DESCRIPTION OF THE ASTEC GREEN SYSTEM

Double Barrel Green®, Green Pac™ for Continuous, Green Pac™ for Batch
The Astec Green Pac™ systems, based upon the same technology as the Double Barrel Green®, are designed to work on all types of asphalt plants from all manufacturers. The Double Barrel Green® is merely a configuration of the Astec Green Pac™ system specifically designed for the Astec Double Barrel®. The units may be installed on both new equipment or as a retrofit package.

What comes with the system?
All Astec Green Pac™ systems come complete with:

1. Green Pac™ manifold. This manifold is mounted either directly on the mixing device or inline with the AC delivery piping. The manifold includes all valving, hot oil, piping sections and spool pieces, flanges, offsets, and/or any other fitting(s) necessary to appropriately integrate it with existing equipment. If not a retrofit, the Green Pac™ manifold is already fully integrated with the new plant.

2. Green Pac™ Skid. The skid is a metal skid that comes in two standard sizes:
   a) large to accommodate a 550 gallon (2080 liter) opaque water tank and b) small to accommodate a 165 gallon (624 liter) opaque water tank. The skid serves as a mounting platform for:
      a. Control Cabinet (NEMA 4) containing
         i. Power shutoff switch (external).
         ii. Variable Frequency Drive (VFD) for water pump (VFD interface remote mounted in panel door to enhance arc flash compliance).
         iii. Control signal conditioning equipment (I/O)
         iv. Circuit protection.
         v. 480VAC to 120VAC transformer providing power to a weatherproof 4-gang receptacle box (all GFI) for providing power to an optional cold weather package.
         vi. Remote dual output tachometer if plant is equipped with a pump-to-pump AC metering package. Tachometer is remote mounted on AC flowmeter.
   b. Water tank (opaque polyurethane) including
      i. Fill valve and float for connecting tank to continuous water supply.
      ii. Water level sensor for alarming operator if water level becomes low.
      iii. Drain
      iv. Inspection port
   c. Direct drive piston water pump and motor including
      i. Inlet strainer
      ii. Water flowmeter
      iii. Outlet piping including calibration lines and valves.
      iv. Water bypass pressure relief valve and bypass switch

3. Green Pac™ Touch Panel (unless integrated into plant control)

4. All necessary power, communication cable, and software.

5. High pressure water line between skid-mounted water pump and Green Pac™ system manifold.

6. 24/7 service and support.
General Description of the Astec System
The Astec Green System (Double Barrel Green®, Green Pac™ for Continuous and Green Pac™ for Batch) consists of multiple water injectors, foaming standpipes or foaming plenum, and nozzles supplied by integrated liquid asphalt cement (AC) and water manifolds.
1. Water is injected via water injectors into foaming standpipes/plenum.
2. The water flow rate (Double Barrel Green® and Green Pac™ for Continuous) is maintained by feedback control of the PLC trimming the speed of a positive displacement water pump to maintain measured water flow equal to a calculated target flow rate.
   a. Target water flowrate is calculated based upon the output of the AC flowmeter.
   b. Actual water flow is determined from the output of a water flow measurement device.
3. The multi-nozzle foaming assembly has matched water injectors/foaming standpipes/foaming valves/plenum.
4. Water flow is calibrated via a calibration routine detailed in Appendix 4: “Calibration Instructions”.

Description of Operation (Double Barrel Green and Green Pac™ for Continuous)
1. The foaming assembly is typically plumbed into the AC metering system as a primary dispensing point.
2. When the foam system is enabled, water is injected into and intimately mixed with the liquid AC. Refer to Appendix 2: “Green System Water Injection”.

Sequence of Operation, Continuous
When the system is enabled, the water pump starts and begins controlling flow. Once the unit reaches its targeted water flow within a settable tolerance, water nozzles open allowing water and AC to mix together within the unit. Upon disabling the system or performing a mid-stream stop, the unit ceases spraying water into the foaming standpipes/plenum by closing the water injectors and stopping the water pump.

Green Pac™ for Batch
The Green Pac™ for Batch may be installed on either positive displacement or gravity feed plant configurations from any manufacturer. In the case of a positive displacement system, the green system manifold is installed between the AC injection pump and the pugmill spraybar. In the case of a gravity feed system, an AC injection pump is added to provide the motive force to push the AC through the foaming manifold thus adding positive displacement capability to the plant for the production of both warm mix asphalt (WMA) and hotmix asphalt (HMA) without affecting the plant capability of employing the existing gravity feed system.

Sequence of Operation, Batch
Green Pac™ for Batch is controlled by setting the pump to run at the appropriate speed via a manual calibration. Once in operation and enabled, the water pump runs at this speed continuously with the flowmeter output displayed for reference. The Green Pac™ for Batch PLC receives signals from the existing plant batch control to determine when water is to be injected into the foaming manifold or bypassed back to the water reservoir. If the plant uses gravity to dispense AC into the pugmill, the Green Pac™ for Batch PLC also receives signals from the existing weigh system to control the filling and emptying of the plant’s weighpot.
WATER SUPPLY AND METERING
(Double Barrel Green® and Green Pac™ for Continuous Plants)

A positive displacement piston pump is used as part of a feedback-controlled PID within a PLC to meter water at the target rate via VFD control.

1. A target water flow rate is calculated based upon the current AC flow rate as measured by the AC metering pump or AC flow meter.
2. The speed of the water metering pump is controlled by the PID control using the output of the water flow meter.
3. Water is typically injected at a rate of 2% of AC flow by weight. However, greater water flow rates are not detrimental to the mix and have been shown to enhance foaming at low production rates (see Appendix 1, “Green System Water Injection”).

4. For example, a virgin mix being produced at 300TPH (272MTPH) with 5%AC requires 15TPH (13.6MTPH) of liquid AC.

   • Fifteen (15) TPH (13.6 MTPH) of AC is approximately 60 GPM (227 LPM) of AC assuming specific gravity of AC near 1.0.
   • If water having a specific gravity of 1.0 is injected at a rate of 2% of liquid AC flow, the required water flow rate will be 1.20 GPM (4.54 LPM).

WATER SUPPLY AND METERING
(Green Pac™ for Batch Plants)

All of the water supply and metering components are essentially the same for Green Pac™ for Batch as for Double Barrel Green® and Green Pac™ for continuous plant configurations.

1. Green Pac™ for Batch uses a larger water pump and larger relief valve of the same type to achieve the high water flowrate required during AC injection.
2. Water flow relieves back to the water reservoir when not being injected to ensure accurate metering of water into the liquid AC as it is delivered into the pugmill.
3. Green Pac™ for Batch water flowrate (based upon the rate at which AC leaves the weighpot) is set by setting pump speed to particular level via a calibration routine using the flowmeter as a reference. Refer to Appendix 4: “Calibration Instructions”.


What is warm mix?
Warm mix asphalt (WMA) is similar to hot mix asphalt (HMA) except that it is produced and placed at lower temperatures (typically 50°F to 100°F [28°C to 56°C] cooler). The liquid AC is temporarily made to have a lower viscosity by either the introduction of a wax, chemicals or water. Water may be introduced via a number of carriers. Rather than using a mineral carrier, Astec Green Systems inject water via water injectors/foaming nozzles.

How does the Astec Green System work?
The Astec Green System intimately mixes water and liquid AC to form a foam containing microscopic steam bubbles. The presence of microscopic steam bubbles lowers viscosity of the liquid AC until the mix until it is compacted and drops below 212°F (100°C).

How will warm mix change my mix design?
Using the Astec Green Systems, mix design is unaffected. The same mix designs used for hot mix may be used for warm mix since nothing is added to the mix except a very small amount of water. Only a very small amount of this water (a maximum of 0.0012%) remains in the mix after compaction. Refer to Appendix 2: “Green System Water Injection”.

What is the HMA Producer’s responsibility to purchase or provide?
The HMA producer need only supply a water supply hose from a suitable water source to the water tank.

What are the electrical requirements of the plant?
Provision is made for any line voltage upon ordering the system. Overall power requirement of the system is minimal. As such, it is typically energized from an existing adjacent power source.

How is the water attached to the system? Is the water required to be used from a holding tank, or can the system be directly connected to a municipal water supply?
All Astec Green Systems include a water reservoir to provide low-pressure uninterrupted water supply to the pump. Municipal water may be hooked directly to the fill valve on the tank. To maintain metering accuracy, municipal water should not be connected directly to the inlet of the pump.

Depending upon requirement, loss of water flow may be used to trigger midstream stop.

What is the dosage rate?
Water dosage rate may be manually varied between 1.5% and 5.0% of the virgin liquid flow. A 2% to 3.5% dosage rate is typical and widely used with 2% being the most common dosage rate. Refer to the Appendix 2 “Green System Water Injection” for a more detailed discussion of dosage rate. There is no deleterious effect associated with injecting excess water.

How is the water dosage controlled? This dosage also needs to be calibrated according to specifications, how will this be accomplished?
Green Pac™ water dosage rate is controlled based upon
1. Operator input (operator may choose the desired water injection dosage rate on the touch screen or on an integrated control screen if the Green Pac™ control is integrated into the plant’s operating system).
2. AC Flowrate. AC flowrate is measured via the existing AC flowmeter. The Green Pac™ PLC uses this flowrate along with the desired dosage rate to calculate a “target” water flowrate.
3. Green Pac™ PLC trims the speed of the water pump using feedback from the water flowmeter to maintain actual water flow at the desired target rate.

A calibration routine is included in the Green Pac™ PLC Control and is accessible from the touch screen in the control house. Refer to Appendix 4 “Water Calibration”. A data recording function, per request, is available that utilizes the PLC and/or plant blending system software for recording and “time stamping” water dosage rate.
Appendix 1: FREQUENTLY ASKED QUESTIONS (FAQ)

Can the dosage rate vary with the type of mix being used? Mix with 20% RAP versus a mix with no RAP?
Though dosage rate has been varied manually at higher RAP percentages, no noticeable effect has been observed. Typically, dosage rate is maintained at 2% of the virgin liquid flow rate. Increasing the dosage rate will not result in any deleterious effect.
For all mixes, the dosage rate is similar and is based upon the amount of virgin binder. Table 1 shows the water injection “dosage” rate for different mixes as requested by NYDOT.

**Table 1. Dosage Rate of Water for Various Mix Binders**

<table>
<thead>
<tr>
<th>Material Used</th>
<th>Typical Starting Dosage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virgin Mix</td>
<td>Between 2% and 3.5% of virgin binder (see note)</td>
</tr>
<tr>
<td>PMA</td>
<td>Between 2% and 3.5% of virgin binder (see note)</td>
</tr>
<tr>
<td>RAP 10% or less</td>
<td>Between 2% and 3.5% of virgin binder (see note)</td>
</tr>
<tr>
<td>RAP more than 10%</td>
<td>Between 2% and 3.5% of virgin binder (see note)</td>
</tr>
<tr>
<td>RAP 10% or less/PMA</td>
<td>Between 2% and 3.5% of virgin binder (see note)</td>
</tr>
<tr>
<td>RAP more than 10%/PMA</td>
<td>Between 2% and 3.5% of virgin binder (see note)</td>
</tr>
<tr>
<td>RAP/RAS</td>
<td>Between 2% and 3.5% of virgin binder (see note)</td>
</tr>
<tr>
<td>RAP/RAS/PMA</td>
<td>Between 2% and 3.5% of virgin binder (see note)</td>
</tr>
</tbody>
</table>

Note: Mechanical foaming technology introduces water into the virgin binder. Since the water flashes to steam, all but 0.0017% (amount of steam occupying all air voids post compaction) is lost in the process and does not remain in the mix.

Are there other reasons to vary the water dosage rate?
At very low production rates and high RAP percentages, dosage rate may be manually increased to enhance mechanical mixing of liquid AC and water. Typically, flow is maintained at or above 1 gpm (3.78 lpm).

If some of the water remains in the mix, won’t I show a high AC content?
A small amount of water remains in the mix after compaction; so theoretically, this could show up as AC content. However, since a maximum of 0.0012% of the water remains, the amount of water that remains is beyond the measurement accuracy of AC content (typically reported to the nearest 0.1%). The amount of injected water, at a maximum that remains is about 11ml per mix ton. Refer to Appendix 2: “Green System Water Injection”.

Can (or should) I put anti-freeze in the water?
The effect of anti-freeze of any type on the mix, even at low concentrations, is unknown. As such, adding any type of antifreeze to the water is not advised. Refer to Appendix 5: “Cold Weather and Winterizing”.

How clean should the water be?
Non-potable well water has been used without adverse affect. However, most installations use Municipal water and some have chosen to filter the water via a duplex filter arrangement.
Elaborate filtering is unnecessary. As long as the water is clean and free of contaminants, there will be no problem as the pumps and water injectors/foaming valves are designed to pass small particulate.

**Should the injected water be metered and accounted for in the same manner as an anti-strip additive (ASA) or mineral filler?**

Absolutely not. To do so is not correct and introduces potential AC content discrepancies. Adding water for the purpose of mechanical foaming in the same manner as an ASA or mineral filler demands that it be accounted for in the same manner. **Since the majority of the injected water does not remain in the mix after compaction, accounting for it as if it does causes either AC content or aggregate content to be very slightly over reported.** If accounted for in this manner, the maximum effect on actual AC content would be 0.1% reduction -- a significant difference. By comparison, the maximum effect on aggregate would be approximately 0.01%. Given this, it is more accurate with respect to AC content for water to be controlled separately from the blending system and NOT included as an add mixture.

**Can I start up on warm mix?**

Generally, it is better to start hot then go warm so that the first two loads of WMA are at HMA temperature. This serves to heat soak the metal surfaces at the plant, the paver, and material transfer vehicles to help reduce adhesion to metal surfaces and lower equipment amperage draw. Water may be injected from the beginning regardless of mix temperature. Refer to Appendix 3 “WMA Production Temperatures”.

**Won’t the baghouse temperature be too low when I lower mix temperature?**

It depends on a number of factors. If your baghouse temperature is already low, running warm mix may push it to a level at which condensation within the baghouse may begin. Typically baghouse temperature decreases about 35°F (19.4°C) to 40°F (22.2°C) when running warm mix in a counter-flow dryer (all other factors constant). Warm mix works best with higher RAP usage as the higher baghouse temperature associated with the higher RAP percentage is offset by the lower baghouse temperature afforded by running the warm mix.

**Will coating be affected?**

Coating is affected by many factors: aggregate, mix temperature, AC type, and/or fines content to name a few. Generally, coating decreases with mix temperature. However, good coating has been observed with Astec Green Systems producing mix at 250°F (121°C). Depending upon the aggregate and fines content, coating typically worsens below 240°F (115.5°C). Good coating has been observed below 200°F (93.3°C). At higher temperatures, use of the Green System has significantly improved coating if coating initially appeared less complete.

**What mix temperature should I run?**

Run 240°F to 250°F (115.5°C to 121°C) for virgin mixes. Run 270°F to 280°F (132.2°C to 137.7°C) for mixes containing RAP. Refer to Appendix 3: “WMA Production Temperatures” for a more detailed explanation.

**Is WMA mix temperature a set temperature or a drop of XX degrees from the HMA mixture?**

Since circumstance and environmental conditions play a major role in establishing a rational production temperature (for both HMA and WMA alike), the temperatures provided above should be considered a typical target temperature for ideal conditions. The ability to adjust target temperature up or down based upon mix-specific experience, environmental conditions, and logistics should be considered rather than establishing a fixed target temperature without regard to these factors.

**Can I run warm mix at higher temperatures?**

Yes. There is no danger in running Green System warm mix at the same temperature as ordinary hot mix. The mix will simply remain workable longer.
Appendix 1: FREQUENTLY ASKED QUESTIONS (FAQ)

Won’t I experience a drop in mix temperature since I am adding water?
No. Significant drops in mix temperature for ordinary hauls in moderate weather are caused by internal moisture. Internal moisture is evidenced by steam and water at the silo tops, water running out of the truck beds, and a drop in mix temperature. The amount of water injected by the Green System is insignificant by comparison. For a virgin mix having 5% AC, only 2lb per mix ton is injected (0.1%). After compaction, water remaining in the mix from the warm mix process is 0.0012% (refer to Appendix 2). Many states allow up to 0.5% remaining moisture in the mix (over 400 times the maximum possible amount of water remaining in the mix from the water injection process).

Can warm mix produced with the Green System be stored?
In 2007, storage tests were performed using a 30% RAP mix made with PG64-22. The mix was stored for 24 hours in Astec silos in storage mode. At 24 hours, a small drop was made to ensure that all was well. The mix was then stored an additional 24 hours and sold to a private customer without issue. Since this test, WMA produced with the Astec Green System has been stored for up to 4 days. **If the hot mix is a mix design that may be stored, the warm mix version of that mix design may be stored as well.**

Are there any equipment maintenance issues?
None on Generation 2.X units. Generation 1 units may require periodic nozzle and water orifice cleaning. A cold weather package is included to prevent freezing when running mix in cold weather when temperatures fall below freezing. Refer to Appendix 5: “Cold Weather Package and Winterizing” for detailed instructions.

Are there special handling requirements?
None.

Does the sample need to be aged or conditioned before performing volumetric mix testing? (For example, some technologies require the mixture be placed in an oven for 2 hours before testing.)
No. However, the sample may be held in an oven to maintain temperature.

Will rolling patterns change?
It is likely. Generally paving crews have found that they do not need to hold the rollers off of the mat – rolling can begin immediately. Also, compaction has been achieved at some locations with less rolling required. Of course, specific mixes and materials will exhibit different characteristics so, as with HMA, it is best to experiment to determine what compaction effort is sufficient.

Are there special handling requirements?
None.

At what temperature(s) should the mixtures be arriving at the paver?
Expect the temperature differential between the plant and the road to be the same for WMA as that of HMA under similar environmental and logistical conditions.

When compared to conventional mixtures, can the contractor expect to laydown the same loose thicknesses to achieve a specified compacted thickness? (For example, the contractor places the mixture 2 ½ inches thick, expecting to have a 2 inch thick mat after final compaction.)
Yes. The mix acts like HMA without smoke and smell.

At what temperature should the mix be compacted during placement?
This depends upon the mix design. As a rule-of-thumb, consider the compaction temperature differential to be the same as that of the production temperature differential between HMA and WMA given similar environmental and logistical factors.

At what temperature should Marshall and gyratory samples be compacted in the laboratory?
Appendix 1: FREQUENTLY ASKED QUESTIONS (FAQ)

Laboratory compaction temperatures should match placement compaction temperatures to within ±5°F to best achieve compaction similitude with placed mix. However, for consistency and expediency, a set differential from production temperature (see Appendix 3) may also be used. Samples may be reheated or maintained at temperature via a conditioning oven.

Is there a temperature at which the mix returns to acting like a conventional mix?
At approximately 212°F (100°C).

At what temperature is it safe to return traffic to the road?
The same as that of HMA for the same mix design.

If multiple lifts of material are being placed, what temperature should the first lift be at before placing the second lift?
The same as that of HMA for the same mix design.

Are there any concerns with handwork?
In some cases, performing handwork in cold weather (wind, little or no sun, cold ambient temperatures) has become more difficult. In other cases there has been little or no difference in handwork. This appears to be a function of mix design, RAP percentage, and/or environmental conditions.

Does WMA produced with the Astec System look any different than regular HMA?
Most mixes look exactly the same as their hot mix equivalent except that there is no smoke and no smell. On a few occasions, the mix has look slightly richer at the same target AC content as hot mix – especially virgin mixes. The slightly richer look is likely due to the expansion of the film thickness due to the presence of microscopic foam bubbles and/or the presence of light ends that would have escaped as smoke and fumes had the mix been made at higher temperatures.

Do all liquid AC grades from various sources foam equally?
There is reason to believe not all liquid asphalt binders foam in the same manner. Currently, this appears to be associated with the source of the crude oil from which the liquid AC is derived. The phenomena may be associated with less viscous grades, but this HAS NOT been confirmed. Research is currently underway to determine a “marker” that may be used predict the tendency to foam. Current experience indicates a large majority of AC in North America and elsewhere foams sufficiently to produce mechanically foamed WMA.

Is it possible to run stone matrix asphalt (SMA) using mechanically foamed WMA?
Foaming asphalt in Stone Matrix Asphalt (SMA) designs has also been accomplished with the Astec Green System. Virginia runs all of their mix designs with mechanically foamed WMA including SMA since 2008. As such, several projects in Virginia have been placed with mechanically foamed PG 76-22 in an SMA. A contractor producing the mix claimed “we have had zero complaints with this mix.” Although it has not been observed in either the field or laboratory, it is conceivable that drain down sensitivity could increase in the event the binder grade has been modified via the addition of a significant amount of light ends. The drain down propensity of the mix may be tested using Drain Test AASHTO T305. Also, to quantify the light end content of the liquid, an ASTM D255 Steam Distillation Test may be performed on the liquid.

1 The National Center for Asphalt Technology (NCAT uses a sample compaction temperature of 30°F less than production temperature for mechanically foamed WMA samples – a differential that would tend to match typical placement compaction temperatures. By contrast, in 2007 one state adopted a sample compaction temperature of 10°F less than production temperature for mechanically foamed WMA samples. Though there have been no known issues with this approach, it would tend to result in laboratory compaction temperatures consistently higher than field compaction temperatures.
APPENDIX 2: GREEN SYSTEM WATER INJECTION (STANDARD UNITS)

Introduction
The ASTEC Green System produces WMA by injecting a small amount of water into the liquid AC as it is injected into the mixing chamber of a Double Barrel. Mixing water into the AC results in foam; however, the controlled injection of water via specialized nozzles creates microscopic bubbles of steam that increase film thickness and decrease the viscosity of the AC film. As a result, the workability of the mix remains that of hot mix asphalt until it cools below 212°F, or the microscopic bubbles are broken via compaction.

Water is injected in proportion to liquid AC. Typically, the water flow rate between 2% and 3% of the liquid AC flow as measured by the AC Flowmeter. This rate is adjustable by the operator. Accurate metering is maintained by the system via a programmable logic controller (PLC). For a virgin mix having 5% AC, the water injected by the Green System is 2% X 5% = 0.1% of the mix. It will be shown that amount of this water that remains in the mix prior to compaction is very small. Compaction reduces this proportion of remaining water.

Is the proportion of water critical?
Green System WMA uses water to temporarily alter the physical properties of the mix as it is being produced.
• Mix designs are not altered for WMA production.
• Mechanically, the mix design is the same as HMA produced at higher temperatures without the introduction of water to temporarily alter workability.
• Since the mix design is not altered, the pre-compaction and post-compaction volume of WMA is the same as that of HMA.

The Volumetrics physically limit the amount of water that foams the AC in the mix.
To clarify how mix volumetrics limit the development of foamed AC, consider a mix design that has the following properties: AC Content = 5%, Voids = 5% (post-compaction), Mix Density = 110 lb/ft$^3$ (pre-compaction) or 140 lb/ft$^3$ (post-compaction).

Prior to compaction, the mix would consist, by volume, of 75% solids (aggregate and AC) and 25% air voids. One ton$^2$ (2000 lb) of this uncompacted mix would occupy the following volume:

$$\text{Volume of uncompacted mix (ft}^3/\text{ton}) = \frac{2000 \text{ lb/ton}}{110 \text{ lb/ft}^3} = 18.2 \text{ ft}^3/\text{ton}$$

Of this 18.2ft$^3$, 25% (4.54ft$^3$) consists of air voids. As the density of AC is 65 lb/ft$^3$, the volume of AC in one ton of mix may be calculated as follows:

$$\text{Volume of AC (ft}^3/\text{ton}) = \frac{5\% \times 2000 \text{ lb/ton}}{65 \text{ lb/ft}^3} = 1.54 \text{ ft}^3/\text{ton}$$

The total volume that is available for the development of foamed AC is the sum of the uncompacted air void volume and the volume of liquid AC

$$\text{Available volume for foamed AC (ft}^3/\text{ton}) = 4.54 \text{ ft}^3/\text{ton} + 1.54 \text{ ft}^3/\text{ton} = 6.08 \text{ ft}^3/\text{ton}$$

The mass of injected water per ton is

$$\text{Mass of water injected (lb/ton)} = \%\text{AC} \times \%\text{Water} \times 2000 \text{ lb/ton}$$

Substituting,

$$\text{Mass of water injected (lbm/ton)} = 0.05 \times 0.02 \times 2000 \text{ lb/ton} = 2 \text{ lb/ton}$$

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$^2$ For brevity, “ton” is used in lieu of “mix ton” throughout.
APPENDIX 2: GREEN SYSTEM WATER INJECTION (STANDARD UNITS)

The ambient temperature water that is injected instantly flashes to steam as it contacts the hot liquid AC. Presuming that the liquid AC arrives at the foaming nozzle at near 300°F, the injected water would expand from

$$0.016 \text{ ft}^3/\text{lb (ambient temperature liquid)} \text{ to } 30.53 \text{ ft}^3/\text{lb (superheated vapor at 300°F)}$$

If every drop of the water injected (2% of the liquid AC) flashes to steam, the maximum possible expansion of the foamed liquid AC may calculated as follows:

$$\text{Maximum possible expansion} = \frac{\text{Volume of Steam/ton} + \text{Volume of Liquid AC/ton}}{\text{Volume of Liquid AC/ton}}$$

Substituting,

$$\text{Maximum possible expansion} = \frac{(2 \text{ lb/ton} \times 30.53 \text{ ft}^3/\text{lb}) + 1.54 \text{ ft}^3/\text{ton}}{1.54 \text{ ft}^3/\text{ton}} = 62.66 \text{ ft}^3/\text{ton}$$

$$= 40.6 \text{ times}$$

Clearly, the combination of water and liquid AC does not expand over 40 times, as the texture and consistency of the mix would be drastically different than that of ordinary HMA. Numerous field trials reveal mix that looks exactly the same as ordinary mix or has the appearance of being slightly richer than ordinary mix. At the very maximum, the foamed AC fills the remaining void volume as foam in excess of this available volume simply collapses releasing the excess steam to be scavenged by the plant exhaust fan. In the example mix used above, the actual expansion of the combination of water and liquid AC would be

$$\text{Actual expansion} = \frac{\text{Available volume for foamed AC}}{\text{Volume of Liquid AC/ton}}$$

$$= \frac{6.08 \text{ ft}^3/\text{ton}}{1.54 \text{ ft}^3/\text{ton}} = 3.95 \text{ times}$$

The volume (4.54 ft³/ton) of air voids in the uncompacted mix physically limits the amount of water that exists as steam in the matrix of microscopic bubbles that comprise the film thickness of WMA. The mass of water that is in the uncompacted WMA may be calculated as follows:

$$\text{Mass of water (lb/ton)} = \frac{4.54 \text{ ft}^3/\text{ton}}{30.53 \text{ ft}^3/\text{lb}} = 0.149 \text{ lb/ton}$$

As a mass percentage of the mix, the injected water remaining in the uncompacted WMA is

$$\text{Mass \% of remaining injected water} = \frac{0.149 \text{ lb/ton} \times 100\%}{2000 \text{ lb/ton}} = 0.0075\%$$

Such a small percentage of remaining moisture is insignificant compared to AC content and the potential for internal moisture in any drying process. However, compaction further reduces the mass \% of remaining water. When the mix is compacted, voids are reduced to 5\% of the mix volume. One ton (2000 lb) of compacted mix would occupy the following volume:

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3 The first field trials of the Green System used a virgin surface mix and resulted in mix that appeared very rich "to the eye". Tests showed that the AC content of the mix matched the 5.3\% target.
APPENDIX 2: GREEN SYSTEM WATER INJECTION (STANDARD UNITS)

Volume of compacted mix (ft$^3$/ton) = \( \frac{2000 \text{ lb/ton}}{140 \text{ lb/ft}^3} = 14.3 \text{ ft}^3/\text{ton} \)

The volume of the voids (5%) in one ton of compacted mix is

Remaining void volume (ft$^3$/ton) = \( 0.05 \times 14.3 \text{ ft}^3/\text{ton} = 0.715 \text{ ft}^3/\text{ton} \)

The available volume for steam is now 0.715 ft$^3$/ton. Since compaction occurs above 212°F, the matrix of microscopic steam bubbles that exceed the available volume collapses and the steam is released to the atmosphere. Once the mix is compacted, the mass of remaining water is

Mass of remaining water (lbm/ton) = \( \frac{0.715 \text{ ft}^3/\text{ton}}{30.53 \text{ ft}^3/\text{lb}} = 0.0234 \text{ lb/ton} \)

As a mass percentage of the mix, the injected water remaining in the WMA is

Mass % of remaining injected water = \( \frac{0.0234 \text{ lb/ton} \times 100\%}{2000 \text{ lb/ton}} = 0.0012\% \)

From this exercise one may conclude that the proportion of water injected to create WMA is indeed critical as long as this proportion exceeds 0.149 lb/ton. The amount typically injected is far in excess of this amount. More importantly, it may be concluded that retained injected water constitutes only 0.0012% of the final mix at a maximum.

Why inject so much water if so little is needed?
The most common Double Barrel asphalt plant is rated to run 400tph (6.7 tons per minute). Ordinarily such a plant might run a production rate of 300tph (5 tons per minute) due to transportation, paving and/or market constraints. If running the mix considered in the example above, the mass of water that remains in one ton of mix would be:

Mass flow of remaining injected water @ 300tph = \( 0.149 \text{ lb/ton} \times 5 \text{ tons/min} = 0.745 \text{ lbm/min} \).

This is equivalent to 0.089 gpm, a very low flow rate. Since the mix will only hold the amount of foamed AC sufficient to fill the voids in the uncompacted mix, excess water escapes as steam into the mixing chamber and is exhausted via the induced draft of the plant exhaust fan.

Much in the same way burners require excess air for sufficient mixing of fuel with oxygen for adequate combustion, the Green System uses excess water to ensure that water and liquid AC are sufficiently mixed to result in the appropriate formation of microscopic steam bubbles in the foamed AC. Injecting more water than necessary for the formation of WMA, though theoretically unnecessary affords:

- A violent, explosive mechanical mixing of liquid AC and injected water within the foaming nozzles.
- Use of pumps, water flowmeters and water delivery hardware of commonly available sizes and configurations.
- A margin of safety to ensure that the liquid AC is sufficiently foamed to achieve the desired affect on workability in the lower temperature range.
APPENDIX 3: WMA Production Temperatures

As the use of Warm Mix Asphalt (WMA) becomes more prevalent across the United States, contractors and manufacturers of WMA producing equipment have been asked to establish temperature limits that define WMA. Generally this temperature range has extended from about 220°F to about 290°F. The different technologies that comprise the spectrum of technically viable WMA production methods each have specific temperature ranges within which each performs well – each occupying some range within the broad temperature range that defines WMA. Since Astec, Inc. designs manufactures and tests equipment that employs water injection to produce WMA, this and similar technology will be the focus of this discussion.

Early in the development of the Double Barrel Green System, the intent was to be able to mix water and liquid AC together such that the subsequent flashing of the water in concert with the intimate mixing of flashing water with individual streams of liquid AC would produce a completely foamed liquid AC. The extent of the foaming was studied via bench tests first. Subsequently its viability for producing WMA was studied in field trials using full-scale equipment. Since there was little if any field experience that could be used to predict what might occur in full-scale equipment, Astec thought it prudent to proceed with caution.

Full-scale tests began with hot mix asphalt (HMA) being produced at typical HMA temperatures (300°F+). After enabling the system to inject water, mix temperature was reduced while plant operation, process parameters, and mix quality were observed. From these experiments, there came two key learnings:

1. As temperature decreased below approximately 285°F the blue smoke normally visible at the discharge point of the process equipment disappeared. Likewise, the odor associated with this smoke also greatly diminished.
2. As temperature was further lowered to below 240 °F some incomplete coating was observed at the discharge point of the process equipment in some cases. However, WMA produced these lower temperatures continued to coat through subsequent process equipment and achieved desired compaction.

Over the course of several field trials using full-scale equipment, guidelines were developed to identify which temperatures worked best. Recognizing that specialized mix designs might require special consideration, conventional mixes appeared to completely coat and handle adequately when produced at 250°F and below (virgin and low recycle) and 280°F and below (high-recycle). Running WMA above approximately 280°F was not given serious consideration because of the aforementioned smoke point of the liquid AC and the loss of fuel savings associated with running higher mix temperatures. Based upon these observations and experiences, Astec recommended mix production temperature guidelines of 240°F to 250 ºF for virgin and low-RAP mixes; 270°F to 280 °F for high-RAP mixes. Due to the plethora of aggregates available for making mix, producers were encouraged to test these limits for themselves to determine how low temperatures could be lowered while still achieving acceptable compaction.

Since this time, Astec has been asked both by contractors and regulating authorities to define the temperature range for WMA for the Astec water injection process. The lower WMA production temperature (220°F) was deemed representative of the full range of field observation of coating and ability to achieve compaction. The top end of the temperature range was set at 285°F due to the field observations of the typical smoke point of the liquid AC. On one occasion, however, a slight amount of smoke was observed at 240°F. Such a very low smoke

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4 This appears to be a shared result among all of the technologies that employ water as the agent to temporarily reduce the viscosity of the binder. Mix has been observed to coat well as low as 220°F; however, not all mixes may exhibit the same tendency to coat.
point was considered atypical and not included in the development of an upper range of WMA temperatures.

Unfortunately, establishing a temperature range for WMA between 220ºF and 285ºF and the aforementioned mix temperature guidelines has resulted in some misunderstanding and subsequent misinterpretation of the temperature range and temperature guidelines and what they imply. These misunderstandings and misinterpretations are essentially:

1. The misinterpretation that the range establishes a limit of acceptability
2. The misunderstanding that production guidelines establish a limit of acceptability of mix production temperature not to be mitigated by circumstances normally applied to HMA.

To address these misuses of “ranges” and “guidelines” provided for WMA temperatures, each will be addressed separately.

1: Range Defining WMA Does Not Equate to a Limit of Acceptability

For WMA produced via water injection (foaming), there is no adverse affect on the mix from producing mix at temperatures in excess of the established WMA temperature range other than the obvious increase in fuel consumption and emissions. The water that remains suspended as steam in microscopic bubbles within the film of AC coating the aggregate remains there at the higher temperatures. This will result in the same increase in compactability as the mix cools to the WMA temperature range. Some might point out that mix produced at the higher temperature oxidizes more than that produced at WMA temperatures. Of course this is true, but it oxidizes no worse than the same HMA. A similar argument might be made concerning the “grade-bumping” of AC. Some states have established WMA specifications that allow a greater level of recycle usage as long as it is produced using WMA technology. Here it is important to remember that the original reason that AC grade was bumped lower when running higher levels of recycle was to achieve compaction. As long as the viscosity of the liquid is sufficiently decreased at the lower WMA compaction temperature due to the continuing effect of the steam bubbles remaining in the virgin liquid, the temperature of the mix does not have a bearing on the compactability. This has been shown to be the case in many field trials.

2: Production Temperature Guidelines: It is a Guideline.

As with HMA, WMA is not immune from environmental and logistical considerations. Jobs that have a long transit time in cool and/or windy weather will, just as HMA, require that the WMA be produced at a temperature commensurate with the expected temperature loss due to these effects. If a similar job with HMA might require a higher production temperature, the WMA work will require the same increase in production temperature. Though this seems at first consideration obvious, inspectors in some locations have rejected mix due to it being produced at higher temperatures than the WMA guideline during cold weather paving. Again, the key point is that the WMA produced via water injection maintains compactability at lower temperatures – even if it has been produced at a higher temperature.

Certainly, producers have strong incentives to make WMA at as low a temperature as feasible. The ability to extend the compaction window, shorten the time between placing with mix with the paver and commencement of rolling as well as the reduced smoke and smell are all very good reasons to reduce mix temperature when running WMA. However, the strongest incentive is the reduction in fuel consumption and green house gas emissions afforded by running at lower temperature. Table 1 shows expected percent reductions in fuel consumption for WMA as compared to HMA at maximum production. As fuel usage contributes significantly to the production cost, mix producers will very quickly realize that producing mix at lower temperatures will increase their bottom line. This has been evidenced by producers that are
making all private mixes as WMA unless otherwise specified. Likewise, green house gas reduction incentives from regulating authorities and utilities may also serve to sweeten the bottom line.

Table 1. Expected Fuel Savings, WMA versus HMA\(^5\) at Maximum Production

<table>
<thead>
<tr>
<th>RAP %</th>
<th>0%</th>
<th>10%</th>
<th>20%</th>
<th>30%</th>
<th>40%</th>
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<tr>
<td>Stack Temp. (°F)</td>
<td>225</td>
<td>230</td>
<td>235</td>
<td>240</td>
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<td>335</td>
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<td>% aggregate moisture</td>
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</tbody>
</table>

Dispensation of Hot WMA

Since production of WMA produced via water injection at temperatures greater than 285°F using water injection does not result in a condition deleterious to the mix and since the mix continues to retain its increased compactability consistent with WMA at lower temperatures, mix should not normally\(^6\) be rejected if produced at elevated temperatures. Of course, mix produced at temperatures in excess of established temperature limits for HMA should be rejected. Rejection of WMA produced via water injection due to it being at acceptable HMA temperature, even though it can be again utilized as recycle, wastes processing energy. In fact, for every load of WMA rejected while in an acceptable HMA temperature range, approximately 8 additional loads of WMA at lower temperatures would have to be produced offset the wasted processing energy.

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\(^5\) HMA produced at 330°F, WMA at 275°F during continuous steady-state operation. A stack temperature reduction of 35°F is assumed at all levels of RAP usage (this approximates field observations). RAP moisture is assumed to be 3%. Other operational factors are assumed typical. Since other operational factors may affect fuel consumption, these approximations may be considered for budgetary estimates only and do not constitute a guarantee.

\(^6\) Some joint materials expand when subjected to HMA temperatures resulting in pavement failure or the increased potential for failure at the joint. Under such circumstances, hot WMA should be rejected for these reasons. Of course, any rejected mix should be diverted to other jobs if possible to reduce the environmental impact.
APPENDIX 4: Calibration Instructions
(Green Pac™ for Continuous and Double Barrel Green®)

1. Water calibration requires a 5 gallon (19 liter) container and access to a calibrated laboratory scale capable of weighing with sufficient accuracy up to approximately 45 lb (20kg).
2. Tare the bucket and write the tare weight on the bucket for reference.
3. From the “Home screen”, press [H2O], then [CAL]
4. At the water skid, open the 2-way ball valve on the calibration leg of the water line and close the 2-way ball valve on the water supply to the manifold. Set the “H2O Cal Spd”, (water calibration speed) to 30 % of the pump output (this pump speed may need to be adjusted based upon the calibration bucket size). **Note: Some systems may be fitted with a single 3-way valve in lieu of two (2) 2-way valves.**
5. Enter a time, in seconds, into H2O Cal Time. Choose a time that will fill the bucket at least 80% full at the calibration speed.
6. Press and hold [Start] until the timer begins to time countdown. It is important to HOLD your finger on [Start] until the counter begins (approximately 2 seconds).
7. The calibrator is calculating a “Computed Weight”
8. When the timer reaches 0 seconds, remove the bucket and weigh it.
   a. Actual Water Weight = Gross Weight - Bucket (tare) Weight
9. Enter the Actual Water Weight (lbs) in the “Actual Weight” field on the touch screen.
10. The built-in water calibration screen calculates the error and makes the calibration correction automatically.
11. If error is above acceptable limits, try steps 2 -10 again.
APPENDIX 4: Calibration Instructions  
(Green Pac™ for Batch)

1. Water calibration requires a 5 gallon (19 liter) container, a stop watch, and access to a calibrated laboratory scale capable of weighing up to approximately 45 lb (20kg).
2. Tare the bucket. Write the tare weight on the bucket for reference.
3. At the water skid, open the 2-way ball valve on the calibration leg of the water line and close the 2-way ball valve on the water supply to the manifold. **Note:** Some systems may be fitted with a single 3-way valve in lieu of two (2) 2-way valves.
4. Place the Danfoss drive in “Hand On” instead of “Auto On”. Refer to the Danfoss drive manual located in the document sleeve inside the PLC panel mounted on the water skid.
5. Set a water pump speed (Hz) using the Danfoss drive. This will be the “Calibration Frequency”
6. Using the stopwatch, time how long it takes to fill 5-gallon (19 liter) container to near 80% of its capacity (Calibration Time).
7. Weigh the bucket (Gross Water Weight).
8. From any screen: Press [Home]/[System]/[Config].
9. Use the built in calculator to get the required flow rate for this plant.
10. First determine the number of pounds of asphalt the weigh-pot holds, next determine how many seconds it takes to empty the weigh-pot.
11. Enter these numbers and the percentage of water desired (default is 2%) from the touch panel into the appropriate fields on the “Config” screen. The calculator will give you “Calculated Rate (H2O)” in GPM/LPM. H2O Manual Speed (percentage) may be calculated by the following formula (shown on the next page).
12. Input “H2O Manual Speed” into the field on the “Config” screen. The system is now calibrated.

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Standard Units (shortTPH, lb, gallons, GPM):

Calibrated Flow Rate (GPM) = \( \frac{Gross \text{ Water Weight} - \text{Bucket Tare}}{8.337} \div \text{Calibration Time (min)} \)

Metric Units (MTPH, kg, liters, LPM):

Calibrated Flow Rate (LPM) = \( \frac{Gross \text{ Water Weight} - \text{Bucket Tare}}{\text{Calibration Time (min)}} \)

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H2O Manual Speed = \( \frac{\text{Calibration Frequency}}{\text{Calibrated Flowrate}} \times \frac{\text{Calculated Rate} (H2O)}{120} \times 100 \)

Where,

\( \text{Calibration Frequency} \) = the frequency in Hz at which you performed the calibration.

\( \text{Calibrated Flow Rate} \) = the flow rate (GPM/LPM) that determined at during the calibration.

\( \text{Calculated Rate} (H2O) \) = the rate of flow calculated using the built-in calculator on the touch screen.
APPENDIX 5: COLD WEATHER PACKAGE AND WINTERIZING

Cold Weather Package
Often the production of WMA will coincide with temperatures that fall far below freezing overnight. Such low temperatures could result in catastrophic damage to system components due to water freezing within them. A “Cold Weather Package” is available through Astec Parts if the package was not originally included with the system. The cold weather package consists of:

1. Electric heat trace for waterlines and pump.
2. Foam insulation for the water lines
3. Tank heater to prevent the tank from icing.
4. Insulating pump and manifold jacket.
5. Installation hardware.

Since the cold weather package consists mostly of commonly available components, some HMA producers wish to configure their own using their own preferred components.
APPENDIX 5: COLD WEATHER PACKAGE AND WINTERIZING

CAUTION!
The Cold Weather Package is NOT meant as a “winterizing” package. Catastrophic damage to system components may occur if the Cold Weather Package is used as a “winterizing” package.

Winterizing the Unit
To winterize the unit over extended shutdown periods in cold weather, displace the water in the system components and piping with a suitable fluid with freezing point below the lowest temperature expected. Ordinary windshield wiper fluid works well in most regions.

Preparation for Winter:
1. You will need approximately 2-gallons of commonly available windshield wiper fluid and a helper to monitor the level of wiper fluid remaining in the container.
2. Disconnect the inlet hose from the tank. Leave the other end connected to the pump.
3. Drain the water tank (close the ball valve at the tank outlet when finished).
4. Place the tank side of the inlet hose into a container of windshield wiper fluid.
5. Navigate to the “H2O Manual” screen. Input “10” into the “H2O Manual Speed” field. This is 10% pump speed. You may wish to try a higher speed to expedite the process.
7. Press and hold [START] for about 2 seconds. The pump will begin running.
8. Press [H2O 1] to open the water injectors. The pump will draw the wiper fluid into the inlet hose and pump it through the injectors.
9. Have your helper monitor the level of wiper fluid in the container.

**CAUTION**
DO NOT allow the pump to gulp air as the pump may be damaged.

10. Continue until the fluid is visible in the flow indicators. Continue a few more seconds to ensure that fluid has reached and filled the water injectors.
11. Press and hold [STOP] for about 2 seconds. The pump will cease running.
13. Shut the unit off at the PLC panel mounted on the skid. Reattach the supply hose to the water tank.
### Appendix 6: Revision Summary

<table>
<thead>
<tr>
<th>Revision#</th>
<th>Description</th>
<th>Effective Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Added FAQ regarding the observed tendency of some liquid binders to foam differently than others.</td>
<td>3-18-11</td>
</tr>
</tbody>
</table>
| 2         | • Added FAQ on compaction temperatures of plant-produced laboratory specimens for Marshall and gyratory samples.  
• Added “Revision Summary” appendix – Appendix 6. | 5-9-11         |
| 3         | • Added FAQ regarding SMA mixes using PG76-22 to Appendix 1.                | 9-23-11        |
| 4         | • Added the word “plenum” where “standpipe” is used to include latest configurations.  
• Added table of “Dosage Rates” per NYSDOT request to page 5 of 20. | 4-12-17        |