this will vary by utility, this last point is probably the most significant for any given operation.

VFDs help in reducing power use by varying the speed of the applied motor instead of restricting output by installing a mechanic damper or flow adjuster—you are not ‘holding back’ the force delivered by the motor, instead using only the power necessary.

The best illustration of this is probably the exhaust fan on the plant. Fans are applied for maximum required flow. The research conducted for NAPA’s IS-52 in the 1970s not only taught us that every 1% moisture change resulted in a 10% BTU savings, but also that every 1% moisture change is associated with a 12-13% air flow savings or penalty depending on which way the moisture moved. Due to drastic field variables day to day, most plants run between one-half and two-thirds speed while fans run one-half to two-thirds capacity. Fans must be designed and applied for wettest theoretical conditions and maximum tph rates, which is why you typically find large horsepower applied to the exhaust fans (100–400 HP is typical). At 'normal' moistures and lower throughput rates, only about 50% of that power is required.

Fans were historically designed with mechanical dampers on the fan connected to motorized actuators to restrict flow. The fan was turned at 100% required speed for the maximum design conditions and restricted by closing off the outlet putting backpressure on the fan, adding load to the fan wheel. By installing a VFD on the fan motor(s), the fan starts slowly and turns only to the amount required for the required air flow and no backpressure exists. Since plants typically do not operate at maximum moisture removal or maximum rated capacity, this significantly reduces the power required, reducing kilowatt use.

Table 6 allows you to quickly estimate payback for converting from a constant speed motor with damper to a VFD application. Payback will not be as rapid if the motor is running near 100% speed.

Additional Benefits of VFD Applications

- The stress on motors, gearboxes, and bearings is less, causing these mechanical components to last longer and be more trouble-free.
- Sprockets, chains, and slats that wear out primarily from rotation/articulation last longer as they do not articulate as much—the result being less interface between moving wear parts.
- VFDs applied to dryer rotation, along with flights that function at variable speeds, help reduce drying costs and increase RAP capability through more effective heat transfer.
- Ambient noise, especially from fans and blowers, around the plant is reduced. VFDs are commonly used on exhaust fans, burner fans, asphalt pumps, additive pumps, cold feed bins, RAP bins, slat conveyors, bucket elevators, transfer conveyors, and dryers. As the price of VFDs continues to fall, more applications for VFDs in the production process will arise.

Table 6. Annual theoretical savings using VFD on exhaust fan vs. damper to control air volume
Chart is per 100 hp and assumes fan is operating at 60% air volume, which is typical.

	Annual Hours of Operation					
$ KWH	**500**	**1000**	**1500**	**2000**	**2500**	**3000**
$.05	**$1,175**	**$2,350**	**$3,525**	**$4,700**	**$5,875**	**$7,050**
$.06	**$1,410**	**$2,820**	**$4,230**	**$5,640**	**$7,050**	**$8,550**
$.07	**$1,645**	**$3,290**	**$4,935**	**$6,580**	**$8,225**	**$9,870**
$.08	**$1,880**	**$3,760**	**$5,640**	**$7,520**	**$9,400**	**$11,280**
$.09	**$2,115**	**$4,230**	**$6,345**	**$8,460**	**$10,575**	**$12,690**
$.10	**$2,350**	**$4,700**	**$7,050**	**$9,400**	**$11,750**	**$14,100**
$.11	**$2,585**	**$5,170**	**$7,755**	**$10,340**	**$12,925**	**$15,510**
$.12	**$2,820**	**$5,640**	**$8,460**	**$11,280**	**$14,100**	**$16,920**
$.13	**$3,055**	**$6,110**	**$9,165**	**$12,200**	**$15,275**	**$18,330**
$.14	**$3,290**	**$6,580**	**$9,870**	**$13,160**	**$16,450**	**$19,740**
$.15	**$3,525**	**$7,050**	**$10,575**	**$14,100**	**$17,625**	**$21,150**

For a 150 hp fan, multiply numbers by 1.5; for a 200 hp fan, multiply by 2.0; for a 300 hp fan, multiply by 3.0; etc.
Fans operating at 90-100% air volume will not benefit appreciably with VFD application.

Other Ways to Reduce Electrical Energy Consumption in Production

- Operators typically leave loaders on to keep the enclosed cab at a comfortable temperature, but it is easy to leave the machine running for extended periods of time. Since 10% or more of the energy costs associated with a plant are associated with these machines, managing excessive run time is logical. Setting loaders to shut off automatically after 15-20 minutes of non-movement dramatically saves fuel costs and the wear and tear on engine components. Most newer machines have this capability. Consult the service department of your local dealer.
- Plant equipment not in use (like traverse conveyors and pneumatic blowers) should remain off until needed. While it is tempting to keep this equipment operational in case of an upset condition, continual operation wears it out and consumes energy.
- Lights for offices, bathrooms, warehouses, tool rooms, and parts rooms can be installed with sensors that automatically come on when someone enters the room and shut off when they leave.
- Security yard lighting can be set up on photocells to turn on automatically at dusk and turn off automatically at dawn.
- LED lights use 75-80% less energy than incandescent bulbs and can be installed in offices, warehouses, and yard security lights.

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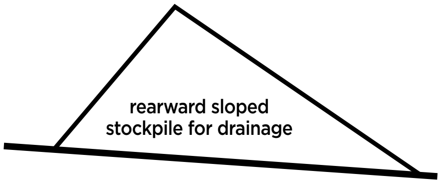
Appendix A: Stockpile Management

Energy Analysis - Stockpile Management

Plant ______________________________ **Date** ______________



Every 1% composite moisture reduction lowers fuel consumption 10% and raises tph 13%!

What are the typical moistures for materials at this site? (List by material type - moistures vary)

____

Do materials have a chance to dry before being transferred to this plant? ______________________

____

Do materials have a chance to dry on site before being fed into the dryer? ______________________

____

Are stockpile floors sloped or crowned to promote drainage? ____________________________

____

Is there an opportunity to re-slope or re-profile the stockpile floor to improve drainage? ____________

____

Would left side / right side stockpile management be useful at this site? ______________________

If so, would side walls be required to increase stockpile capacity? ________________________

If space is limited, would the installation of “French drains” be useful / possible at this site? __________

____

Are there any RAP / RAS processing techniques that would help reduce moisture during processing? _____

____

Are RAP / RAS stockpiles properly sloped to promote drainage? ___________________________

Are RAP / RAS stockpiles conically shaped and/or crowned to reduce moisture from rain/snow events? ____

____

Would covering fine materials at this site significantly reduce moisture from rain/snow events?

____

If so, which ones? ______________ What is the estimated moisture reduction? ______________

Has a test been performed to confirm this? _____ What percentage of the mix is this material? ________

Has an equipment cost / benefit analysis been done? ______ Outcome? ____________________

Other Observations / Ideas: (use back if needed)

Appendix B: Dryer Efficiency

Energy Analysis – Theoretical BTU Expectations

Target Dryer Fuel Consumption Expectations

The following charts are based on NAPA and CIMA/BAEB industry standards outlined in NAPA's *The Fundamentals of the Operation and Maintenance of the Exhaust Gas System in a Hot Mix Asphalt Facility* (IS-52) and *Applying IS-52: Performance Expectations From Your Facility* (TAS-22). These documents conclude that one cannot expect to operate a dryer more efficiently than under 25% excess air conditions (as a percent of stochiometric volume, or the perfect amount of air volume required to combust and convert fuel to useable energy). Most burner and plant manufacturers, however, use 40-50% excess air conditions when sizing and designing plant equipment. Field operating experience also shows that 50% excess air conditions provide a more practical guideline to use when establishing dryer performance expectations. Both 50% and 25% excess air charts are provided for analysis. Actual production performance should fall within these two ranges.

For fuel consumption analysis, assume:

- 138,000 BTU/gal for No. 2 fuel oil
- 142,000-145,000 BTU/gal for reclaimed and/or No. 4 fuel oil
- 1,000 BTU/CF for natural gas
- 2,500 BTU/CF for vaporized propane
- 92,000 BTU/gal for liquid propane fuels
  Or consult your fuel supplier for their declared values.

Note that fuel consumption requirements do not change with elevation, although production expectations do. One needs to move more air per tph at higher elevations to properly burn the fuel, but the fuel (BTU) requirement remains essentially unchanged.

Also note with drum-mix type plants that it is practical to simply look at total composite moistures of both the virgin aggregate and RAP when estimating BTU requirements per ton. Technically with counter-flow drum mixers, the aggregate is super-heated, then is used to heat the RAP; conductive heat transfer is not equivalent to convective heat transfer, so the fuel requirements are slightly different than with parallel-flow plants. Without knowing the RAP moisture percentage and analyzing this separately, one cannot adequately estimate the fuel consumption required to heat and dry the RAP in these type plants.

To complicate matters further, some counter-flow drum mixers add RAP to the combustion zone area of the plant, taking advantage of the conductive heat transfer from the flights and shell and the radiant heat transfer from the flame, lowering the required BTUs.

To check whether a counter-flow drum mixer is operating within expected ranges, it is practical to simply look at the combined or composite overall moisture and check it against the charts provided.

For batch plants super-heating aggregate to heat RAP, and known virgin aggregate discharge temperatures, add 2% to the BTU requirement to that shown on the chart for every additional 10° F; or calculate the combined moisture of the virgin aggregate and RAP as suggested above to arrive at an estimated BTU requirement for efficiency analysis.

Realize that frequent starts and stops raise fuel consumption 20-30% above these values. Therefore, fuel consumption should be checked only with sustained runs under known moisture and temperature conditions.

If actual fuel consumption is 5-10% more than the values shown on these charts, further investigation to the cause is warranted. It typically indicates defective combustion flights (and material dropping through the developing flame), an improperly tuned burner, worn flights, or an extremely poor flight design, in that order—once frequent starts and stops are eliminated from the analysis.

Table 1. **BTUs required (50% excess air conditions)**

		270°F	280°F	290°F	300°F	310°F	320°F
Percent Moisture	3%	207,300	211,500	215,800	220,200	224,600	229,000
	4%	233,000	237,800	242,700	247,700	252,700	257,600
	5%	259,000	264,300	269,700	275,200	280,700	286,200
	6%	284,900	290,700	296,600	302,700	308,800	314,800
	7%	310,800	317,100	323,600	330,200	336,800	343,400
	8%	336,700	343,600	350,600	357,800	365,000	372,100

BTUs required (25% excess air conditions)

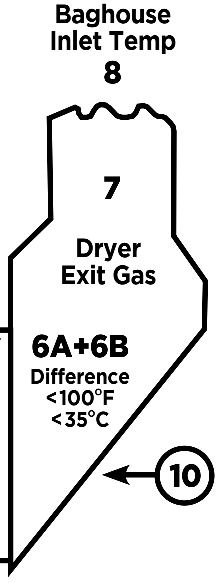
		270°F	280°F	290°F	300°F	310°F	320°F
Percent Moisture	3%	203,600	207,800	212,000	217,300	221,700	226,000
	4%	230,100	234,800	239,600	244,400	249,300	254,200
	5%	255,700	260,900	266,200	271,600	277,000	282,500
	6%	281,200	286,900	292,800	298,800	304,800	310,800
	7%	306,700	313,000	319,400	325,900	332,400	338,900
	8%	332,100	338,900	345,900	353,000	360,000	367,100

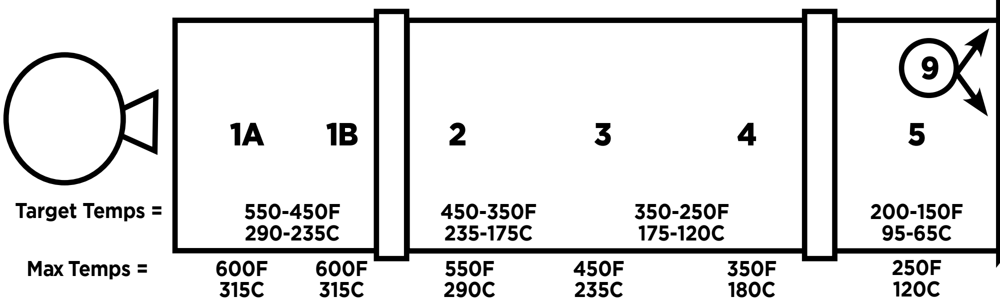
Energy Analysis - Drying Efficiency

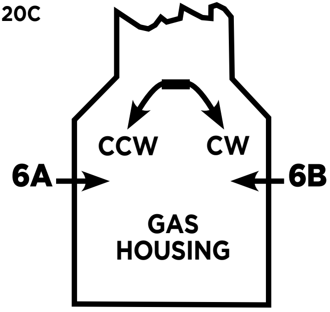
Plant ______________________ Date ____________

Notes to Remember When Analyzing Drying Efficiency:

Every 10°F/5°C rise in mix temperature raises fuel consumption 2%.
Every 10°F/5°C exit gas reduction = 1% fuel savings. 40°F/20°C gas savings = 4% fuel savings. Target exit gas temps for CF dryers <240°F/115°C and 10°F/5°C above mix temp for PF dryers. Every start/stop raises fuel cost / ton. Multiple starts/stops raises fuel consumption 20-35%.







Fuel efficiency acceptable? (See chart + analysis below) ____________

Combustion analysis acceptable? (Target 350 ppm CO @ 7% O2) ____________

Number of starts / stops in a day? Can they be reduced? Qty? (Multiple starts / stops raise fuel consumption 20-35%.) ____________

Typical mix temps? Can mix temps be lowered to better manage fuel costs? ____________

Is a warm mix system in use to lower mix temps? ____________

Typical exit gas temperatures? This may vary with tph or between virgin / low RAP mixes and high RAP mixes (7 or 8). ____________

Are dryer seals effective at the exit gas end (9)? Are they pulling down exit gas temperatures. making you think they are more effective than they are? ____________

Are dryer inlet seals effective (10)? Are they pulling down the exit gas temperatures, making you think they are more effective than they are? ____________

Exit gas temp differential (6A and 6B)? Differential can be measured off the gas housing surface after the dryer runs at least one hour. 100°F/35°C or more shows worn flights or inneffective flight pattern. ____________

Dryer shell temperatures? (High shell temperatures indicates worn or ineffective flights.) 1A ______ 1B ______ 2 ______ 3 ______ 4 ______ 5 ______

Is annual tonnage / fuel expense high enough to consider shell insulation? Insulation typically saves 5-7% but costs $15-30,000 to install. ____________

Miscellaneous (use back if needed):

Combustion Analysis

_____ ppm CO
@ _____ % O2 = _____
ppm CO @ 7% O2

PPM CO @ 7% O2 = Meassured PPM of CO x 13.9 (20.9 - Measured O2 %)

Fuel Efficiency Analysis

Typ BTU/Ton = ________
Req BTU/Ton = ________

(See chart vs. average moisture of RAP and VAM at final mix temp)

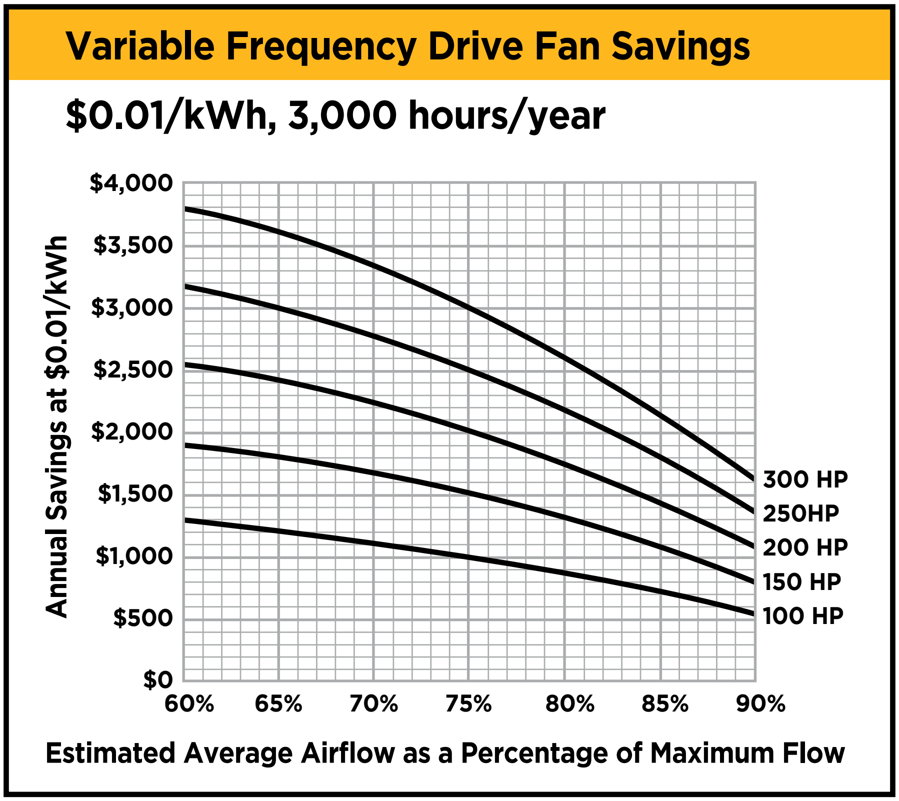
Fuel Efficiency Ratio = _____

(Actual BTU/Ton Required BTU/Ton is Fuel Efficiency Ratio)

Appendix C: VFD Exhaust Fan

Energy Analysis – VFD Application for Exhaust Fan

Potential Savings in Electical Energy by Applying VFD to Fan vs. Damper
The graph below is borrowed from Alliant Energy and NAPA's QIP-126 and can be used for a simple calculation to determine the annual savings potential from using a VFD on an exhaust fan at a plant. Your local electrical contractor or utility will also be able to provide help in estimating these cost savings.



Source: Alliant Energy

Use Alliant's variable speed drive calculator to see your potential savings.

The following example illustrates how to use the chart to estimate savings:

1. Assume a VFD for a 200 hp fan motor on a 300 tph plant. The damper operates at an average position representing airflow of 70%.
2. Using the graph below draw a vertical line from the 70% until it intersects the line for the 200 HP motor. Then draw a horizontal line to the left to determine the annual cost savings at $0.01/kWh.
    - *a.* The estimated annual savings based on current or estimated electrical rate.
3. Calculate the annual cost savings based on current or estimated electric rate.
    - *a.* If the current electric rate is $0.05/kWh multiply the estimated annual savings above. Estimated annual savings = 5 x $2,250/yr = $11,250/yr.
4. Now adjust savings by hours run. This graph assumes 3,000 hours of operation. If hours of operation are 2,000, then multiply savings by a ratio of the true hours.
    - *a.* 2,000 ÷ 3,000 x $11,250 = $7,500/yr.
5. Estimate time to payback by dividing installed cost by annual savings.
    - *a.* If intalled cost is $22,500, then payback will be 3 years ($22,500 ÷ $7,500 = 3).

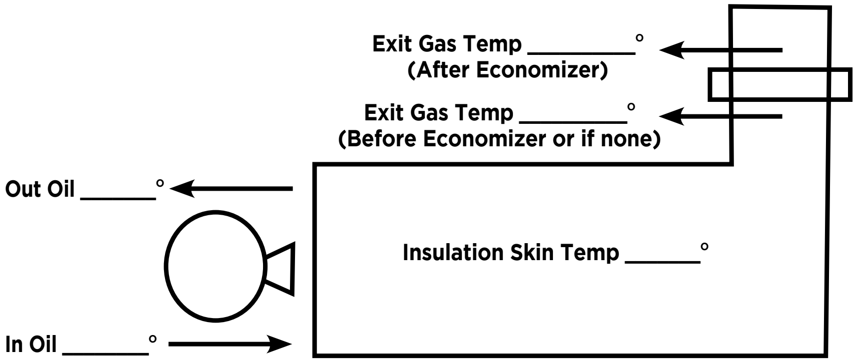
Appendix D:
Hot Oil System

Energy Analysis - Hot Oil Heater & Insulation Efficiency

Plant ______________________________ **Date** ______________

Notes to Remember When Analyzing Hot Oil Heater / Heat Transfer Oil Efficiency:

- Low gas temps out of the heater are a primary indicator of efficient conversion of fuel to hot oil (see chart).
- Combustion efficiency of less than 100 ppm CO @ 7% O_2 expected. (Heaters burn cleaner than dryers.)
- Older heaters with shorter bodies have a tendency to have higher gas temperatures and are not as efficient as newer units with more coils and longer bodies.
- Heat exchangers / "economizers" in the exhaust gas can reclaim heat, lower exit gas temperatures, and transfer some of that heat into the hot oil before it enters the heater, saving energy.
- All pipes and lines should be insulated and surface temp of insulation should be <100F/35C. (See chart for calculating pontential savings from insulating un-insulated pipes and lines.)
- Cycling heat off and on for equipment not being used (like silos and slats at night) saves energy.



Combustion Analysis

____ ppm CO @ ____% O_2
= ____ ppm CO @ 7% O_2

PPM CO @ 7% O_2 = Measured PPM of CO x 13.9 ÷ (20.9 - Measured O_2 %)

CO levels of <100 ppm @ 7% O_2 are expected and typical. Higher levels indicate need to adjust burner. Take readings on high fire AFTER burner stabilizes.

Exit gas temperature is a measure of efficiency of the conversion of fuel to hot oil

1070° = 71% eff.	945° = 75% eff.	805° = 79% eff.	665° = 83% eff.	525° = 87% eff.
1039° = 72% eff.	910° = 76% eff.	770° = 80% eff.	625° = 84% eff.	495° = 88% eff.
1003° = 73% eff.	875° = 77% eff.	746° = 81% eff.	595° = 85% eff.	465° = 89% eff.
972° = 74% eff.	840° = 78% eff.	708° = 82% eff.	558° = 86% eff.	435° = 90% eff.

(Data in table above taken from Astec T-140 publication.)

AC Tank Temperature Data

Tank #	Insulation Temp	Oil Temp In	Oil Temp Out	Product Temp

Monitoring insulation temperatures, the drop of the oil temperature through the tank, and the temperature of the stored product over time are all indications of efficiency. Storage temperatures that drop even though hot oil temperature is consistent indicate buildup around heat transfer tubes, negating their effectiveness. Storage temperatures that are different but are on the same heating circuit can also indicate heat transfer problems. Hot oil temperature dropping significantly while it is attempting to heat a tank may indicate damaged and poor insulation. The skin temperature of the insulation can also tell you the effectiveness of the insulation. Monitoring temperatures over time are an effective tool of tracking efficiency and may prompt emptying the tank to check internal conditions.

Un-Insulated Pipe and Hot Oil Line Savings Potential Calculation - **(All plants have some quantity of un-insulated pipes and lines. Use this form to calculate energy savings potential from insulating pipes / lines better.)**

Pipe or Hot Oil Line	Linear Feet Not Insulated	Savings / Mo. Per Linear Foot	MM BTUs Saved / Mo.	Savings in $ ____ / Mo.*
4” Jacketed AC Pipe (per foot)		1.084MM		
5” Jacketed AC Pipe (per foot)		1.346MM		
6” Jacketed AC Pipe (per foot)		1.599MM		
7” Jacketed AC Pipe (per foot)		1.849MM		
8” Jacketed AC Pipe (per foot)		2.743MM		
1” Hot Oil Pipe (per foot)		.347MM		
1 1/2” Hot Oil Pipe (per foot)		.453MM		
2” Hot Oil Pipe (per foot)		.570MM		
2 1/2” Hot Oil Pipe (per foot)		.698MM		
3” Hot Oil Pipe (per foot)		.865MM		
1/2” Hot Oil Jumper (per foot)		.080MM		
3/4” Hot Oil Jumper (per foot)		.126MM		
1” Hot Oil Jumper (per foot)		.174MM		
1 1/2” Hot Oil Jumper (per foot)		.219MM		
Total Savings Potential →				

* Multiply MM BTU / Month x $29.00. $29.00 per MM BTU is based on $4.00 diesel fuel and 138,000 BTUs/Gallon. MM = Million. The values in this chart are determined from data from Turner & Malloy and Astec’s T140 publication.

Heating and Storage Cost Calculation (Calculate When Plant Not Producing):

Stop Fuel Units: ____________ - Start Fuel Units: ____________ = Total Fuel Units ____________________
Cost Fuel Unit: ____________ x Total Fuel Units: ____________ = Total Fuel Cost ____________________
Stop Test Time : ____________ - Start Test Time: ____________ = Total Test Time (hrs) ________________
Total Fuel Cost: ____________ ÷ Total Test Time (hrs) ________ = Cost per Test Hour ________________
Cost per Test Hour: __________ ÷ Total Gallons Stored ______ = Store Cost per Gallon ________________
Store Cost per Gallon x 30,000 = Cost to Store 30,000 Gallon This Facility __________________________

Miscellaneous Notes This Facility:

____

____

____

____

Appendix E: Fuel Equivalent Table

Chart showing equivalent prices of different fuels based on BTU content (courtesy Astec)

Type of Energy	**Heating Value (Net or LHV)**		**Billing Units**	**Cost Comparisons Based on Heating Values**						
No. 2 Fuel Oil	BTU/gal.	132,000	Per Gallon	$1.00	$1.10	$1.20	$1.30	$1.40	$1.50	$1.60
No. 5 Fuel Oil	BTU/gal.	143,250	Per Gallon	$1.09	$1.19	$1.30	$1.41	$1.52	$1.63	$1.74
Propane (LPG)	BTU/gal.	84,345	Per Gallon	$0.64	$0.70	$0.77	$0.83	$0.89	$.096	$1.02
Natural Gas	BTU/CCF (see note)	90,500	Per CCF	$0.69	$0.75	$0.82	$0.89	$0.96	$1.03	$1.10
Gas	BTU/Therm	100,000	Per Therm	$0.76	$0.83	$0.91	$0.98	$1.06	$1.14	$1.21
Electricity	BTU/kWh	3,413	Per kWh	$0.03	$0.03	$0.03	$0.03	$0.04	$0.04	$0.04
Coal	BTU/lb	12,000	Per Ton	$182	$200	$218	$236	$255	$273	$291

Each column of cost comparisons relates the costs of various types of energy to each other based on heating values. For example, the cost of No. 2 fuel oil at $1.00 per gallion is equivalent to a cost of $1.09 for No. 5 fuel oil for the same BTU. Thus, if No. 2 fuel is $1.00 per gallon it doesn't pay to choose No. 5 fuel oil unless it is less than $1.09. Likewise, it wouldn't pay to use electricity unless it is less than $0.03 per kWh.

Type of Energy	**Cost Comparisons Based on Heating Values (continued)**													
No. 2 Fuel Oil	$1.70	$1.80	$1.90	$2.00	$2.10	$2.20	$2.30	$2.40	$2.50	$2.60	$2.70	$2.80	$2.90	$3.00
No. 5 Fuel Oil	$1.84	$1.95	$2.06	$2.17	$2.28	$2.39	$2.50	$2.60	$2.71	$2.82	$2.93	$3.04	$3.15	$3.26
Propane (LPG)	$1.09	$1.15	$1.21	$1.28	$1.34	$1.41	$1.47	$1.53	$1.60	$1.66	$1.73	$1.79	$1.85	$1.92
Natural Gas	$1.17	$1.23	$1.30	$1.37	$1.44	$1.51	$1.58	$1.65	$1.71	$1.78	$1.85	$1.92	$1.99	$2.06
Gas	$1.29	$1.36	$1.44	$1.52	$1.59	$1.67	$1.74	$1.82	$1.89	$1.97	$2.05	$2.12	$2.20	$2.27
Electricity	$0.04	$0.05	$0.05	$0.05	$0.05	$0.06	$0.06	$0.06	$0.06	$0.07	$0.07	$0.07	$0.07	$0.08
Coal	$309	$327	$345	$364	$382	$400	$418	$436	$455	$473	$491	$509	$527	$545

When No. 2 fuel oil is $1.00 per gallon. The actual heating values of various fuels vary somewhat from one region to another. However, the values used here are for fuels commonly used in the United States. CCF stands for 100 cubic feet. The net heating value of one cubic foot of natural gas is 905 BTU. However, natural gas is normally billed at its gross heating value, which is approximately 1,000 BTU per cubic foot.

Appendix F: Stockpile Feeding Practices for Moisture Reduction

Introduction

When feeding aggregates from stockpiles, one easy-to-implement practice for reducing the aggregate moisture being fed into the plant is having the loader stay 12” above the grade when extracting material from the piles. This appendix includes examples of how this practice can reduce the overall moisture being fed into the asphalt plant dryer, and how that can lead to a number of benefits, including:

- Reduced burner fuel consumption
- Improved mix production temperature control
- Improved plant operation (less fluctuation)
- Improved quality of the final product

Duval Case Study

A case study conducted by Duval Asphalt demonstrated the potential benefits of staying up 12” when feeding aggregates from the stockpiles. In the study, stockpiled aggregates and RAP were sampled from at grade, 12” above grade, and 24” above grade on the feeding face of the stockpile. The results showed that the moisture content of the materials sampled at 12” was lower than the moisture content of the materials sampled at grade. The most significant differences in moisture were noted in the fine aggregate materials. The RAP material in the case study was low in moisture, resulting from the benefits of practices employed at this site, such as unprocessed milling stockpiles, using the least amount of moisture during processing to manage dust emissions, and conical stockpiling of the final RAP material.

Table 1. Moisture content at three elevations

	At Grade	12” Above Grade	24” Above Grade
Natural Sand	7.2%	2.97%	2.7%
Manufactured Sand	6.3%	3.92%	3.87%
3/8” Aggregate	2.3%	1.4%	1.3%
1/2” Aggregate	.6%	.6%	.6%
3/8” Minus RAP	2.86%	2.56%	2.56%

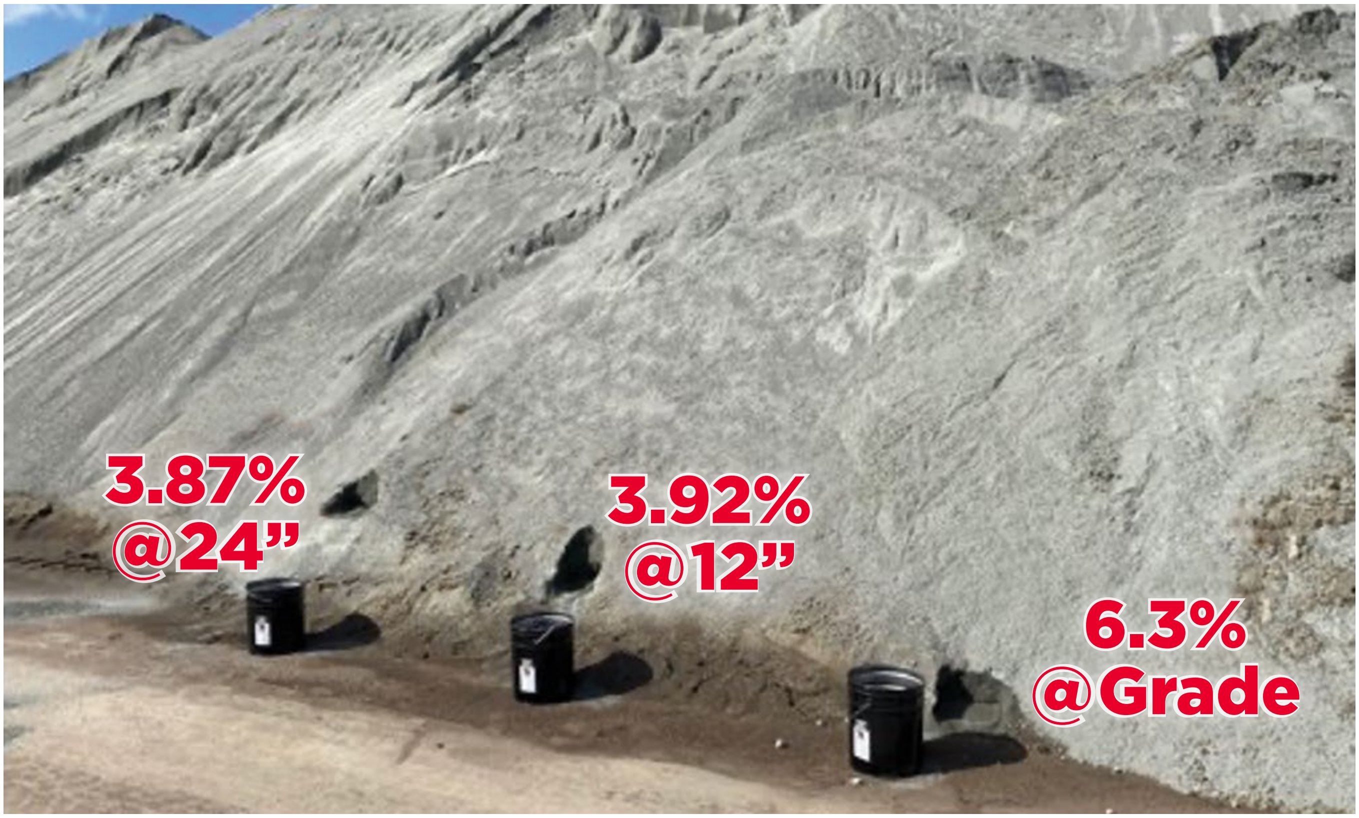


Figure 1. **Manufactured sand stockpile moisture measurements**

Figure 2. **Natural sand stockpile moisture measurements**

A sample calculation to illustrate the impact of staying up 12" when feeding the plant follows. For the calculations, we assume that a 4-to-5-foot loader bucket feeding from grade level would have 50% of the bucket filled with this wetter material (first 12") and as the operator 'curls' the bucket upward from grade, the remaining 50% of the bucket will be filled with drier material from 12" to 24" up in the pile.

Table 2. **Moisture calculation starting at grade level**

	Natural Sand	Manufactured Sand	3/8" Agg.	1/2" Agg.	3/8" RAP	Total Moisture
At Grade	7.2%	6.3%	2.3%	.6%	2.8%	
12"	2.97%	3.9%	1.4%	.6%	2.56%	
Average H_2O	5.1%	5.1%	1.85%	.6%	2.68%	
% of Feed	10%	30%	10%	15%	35%	
Total H_2O	.51%	1.53%	.19%	.09%	.94%	3.26%

Table 3. **Moisture calculation starting at 12” above grade level**

	Natural Sand	Manufactured Sand	3/8” Agg.	1/2” Agg.	3/8” RAP	Total Moisture
Feed Up 12”	2.97%	3.9%	1.4%	.6%	2.56%	
% of Feed	10%	30%	10%	15%	35%	
Total H_2O	.297%	1.17%	.14%	.09%	.896%	2.59%

Using these calculations, the composite moisture for the feed from 12” up can be subtracted from the composite moisture of the feed from grade to determine the moisture reduction:

3.26% H_2O – 2.59% H_2O = 0.67% Moisture Reduction

Applying the rule of thumb that 1% overall moisture reduction results in a 10% fuel reduction (as discussed in the main body of this document), this example illustrates that staying up 12” would result in about 7% fuel savings. Burning 7% less fuel would lead to significantly reduced production costs, along with significantly reduced greenhouse gas emissions.

Conclusion

The benefits of staying up 12” when loading stockpiled aggregates into the asphalt plant are clear. By following this simple practice, loader operators can play a significant role in reducing plant burner fuel consumption, improve mix temperature control, and improve the quality of the final product.