ENVIRONMENTAL SUSTAINABILITY ISSUES IN PAVING INDUSTRY "WARM MIX ADDITIVES"

NABin Conference

Oslo, Norway

October 23, 2018

Serji Amirkhanian

Human Being

University of Alabama

UNIVERSITY OF ALABAMA

- Opened in 1831
- 1,970-acre (800 ha) campus
- 297 buildings; 1,000,000 m2 of space
- ~40,000 students and offers over 275 degrees
- 6,034 faculty and staff
- University's expenditures/year = 1.2 billion USD



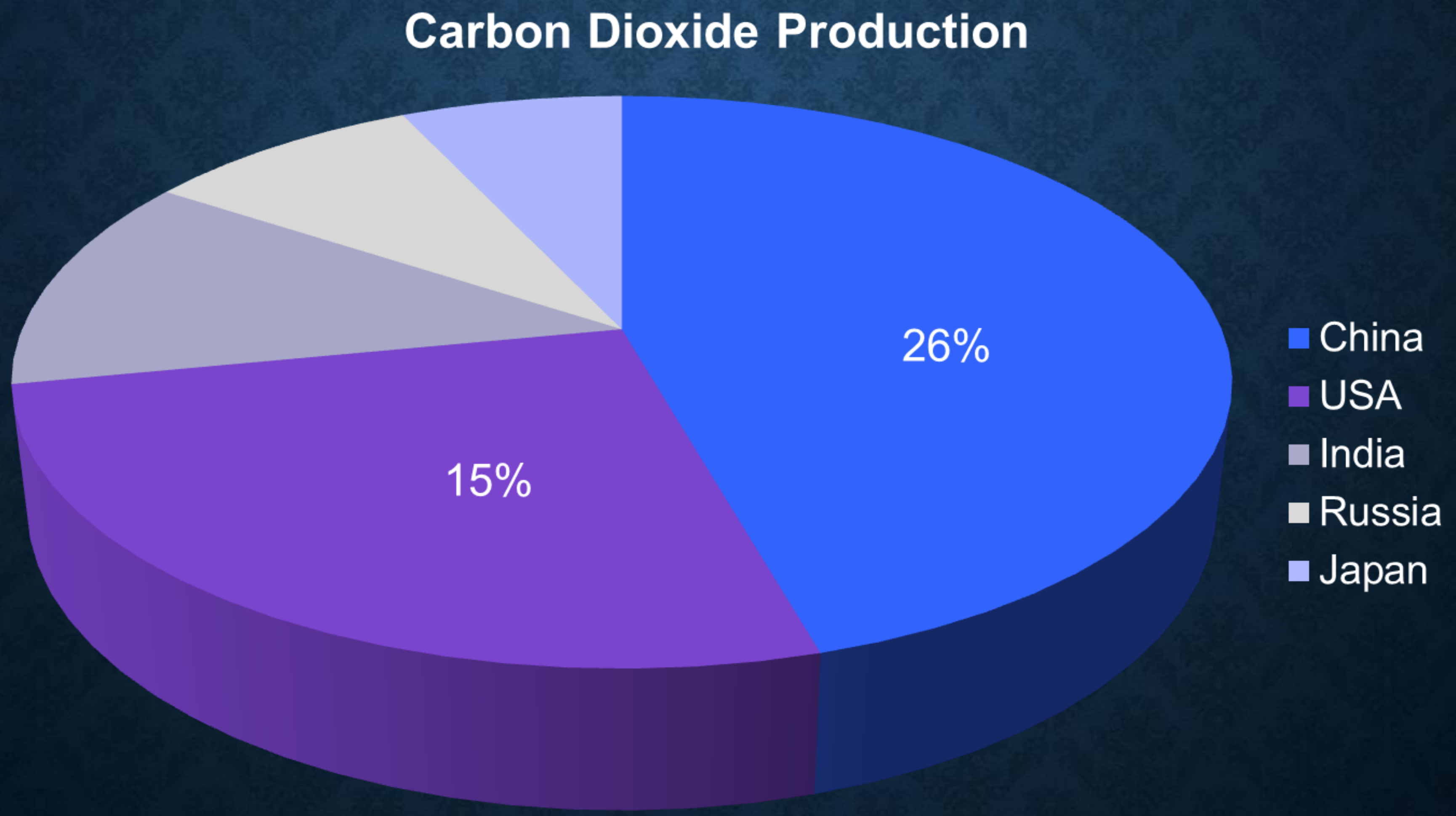
HOW DO YOU DEFINE SUSTAINABILITY?

WHAT IS A CARBON FOOTPRINT – DEFINITION

- The total amount of greenhouse gases produced to directly and indirectly support human activities
- Expressed in equivalent tons of carbon dioxide (CO2)

Home energy accounts for 21% of America's global warming pollution. If we make smart choices, we can cut more pollution than the entire emissions of over 100 countries!

AS OF THIS MORNING

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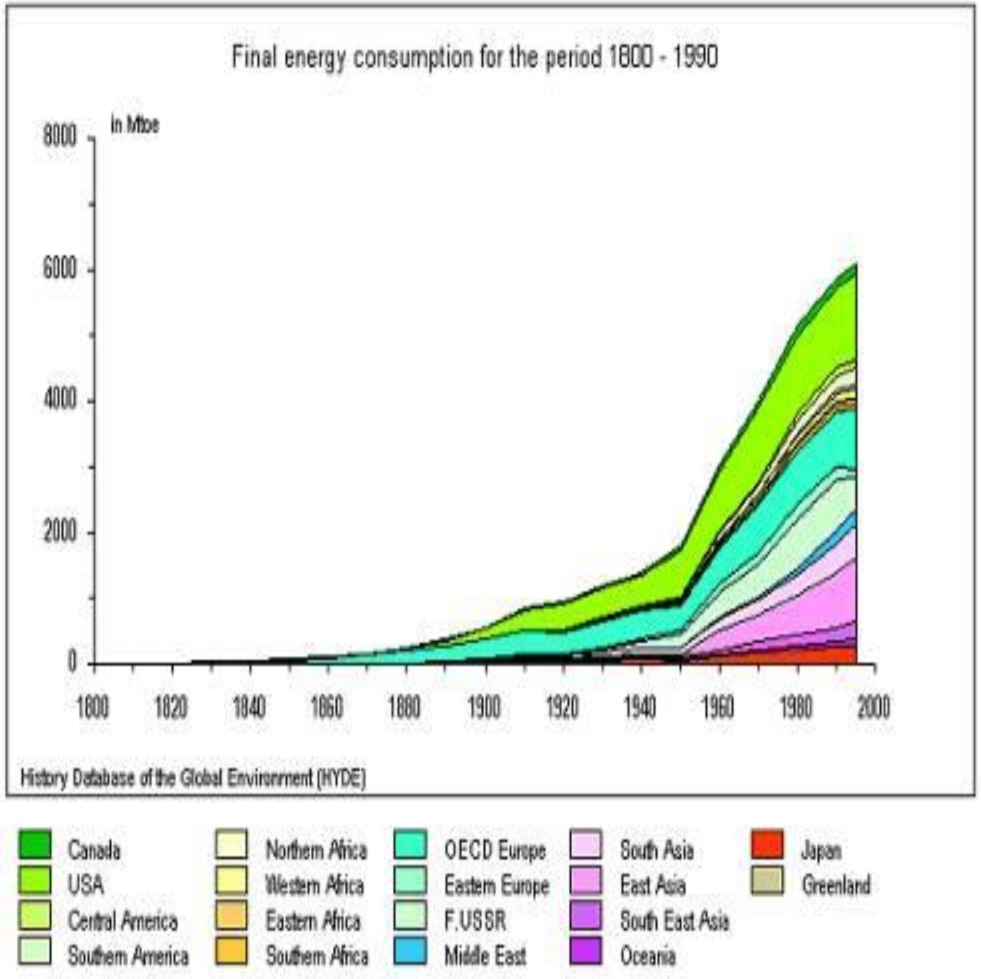
60% ate is
acc ed to

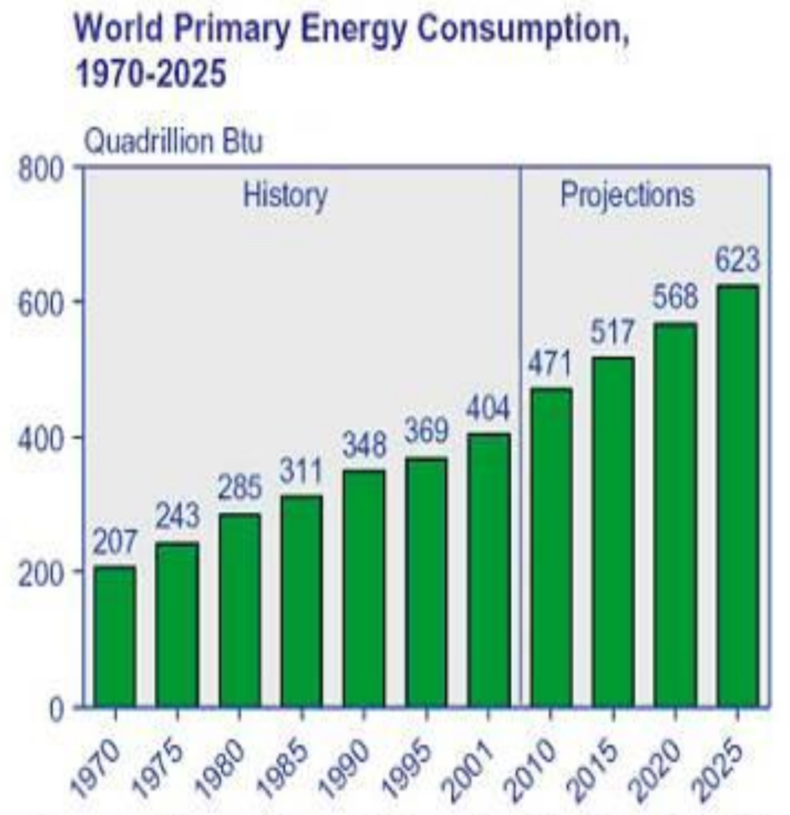
Future Problems??

- The developed world is 75% urban
- Rate is accelerating in the developing world
- By 2030: urban population is expected to rise to five billion or 60% of the world’s population

World energy consumption pattern

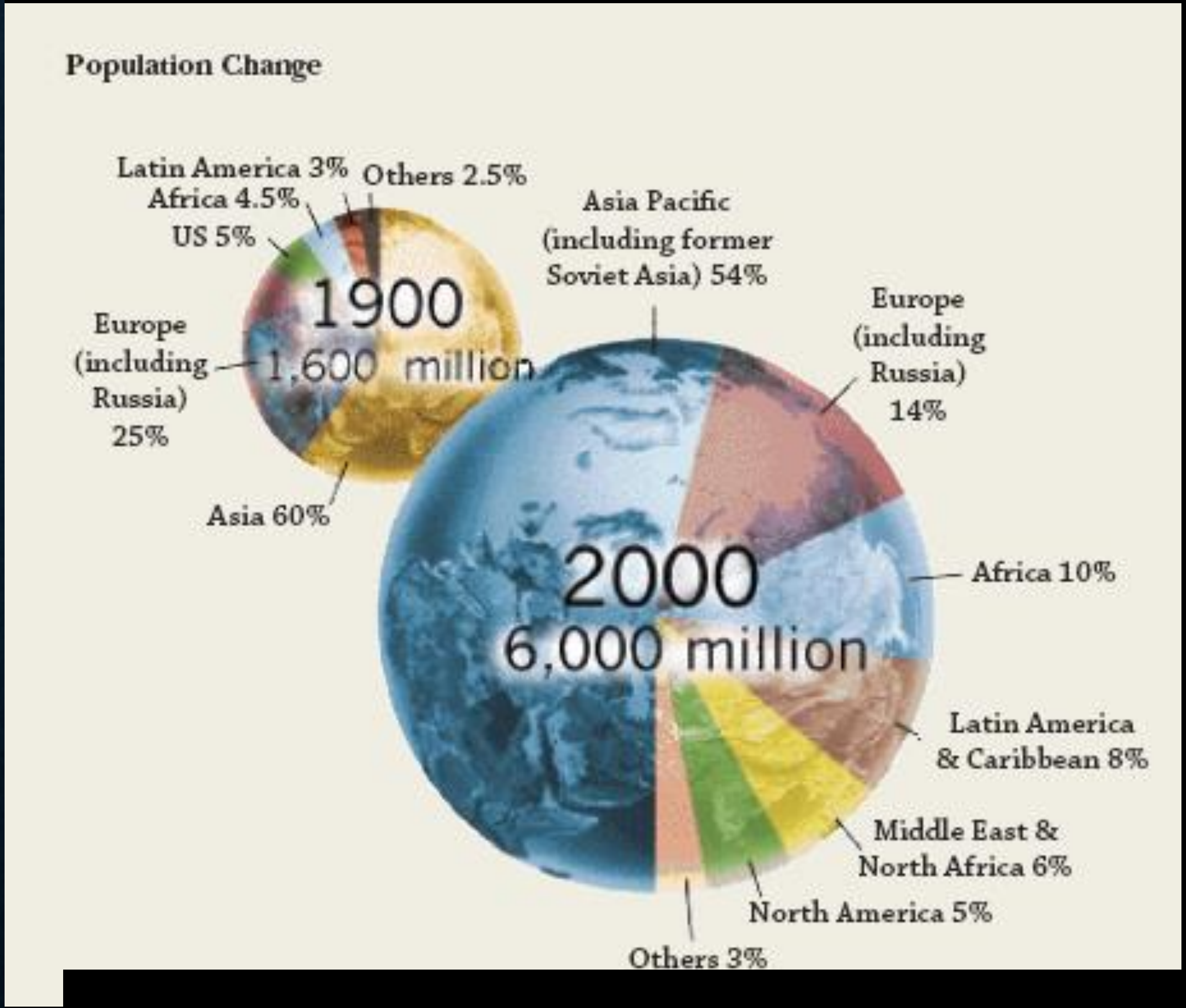


Source: Darmstadter (1971), Etemad et al. (1991), IEA (1998).



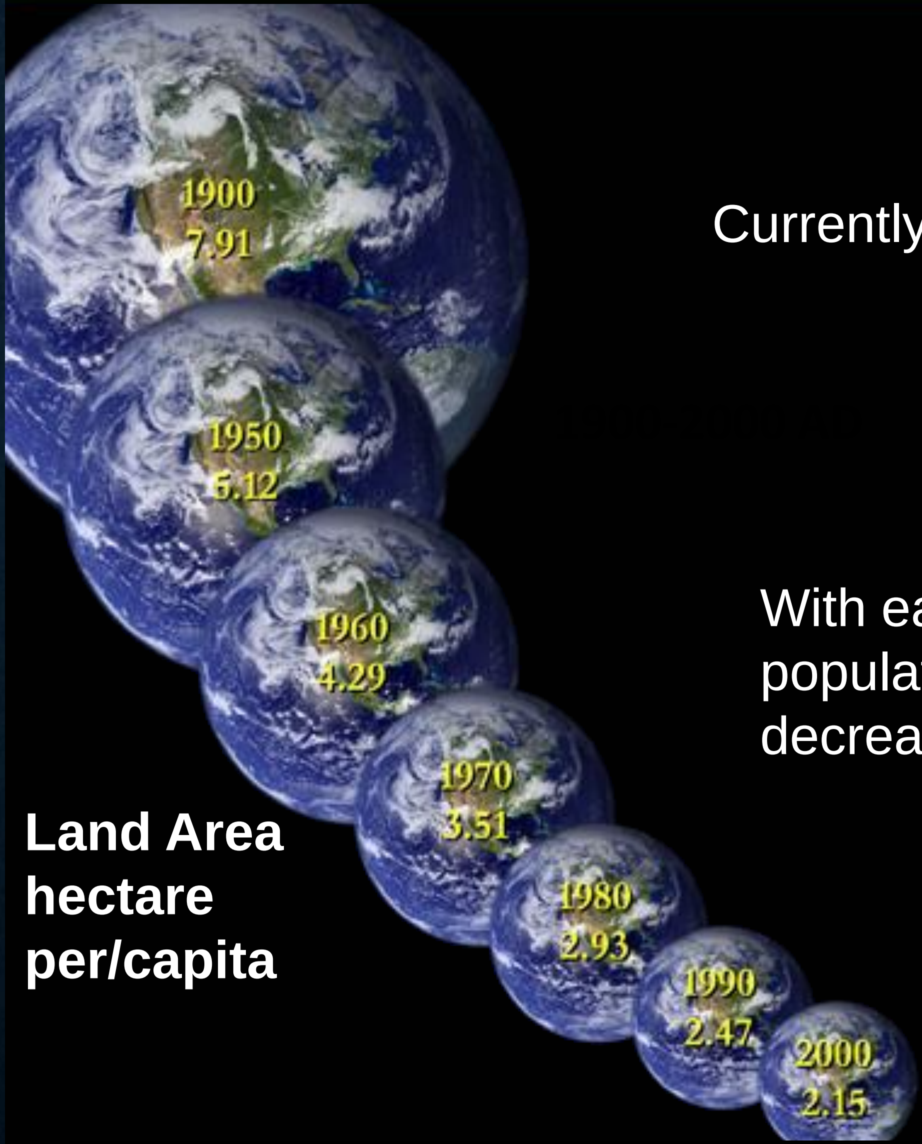
Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2001*, DOE/EIA-0219(2001) (Washington, DC, February 2003), web site www.eia.doe.gov/iea/. **Projections:** EIA, System for the Analysis of Global Energy Markets (2004).

Our growing population



Population Change from 1900-2000

Earth’s Shrinking Biosphere



Land Area hectare per/capita

Currently, the Earth is the only home we have

With each new person added to our growing population, the amount of our living space decreases

Human influence on the planet

- Population
- World Energy Consumption
- Water Pollution
- Biodiversity
- Invasive Species
- Protected Areas
- Air Pollution

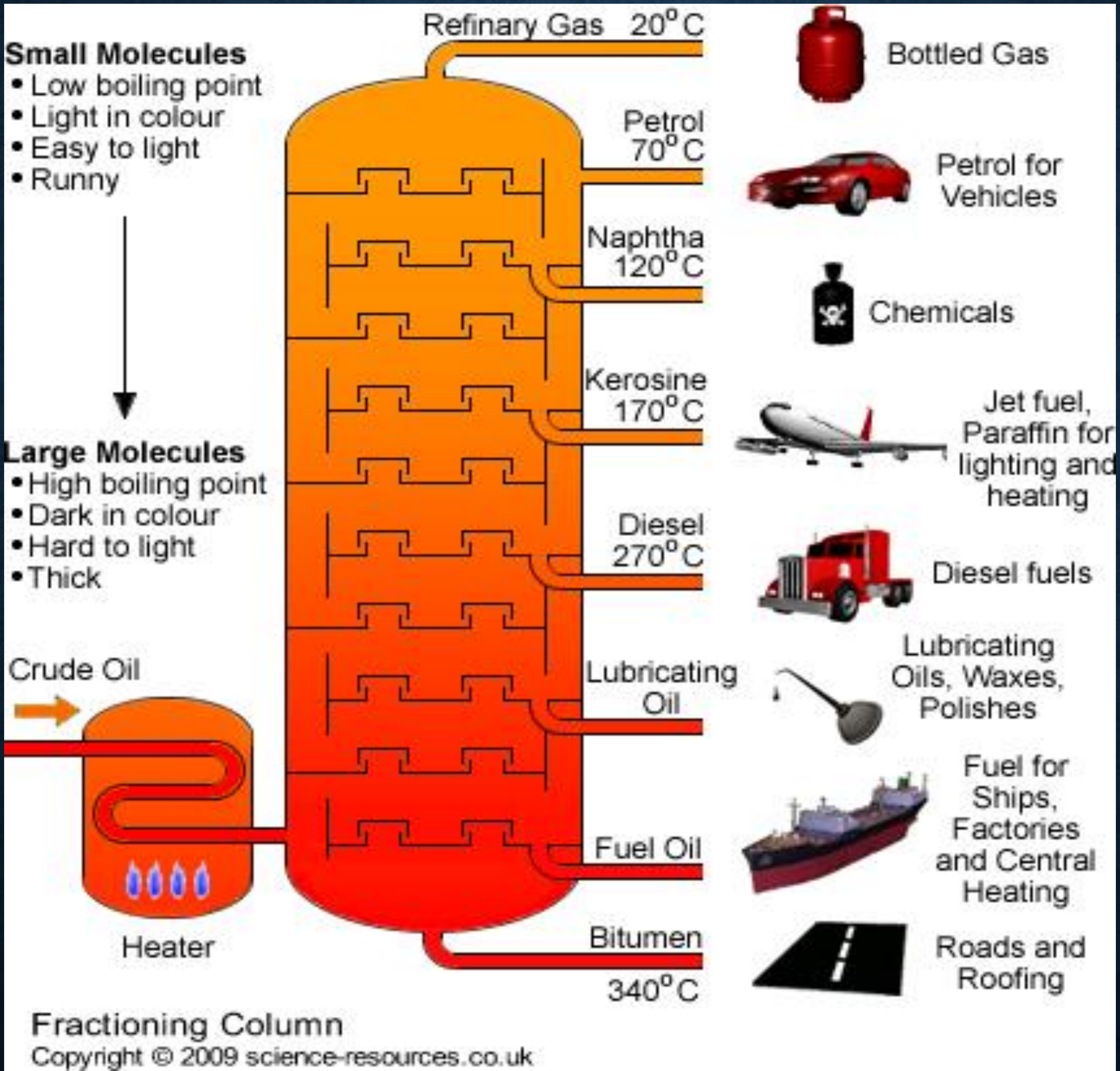
UNEP

POPULATION ISSUES

- 2025: 8,000,000,000
- 2040: 9,000,000,000
- 2100: 11,000,000,000
- The world economy: will grow 26 times this century
- Resources NOW: use 160%
- Can we sustain this rate of growth!

NUMBERS, NUMBERS AND MORE NUMBERS! GLOBALLY (2018, UP TO SEPT 2018)

- Tons of resources extracted from earth: 36,250,000,000
- Tons of waste dumped: 1,400,000,000
- # of consumers: 3,220,800,000
- # of planet earths we need to provide resources & absorb our waste: 1.696793548



Refinary Gas 20°C
Bottled Gas
Small Molecules
• Low boiling point
• Light in colour
• Easy to light
• Runny
Petrol 70°C
Petrol for Vehicles
Naphtha 120°C
Chemicals
Kerosine 170°C
Jet fuel, Paraffin for lighting and heating
Large Molecules
• High boiling point
• Dark in colour
• Hard to light
• Thick
Diesel 270°C
Diesel fuels
Crude Oil
Lubricating Oil
Lubricating Oils, Waxes, Polishes
Fuel Oil
Fuel for Ships, Factories and Central Heating
Heater
Bitumen
340°C
Roads and Roofing
Fractioning Column
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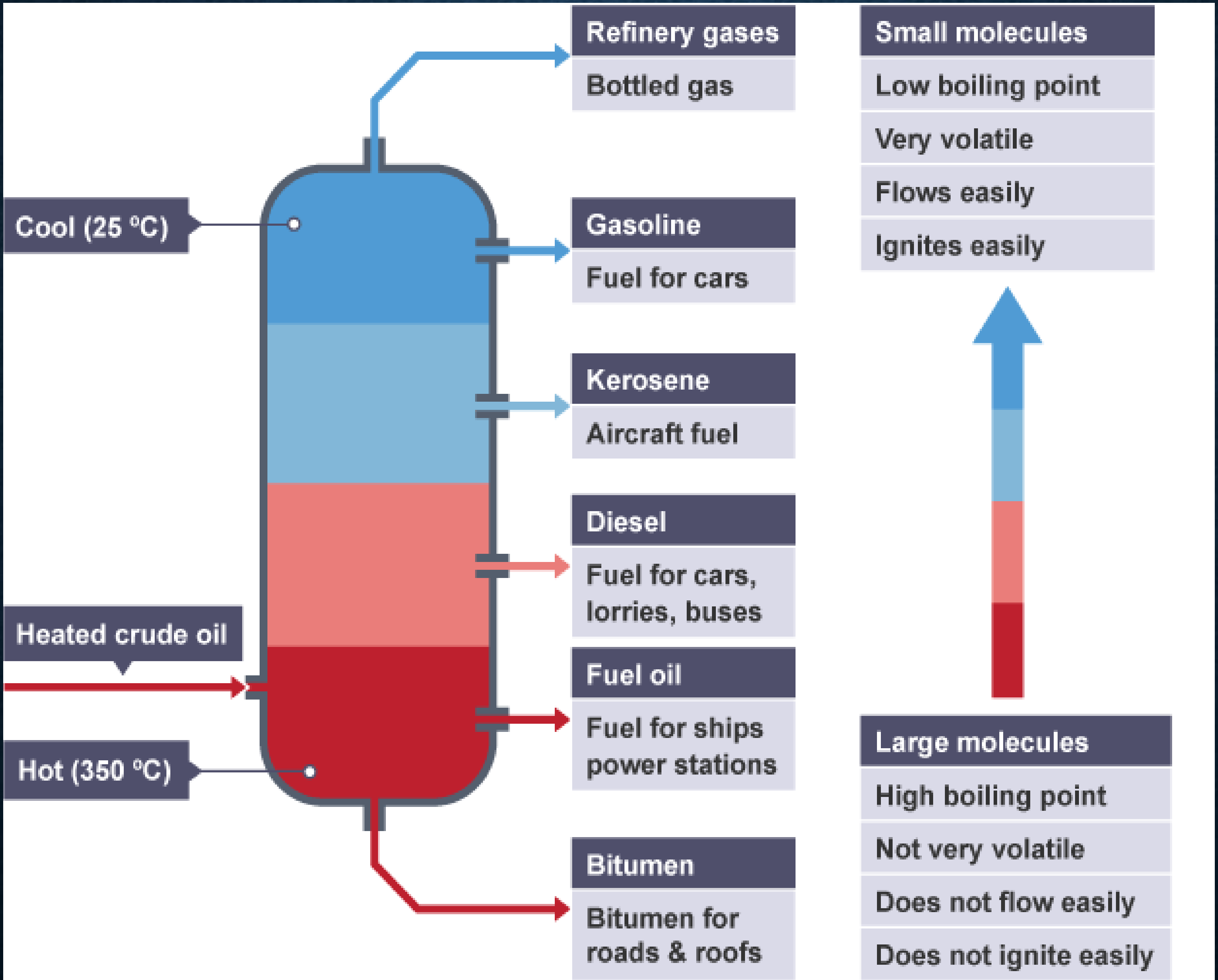
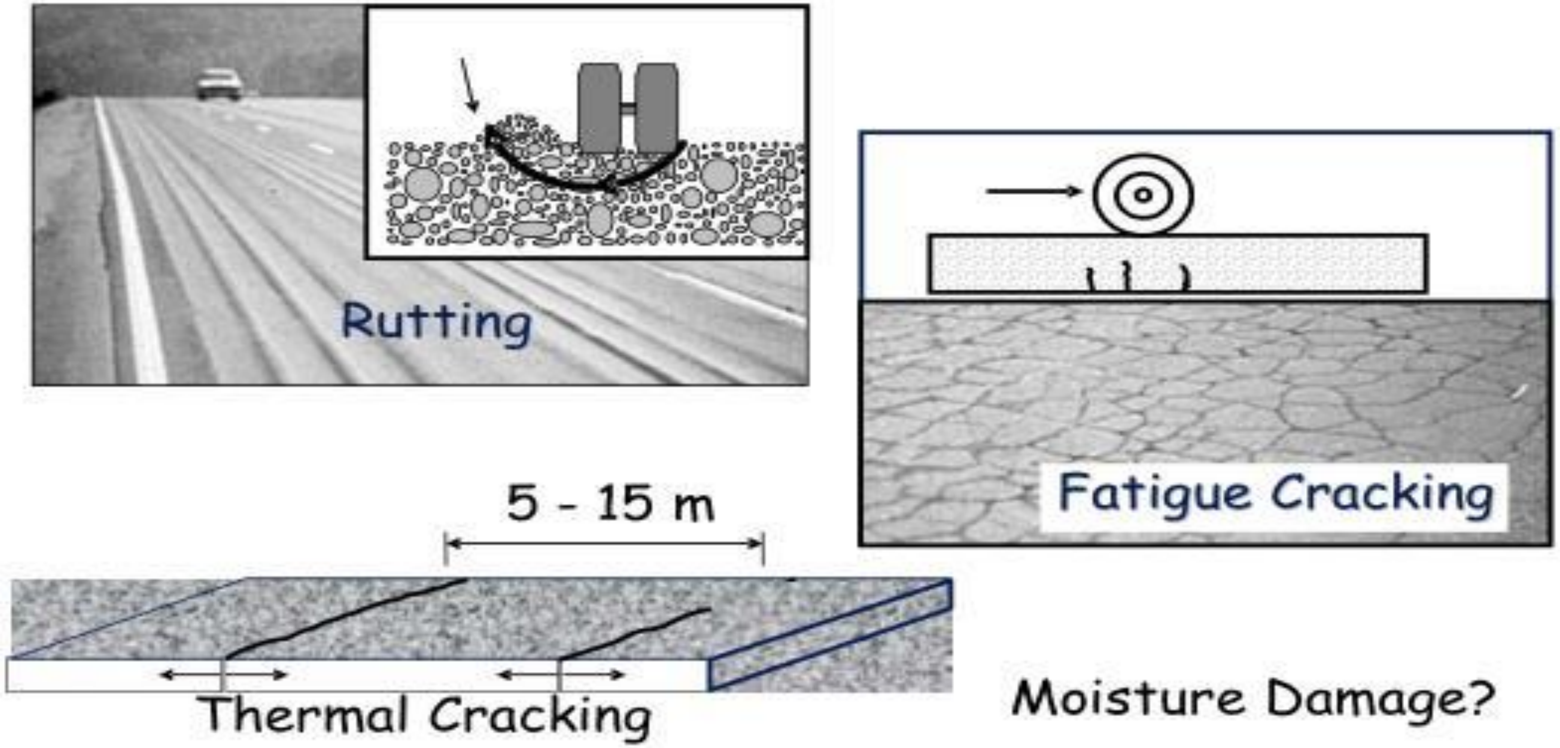

Refinery gases
Bottled gas
Gasoline
Fuel for cars
Kerosene
Aircraft fuel
Diesel
Fuel for cars, lorries, buses
Fuel oil
Fuel for ships power stations
Bitumen
Bitumen for roads & roofs
Cool (25 °C)
Heated crude oil
Hot (350 °C)
Small molecules
Low boiling point
Very volatile
Flows easily
Ignites easily
Large molecules
High boiling point
Not very volatile
Does not flow easily
Does not ignite easily

Primary Distress Modes HMA Pavements



THE PROBLEM

- The road sector produces the highest level of greenhouse gas, directly, through
  - fossil energy used in mining,
  - transportation,
  - paving works… and indirectly through the
    - emissions coming from vehicles.
  - Increase in the number of road vehicles:
    - increase in pollution and
    - noise disturbances.

CHALLENGES

- Cheaper materials
- Better production
- Better construction
- Maintenance issues
- Raw materials are becoming scarce
- The environmental laws are getting stricter regarding air pollution and noise

ISSUES TO CONSIDER

- Environmental Issues
- Cost Issues (Initial and LCCA)
- Compatibility Issues
- Recycling of the New Pavement
- Public Perceptions
- Acceptance by Governmental Agencies

FIRST MODERN ASPHALT FACILITY

Built in 1901 by Warren Brothers in East Cambridge, Massachusetts

CURRENT ASPHALT PLANTS IN UNITED STATES

- ✓ About 4,000 asphalt mixing plants
- ✓ Mostly drum mix plants
- ✓ Produces 550 million tons of HMA

DYNAMIC SHEAR RHEOMETER (DSR)

DYNAMIC SHEAR RHEOMETER (DSR)

- Used to determine rheological properties of asphalt binders.
- Measures the complex modulus $G*$ and phase angle δ resulting from oscillating shear stress.
- The relation $G*/\sin(\delta)$ is found to correlate well with rut resistance at high temperatures
- The relation $G* \sin(\delta)$ is found to correlate well with fatigue resistance at intermediate temperatures.

LOW TEMPERATURES: BBR

THE MULTIPLE STRESS CREEP RECOVERY (MSCR)

- MSCR is an additional test for the DSR.
- It is designed for modified binders to quantify the elastic response introduced by polymer modification.
- The test determines the elastic recovery R and non-recoverable creep compliance Jnr by subjecting the binder to repeated shear strains and allowing it to recover before reloading.
- The MSCR test is performed on RTFO-aged material.

THE STORY OF WMA

BRIEF HISTORY

1997 German Bitumen Forum

2000 Second Euroasphalt & Eurobitume Congress (Barcelona)

NAPA 2002 European Scan Tour

– Germany and Norway

NAPA 2003-2008 Annual Meetings

World of Asphalt 2004

2005-2007 – Numerous U.S. Field Trials

2007 – FHWA/AASHTO Scan Tour

MECHANISM INVOLVED IN WMA

- Organic additives
- Chemical additives
- Foamed bitumen technologies

ORGANIC ADDITIVES

- Addition of an organic wax to bitumen or blending to asphalt concrete mixtures, reducing the viscosity of the binder.
- When the asphalt cools, the additive crystallizes forming a lattice structure of microscopic particles.
- Sasobit- produced from natural gas using the Fisher-Tropsch(FT) process
- Asphaltan-B- blend of wax obtained by solvent extraction from lignite or brown coal (Montan wax) and fatty-acid amides
- Thiopave™- a technology that uses a Sulphur-enhanced additive.

CHEMICAL ADDITIVES

- Chemical additives may reduce the mix and compaction temperatures around 30°C
- Aggregates are heated before mixing, the water within the emulsion vaporizes during the production process and the binder covers the aggregate particles
- Package of products such as surfactants, emulsification agents, aggregate coating enhancers and anti-stripping additives
- Rediset™ WMX and Cecabase RT - surfactant and adhesion agents
- Evotherm™ - emulsification agent

FOAM TECHNOLOGIES

- Bitumen foam is generally obtained by adding a small amount of cold pulverized water into preheated bitumen

- Foamed bitumen is obtained mixed together with aggregate at an ambient temperature or previously heated at a moderate temperature (under 100°C)

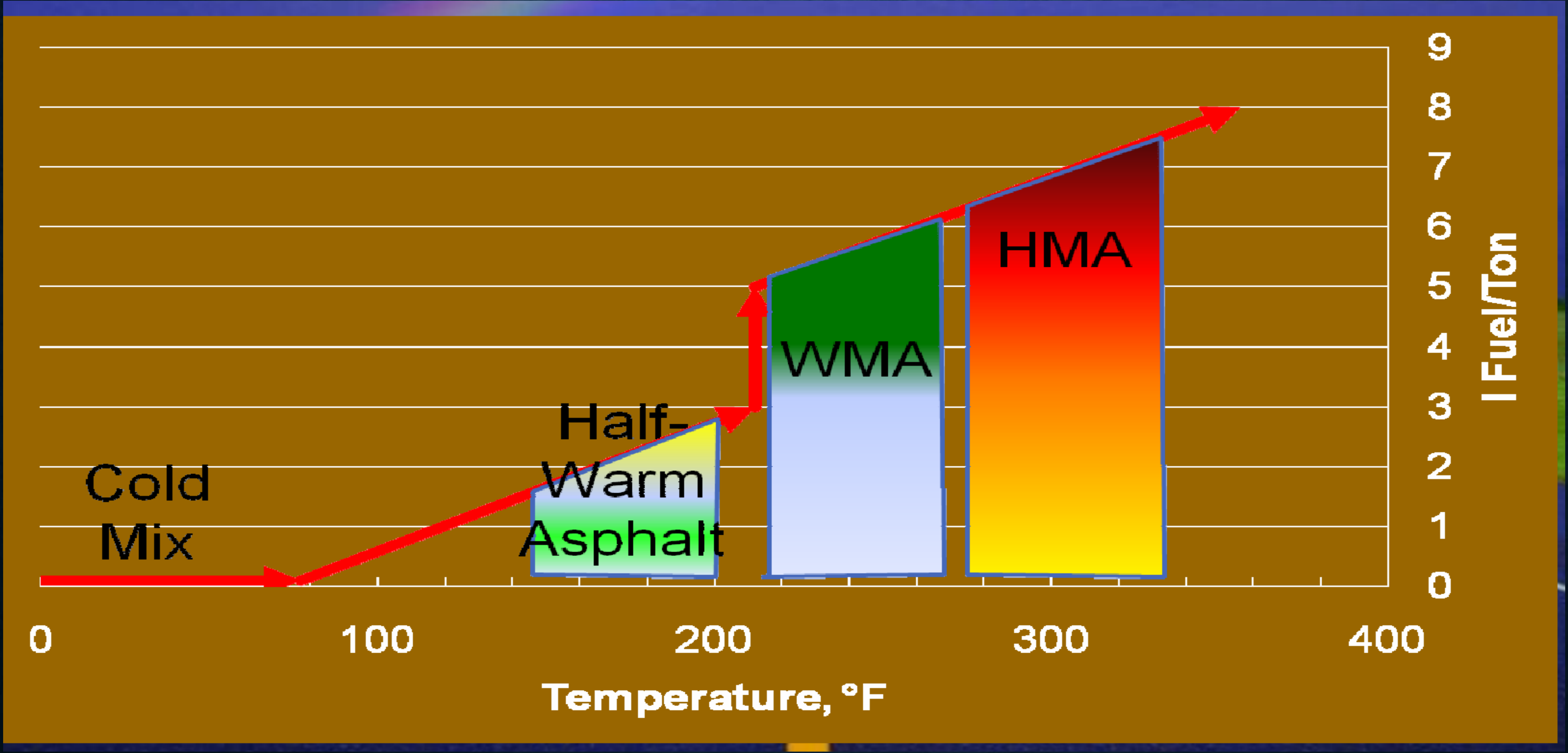
- Subcategorised - water based & water containing

- Water mixing technologies-

  -Low Energy Asphalt (LEA)

  -Warm Asphalt Mixes foam (WAM-foam™)

WARM MIX CLASSIFICATIONS



CAN YOU GUESS WHICH ONE IS WMA MIX?

PAVING IN YELLOWSTONE

MIXING TEMPERATURES OF HMA

Grade	HMA Plant Mixing Temperature, °C	
	Range	Midpoint
PG 58-28	127 ~ 154	140
PG 64-22	129 ~ 160	144
PG 70-22	138 ~ 165	152
PG 76-22	140 ~ 168	154

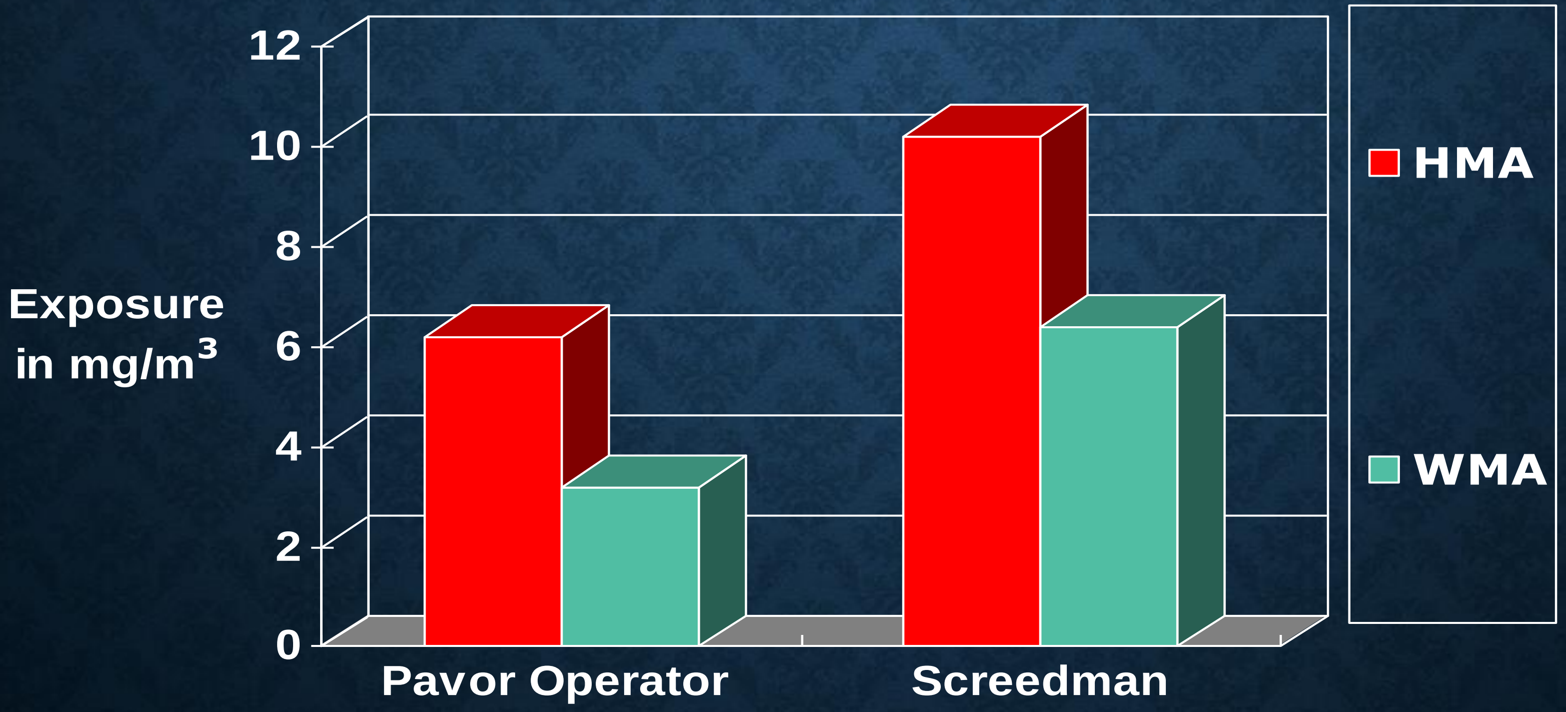
TOO HIGH TEMPERATURE OF ASPHALT MIX

- ✓ During the past century, the asphalt industry has been concerned about keeping the temperature of asphalt mix high enough for adequate coating, placement, and compaction.
- ✓ Therefore: raise the temperature of asphalt mix
- ✓ Now: for better performance and the environment: lower the temperature of asphalt mix by using Warm-Mix Asphalt (WMA)

WORKER'S EXPOSURE TO ASPHALT FUMES

- ✓ About 4,000 asphalt plants (Drum Mix Plants)
- ✓ 7,000 paving contractors
- ✓ Employing 300,000 people
- ✓ 1997: National Institute for Occupational Safety and Health (NIOSH) recommended that workers should not be exposed to airborne particulates at a concentration greater than 5mg/m^3 during any 15-minute period
- ✓ NIOSH: Insufficient evidence for an association between lung cancer and exposure to asphalt fumes during paving
- ✓ Asphalt fumes and PAHs at the HMA job site were below the current acceptable exposure limits

EXPOSURE OF WORKERS TO EMISSIONS WORKING AT HMA AND WMA JOB SITES



WMA PLANTS REDUCE GREENHOUSE GAS

- ✓ **The U.S. Environmental Protection Agency (EPA) issued a rule that was designed to reduce SO_2 by 70% and NO_x emissions by 60% by 2015.**
- ✓ **Some state and local governments require that HMA plants in some ozone sensitive areas limit asphalt production to a certain number of hours per week.**
- ✓ **WMA plants would reduce CO_2 and SO_2 by 30% to 40%, volatile organic compounds (VOC) by 50 percent, CO by 10% to 30%, NO_x by 60% to 70% and dust by 20% to 25%.**

WMA SAVES ENERGY COST COMPARED WITH HMA

	Iceland	Honolulu, HI	Joliet, IL
Fuel source	No. 2 Fuel oil	Diesel	Natural gas
Fuel to make 1 ton of HMA	2-3 gallons	2-3 gallons	2.5-3.5 therms
Fuel Cost	$2.50/gal	$2.20-3.20/gal	$0.70-0.80/therm
Fuel Cost to make 1 ton of HMA	$5.00-$7.50	$4.40-$9.00	$1.75-$2.80
Electricity to make 1 ton of HMA	8-14 kWh	8-14 kWh	8-14 kWh
Electricity Cost	$0.02/kWh	$0.1805/kWh	$0.0445/kWh
Average energy cost for 1 ton of HMA	$5.15-$7.78	$5.84-$11.53	$2.11-$3.44
20% savings with WMA	$1.00-$1.50	$0.88-$1.80	$0.35-$0.56
50% savings with WMA	$2.50-$3.75	$2.20-$4.50	$0.88-$1.40

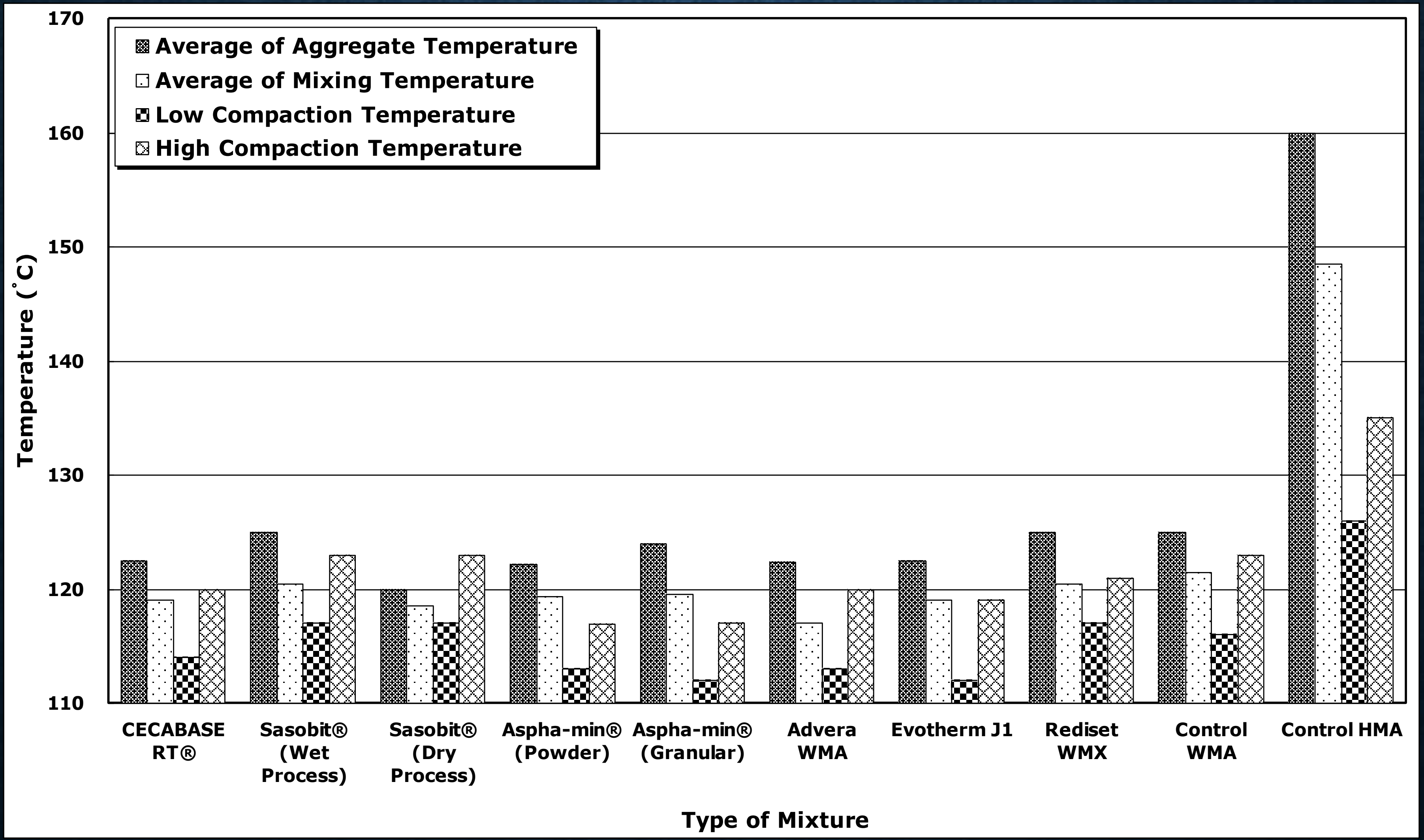
WMA TECHNOLOGIES (EXAMPLES)

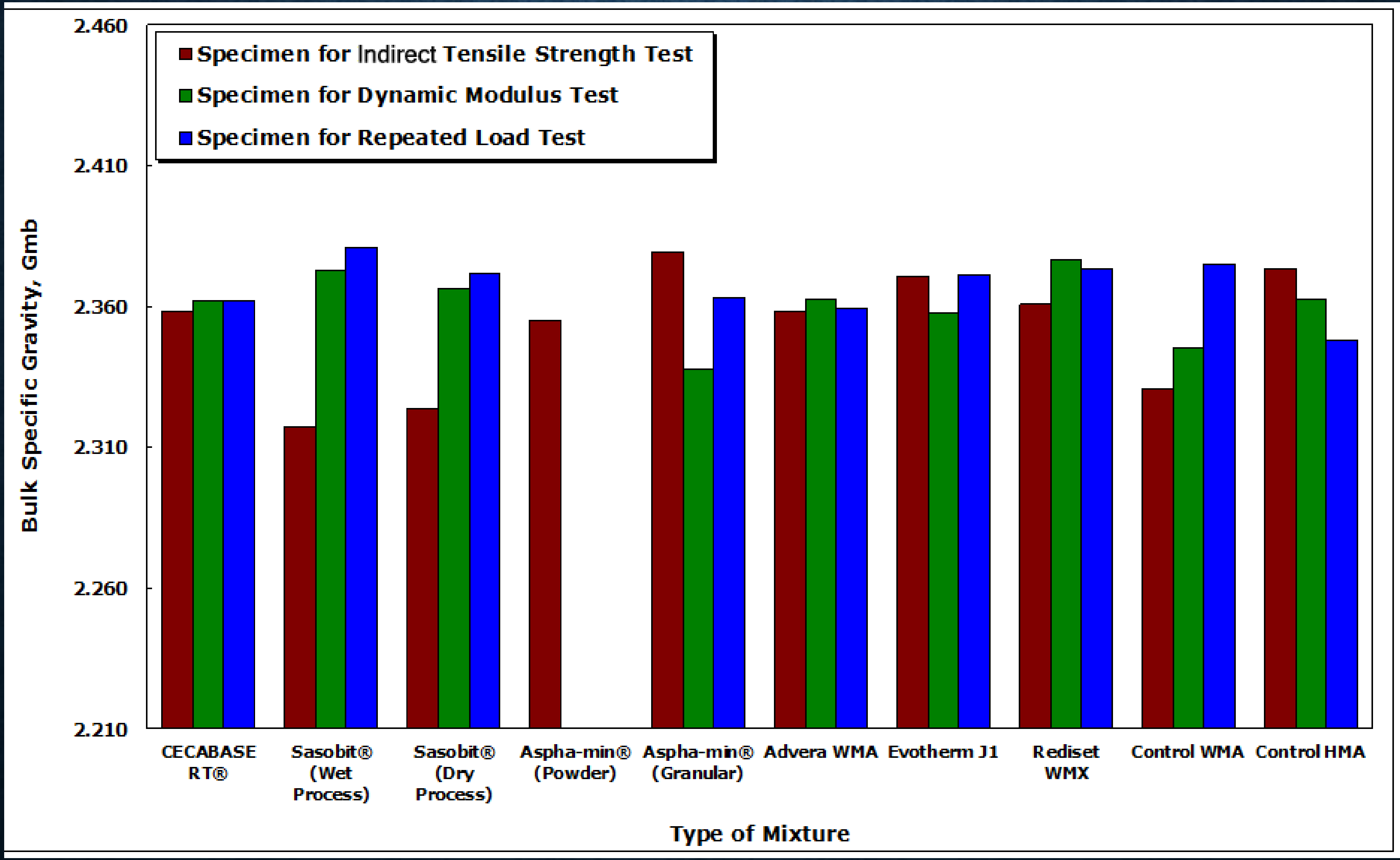
Category	WMA Additive	Company	U.S. Project
Organic	Sasobit®	Sasobit	Yes
	Asphaltan®	Romonta	N/A
	Licomont BS-100	Clariant	N/A
	Cecabase RT®	Ceca	Yes
	LeadCap	Kumho	Yes
Foaming	Advera®	Eurovia	Yes
	Aspha-Min®	PQ Corporation	Yes
	Low Energy Asphalt	McConnaughay Tech.	Yes
	Double-Barrel®Green	Astec	Yes
	Ultrafoam GX	Gencor	Yes
	Terex®WMA System	Terex	Yes
	Aquablack Warm Mix Asphalt	Maxam Equipment Inc	Yes
	WAM-Foam	Kolo Veidekke, Shell	N/A
Chemical	Evotherm J1	MeadWestVaco/Mathy	Yes
	Rediset™ WMA	Akzo Nobel	Yes

MIXING METHOD AND DOSAGE RATE OF WMA ADDITIVE (EXAMPLES)

Additive	Process	Dosage Rate
CECABASE RT®	Wet	0.40% of binder weight
Sasobit®	Dry	1.50% of binder weight
	Wet	
Asphalt-min®	Dry	0.30% of mixture weight
Advera WMA®	Dry	0.25% of mixture weight
Evotherm J1®	Wet	0.50% of binder weight
Rediset™ WMX	Wet	2.00% of binder weight

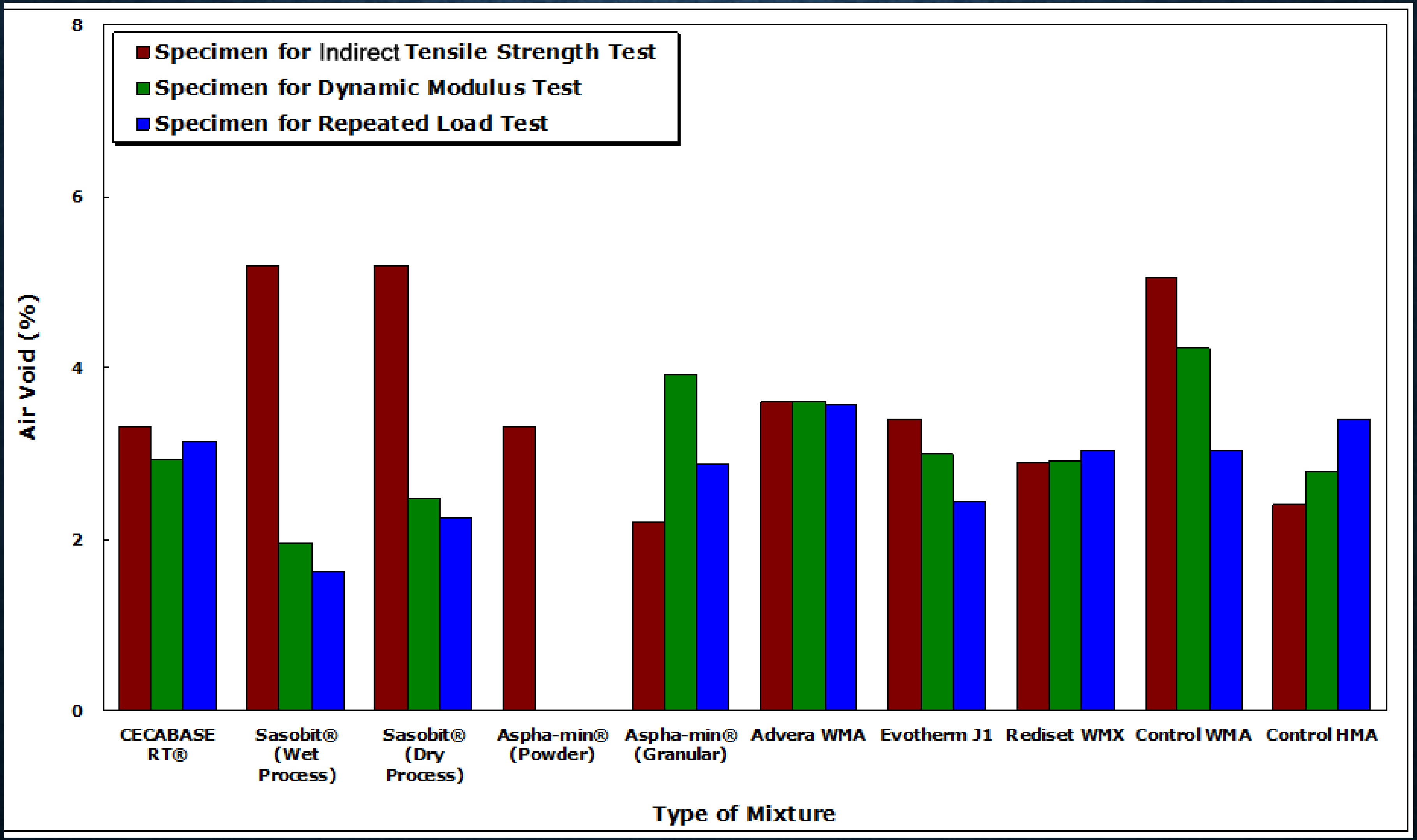
RESEARCH PROJECT:
MIXING AND COMPACTION TEMPERATURES OF WMA MIXTURES





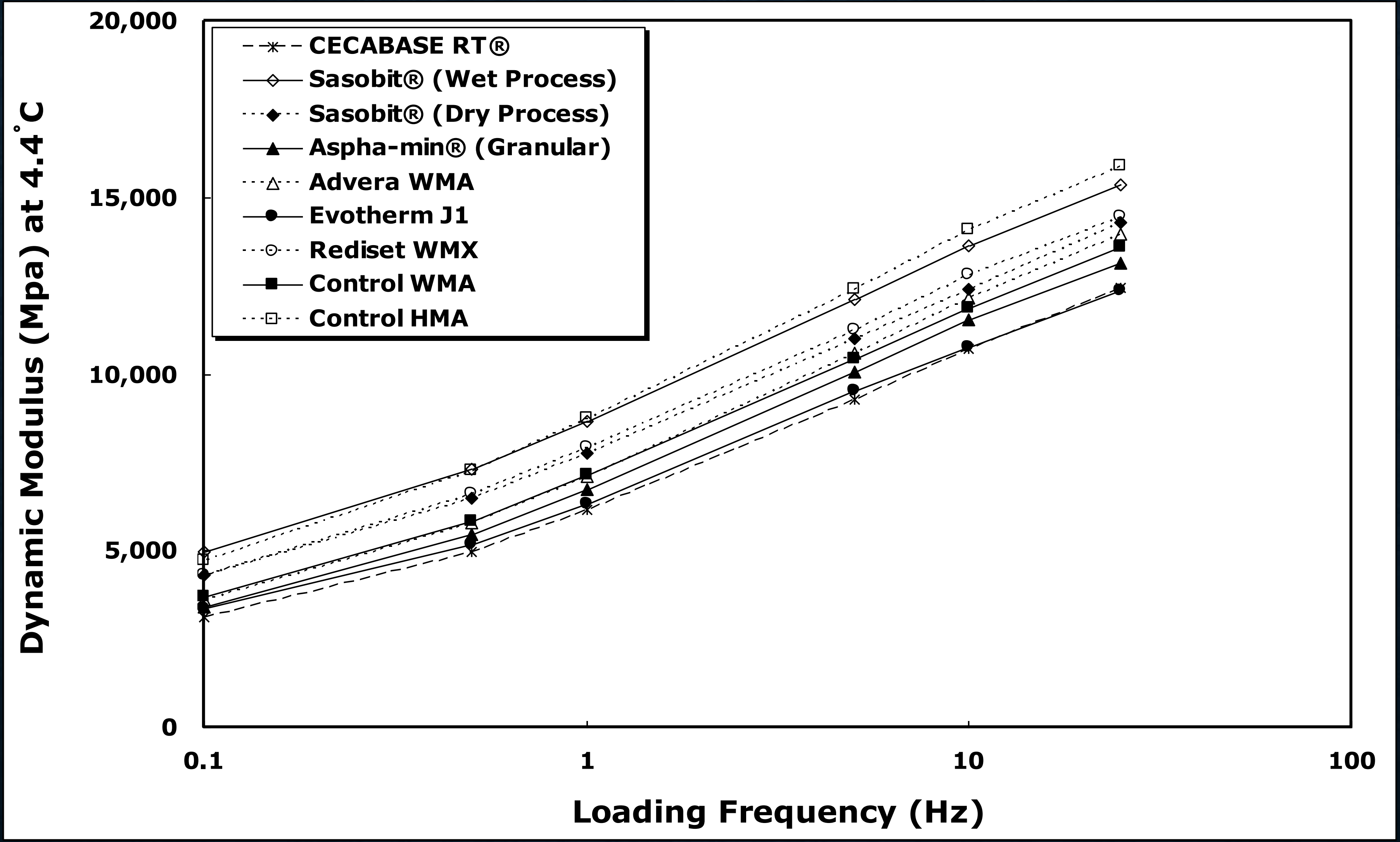
Specimen for Indirect Tensile Strength Test
Specimen for Dynamic Modulus Test
Specimen for Repeated Load Test
Bulk Specific Gravity, Gmb
2.460
2.410
2.360
2.310
2.260
2.210
CECABASE RT®
Sasobit® (Wet Process)
Sasobit® (Dry Process)
Aspha-min® (Powder)
Aspha-min® (Granular)
Advera WMA
Evotherm J1
Rediset WMX
Control WMA
Control HMA
Type of Mixture

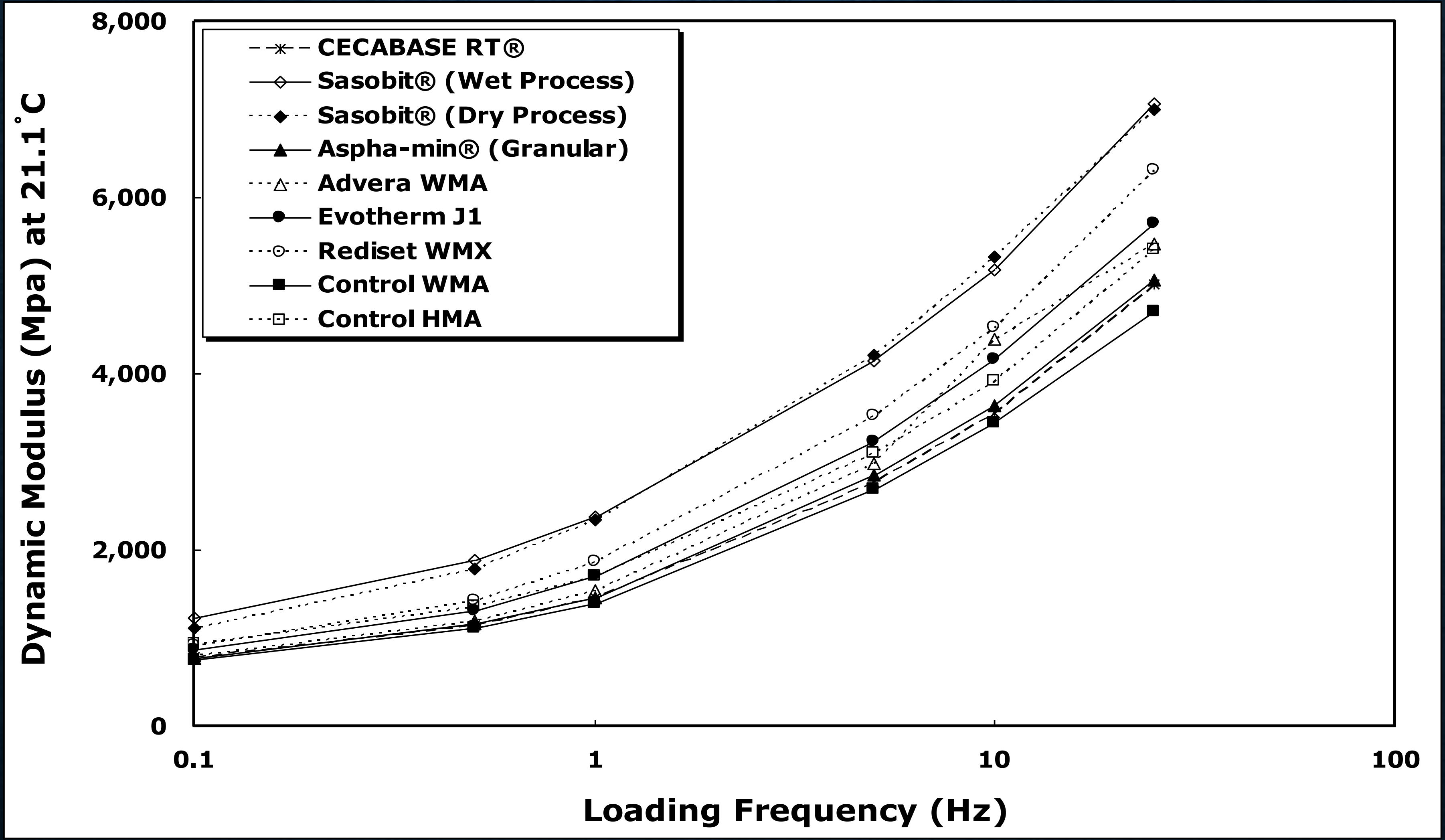
AIR VOIDS OF WMA MIXTURES



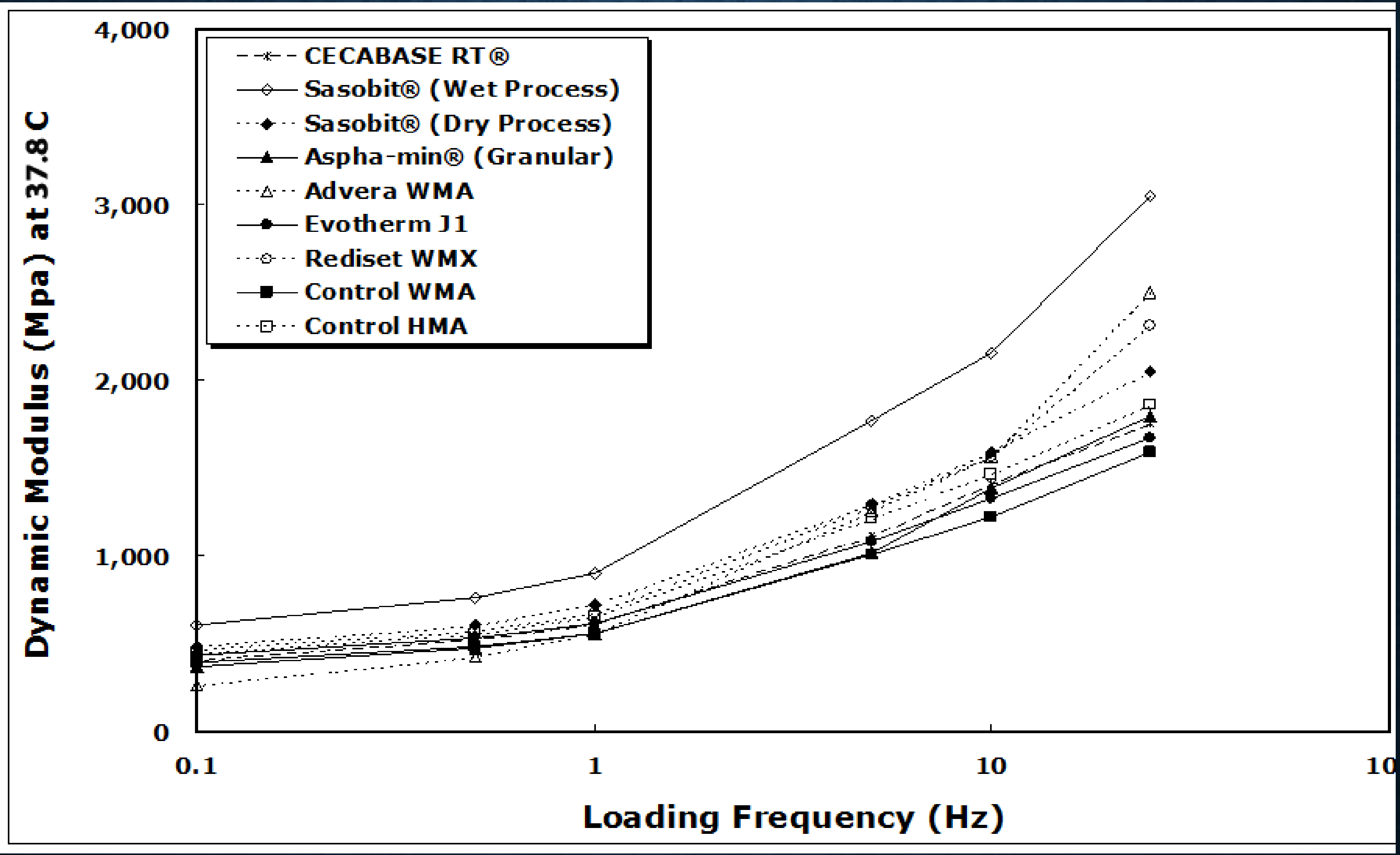
ASPHALT MATERIAL PERFORMANCE TESTING (AMPT) EQUIPMENT WAS USED TO MEASURE DYNAMIC MODULUS AND FLOW NUMBER

DYNAMIC MODULUS @ 4.4° C

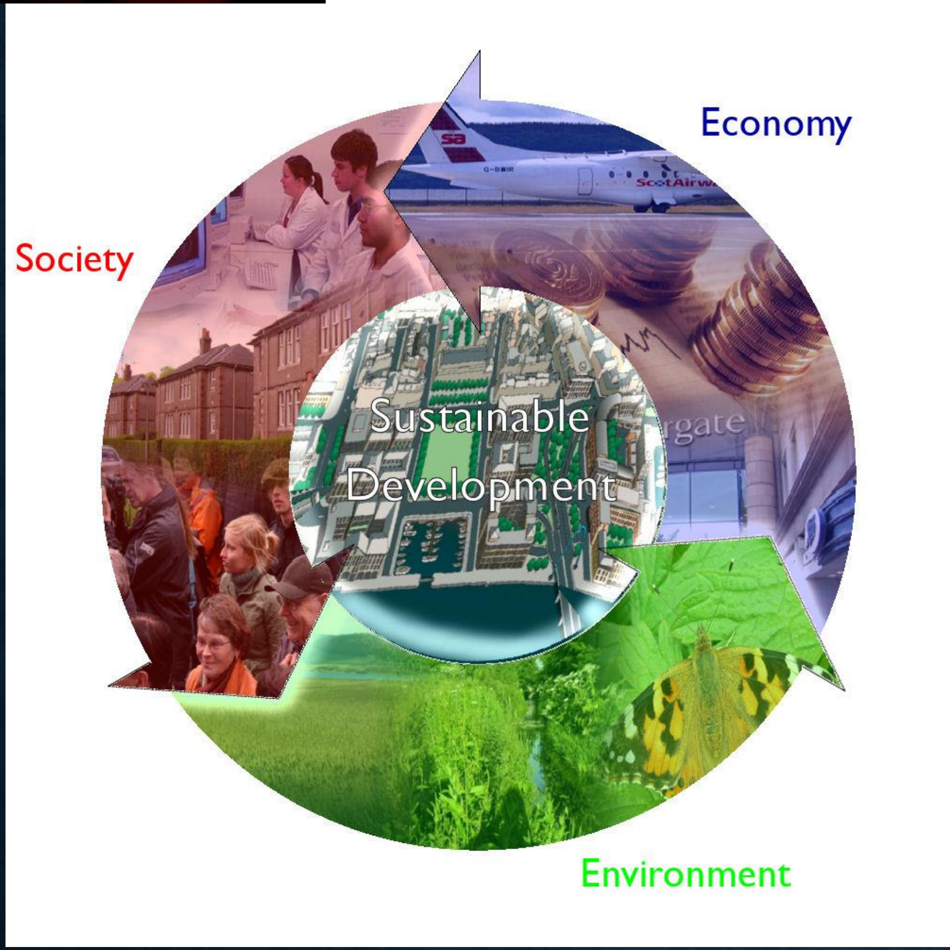




CECABASE RT®
Sasobit® (Wet Process)
Sasobit® (Dry Process)
Aspha-min® (Granular)
Advera WMA
Evotherm J1
Rediset WMX
Control WMA
Control HMA
Dynamic Modulus (Mpa) at 21.1˚C
Loading Frequency (Hz)
8,000
6,000
4,000
2,000
0
0.1
1
10
100


CECABASE RT®
Sasobit® (Wet Process)
Sasobit® (Dry Process)
Aspha-min® (Granular)
Advera WMA
Evotherm J1
Rediset WMX
Control WMA
Control HMA
Dynamic Modulus (Mpa) at 37.8 C
4,000
3,000
2,000
1,000
0
0.1
1
10
10
Loading Frequency (Hz)

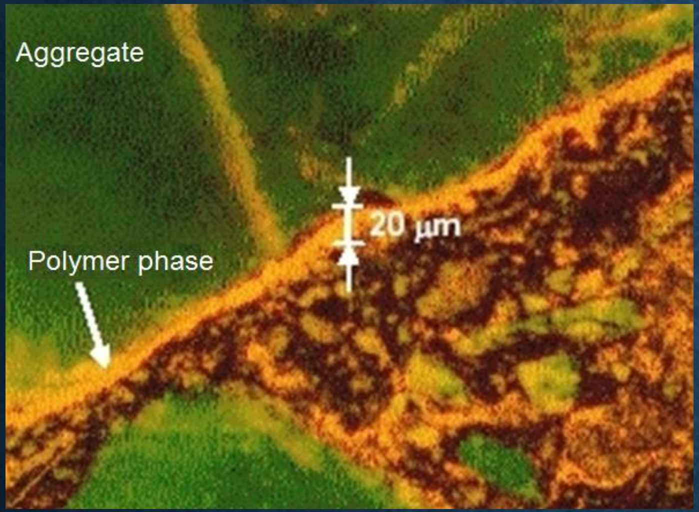
Introduction



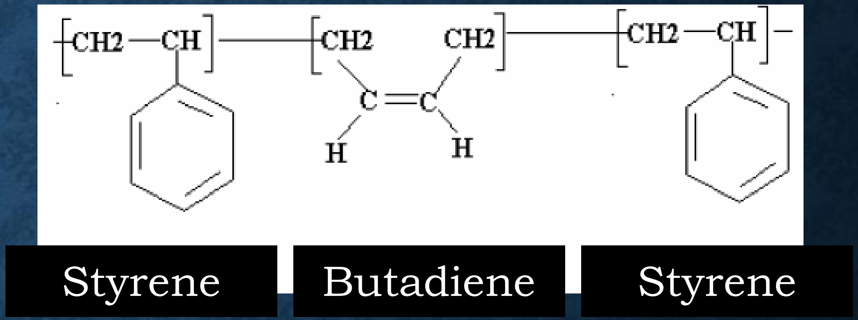
HMA Plant near
Columbus, OH

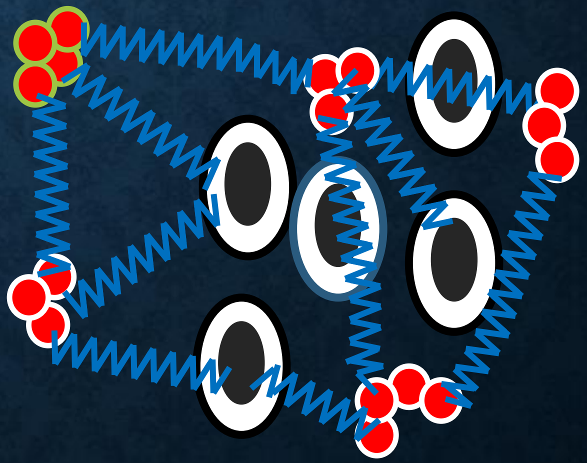
Introduction

PMA



SBS





Materials

Aspha-min

Mineral powder type containing 20% crystalline water

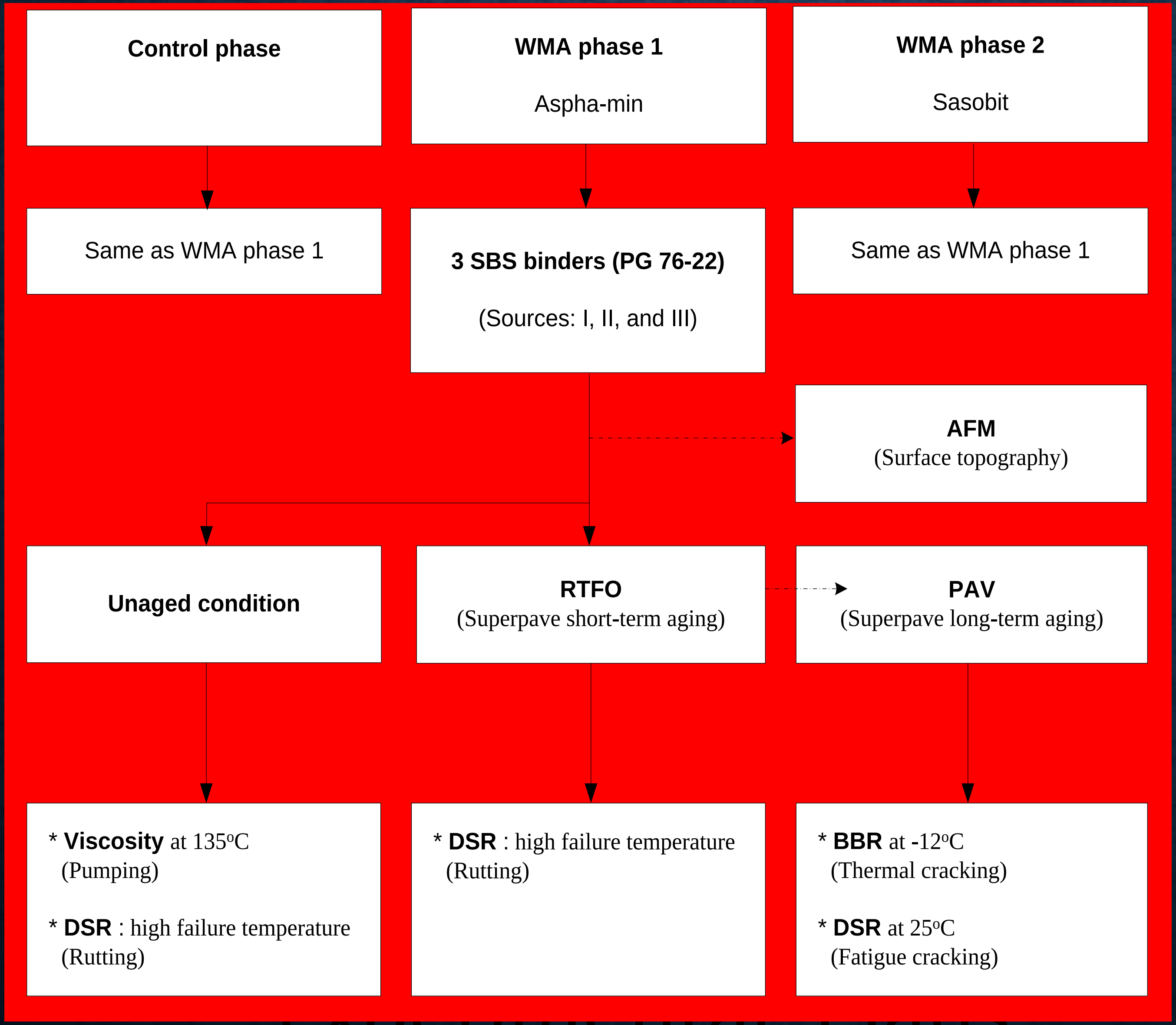
Above 212oF, the water is slowly released, casing micro-foaming in asphalt mixtures

Sasobit

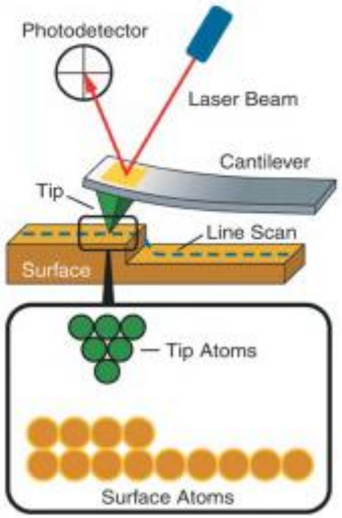
Organic hard wax type from coal gasification

Above 240°F, the wax is completely melted and acts as a lubricating agent in asphalt binders

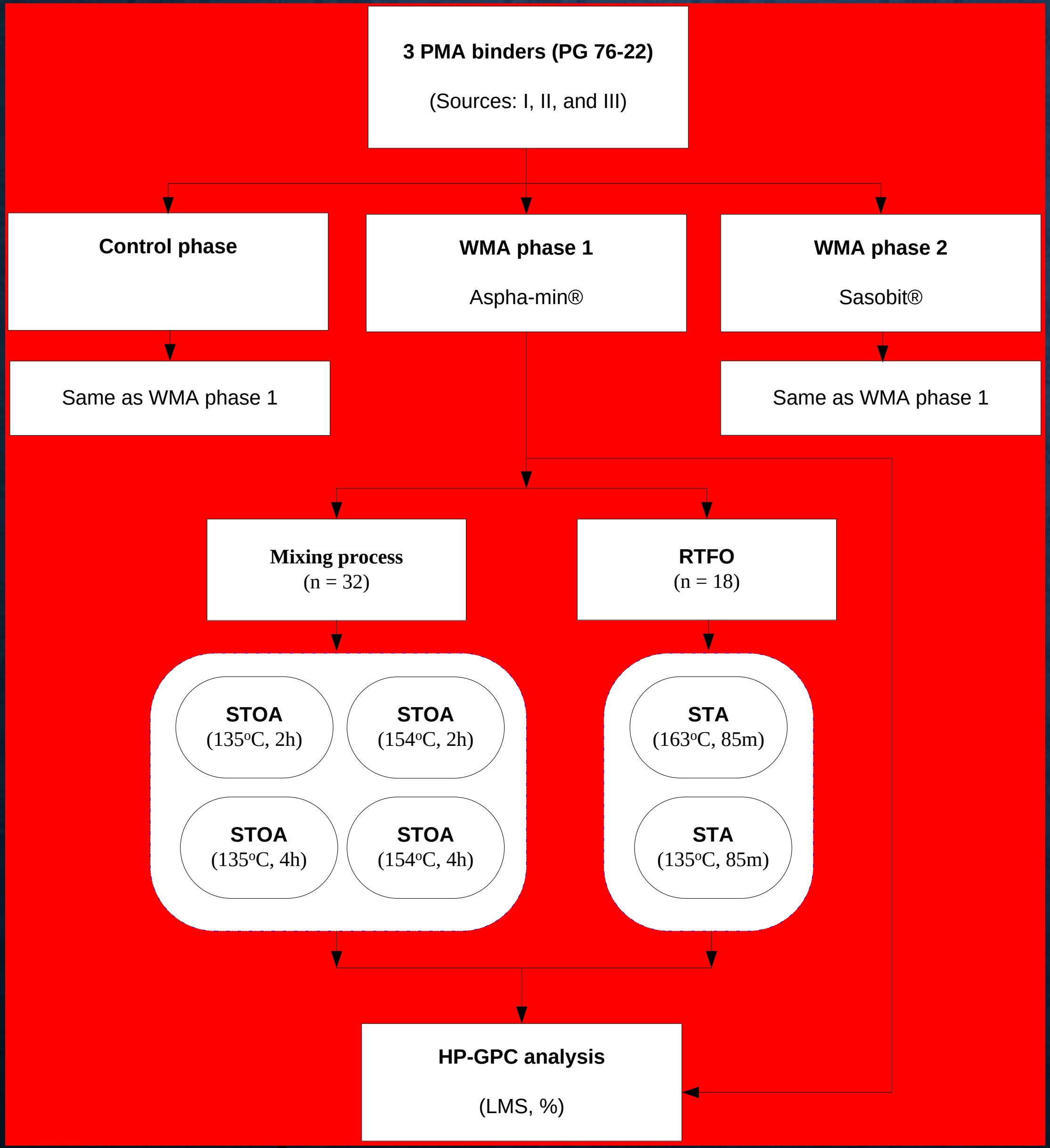
Task 1 : Binder Analysis



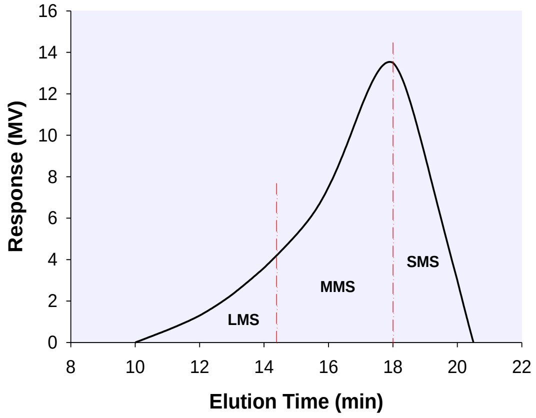
Experimental Plans



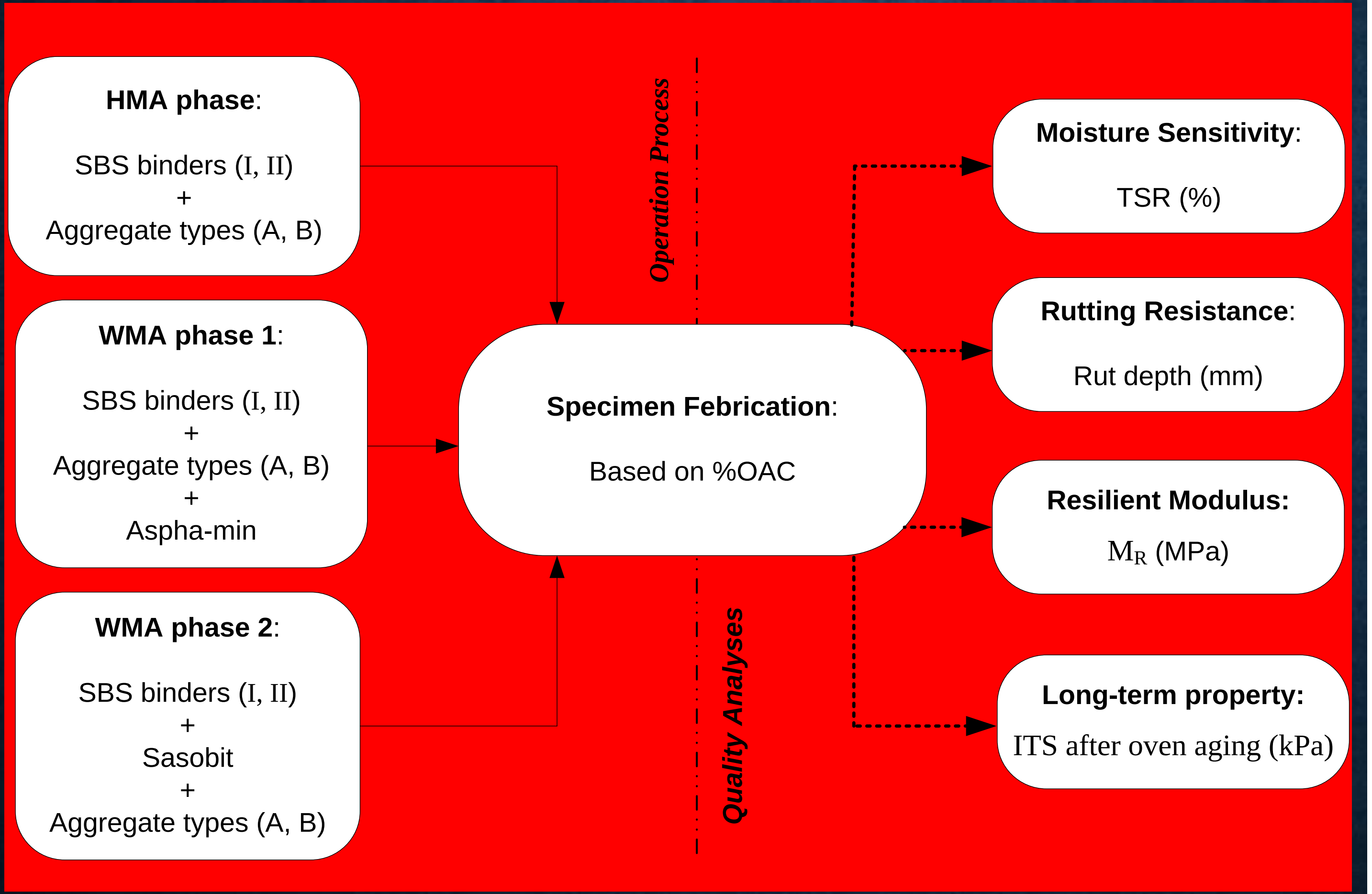
❑ Task 3 : Oxidative Aging Study



Experimental Plans



Task 4 : Mixture Performance Analysis

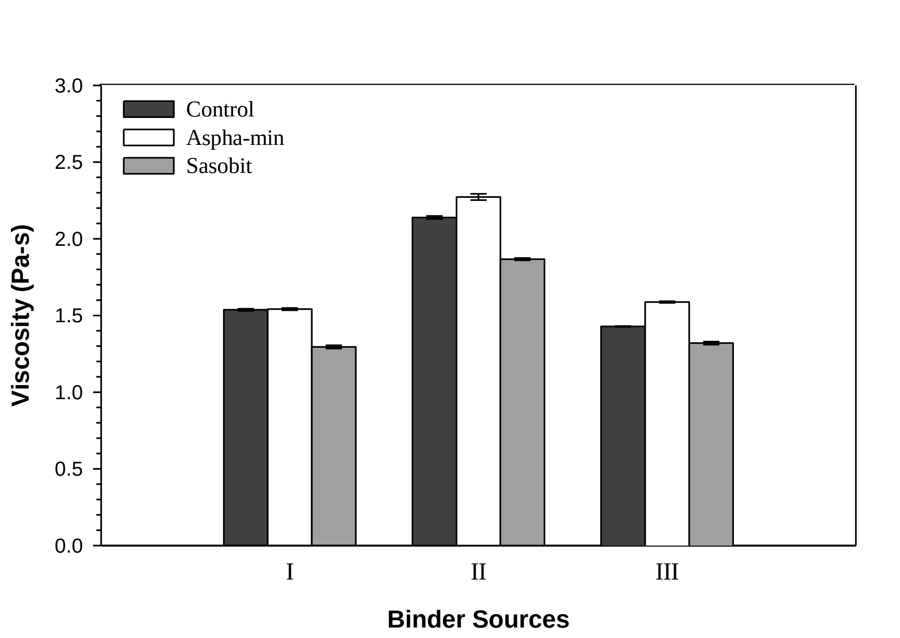


Experimental Plans

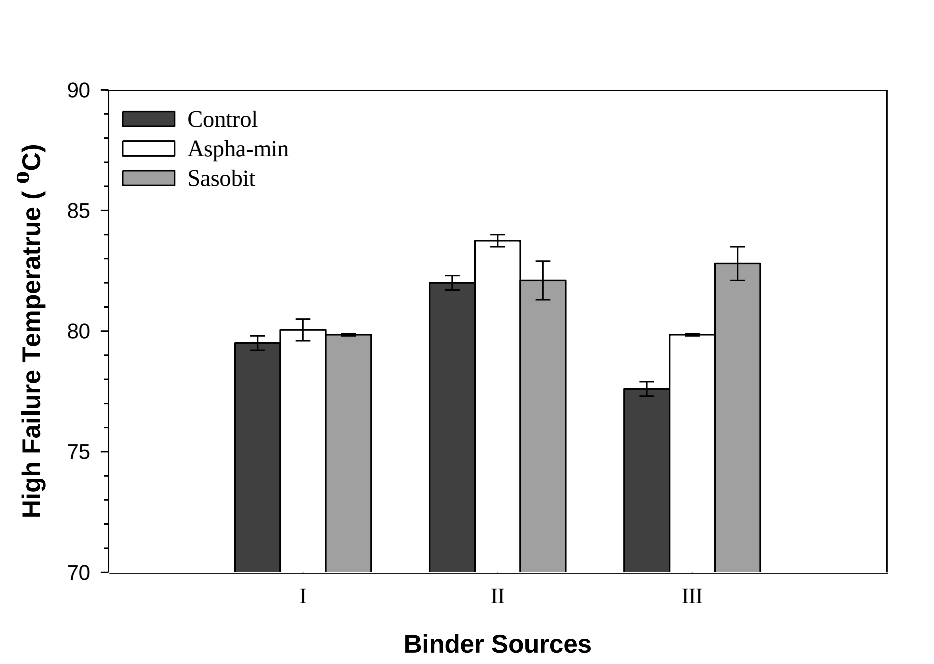
Experimental Plans

Binder Analysis

- Viscosity at 135°C

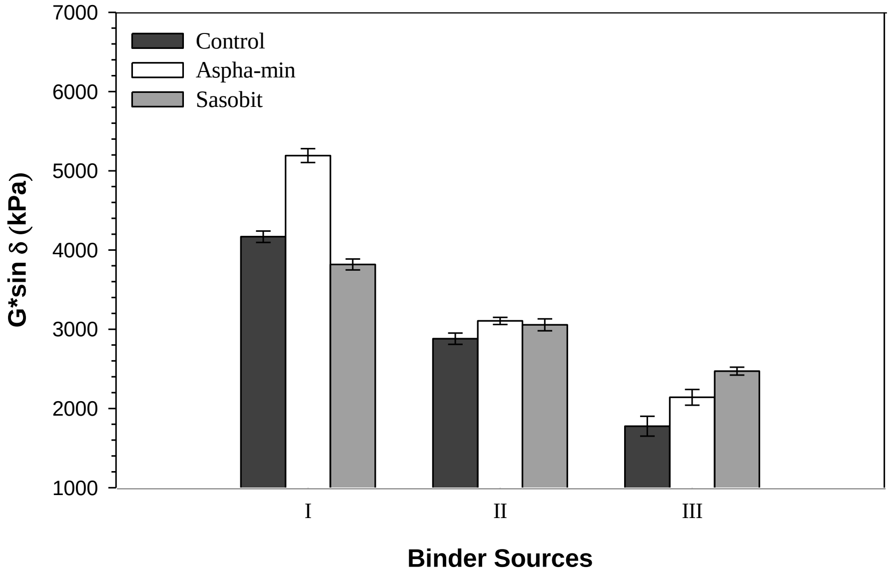


- Rutting property

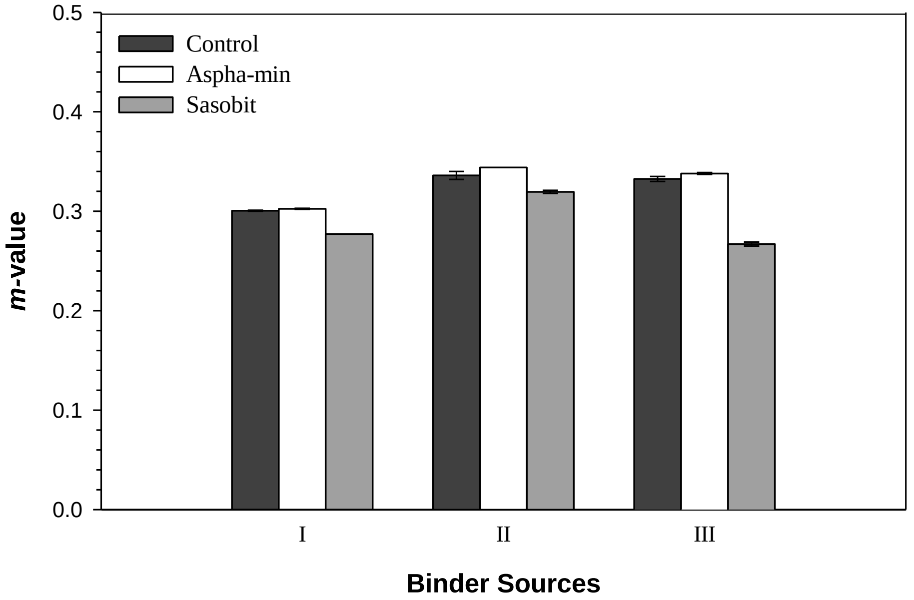


Binder Analysis

- Fatigue cracking property at 25°C



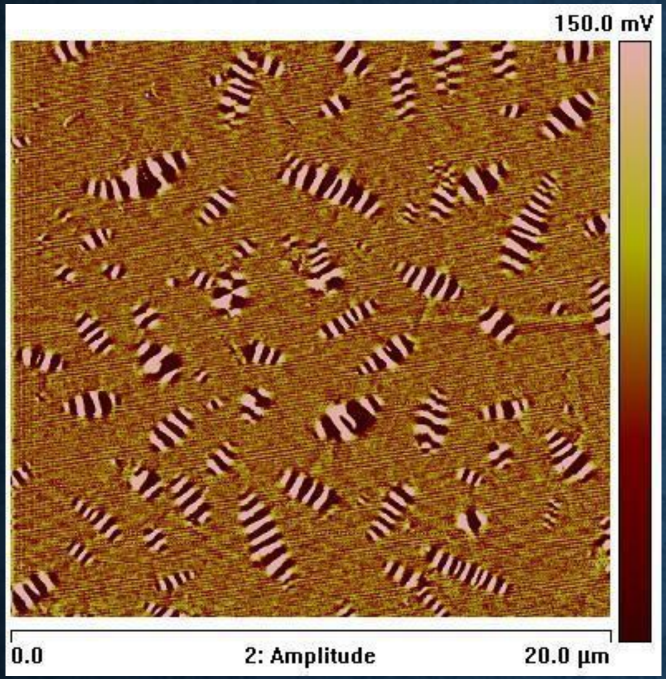
- Thermal cracking property at -12°C



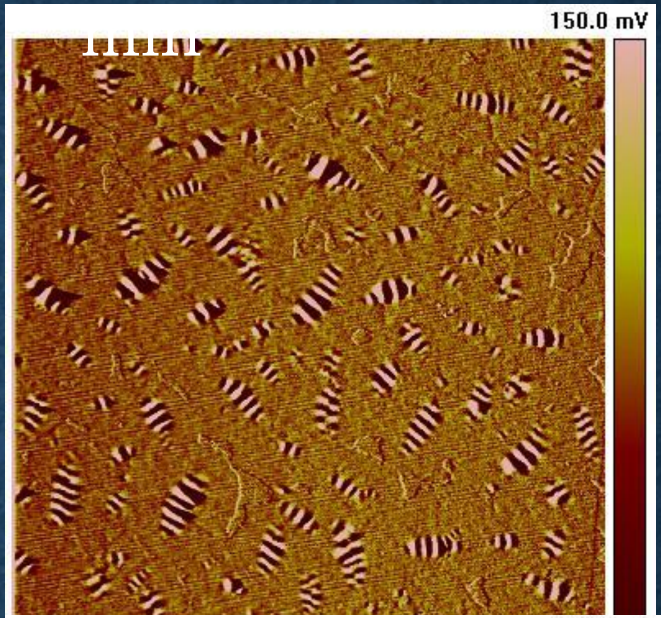
AFM Images 2D

Binder I

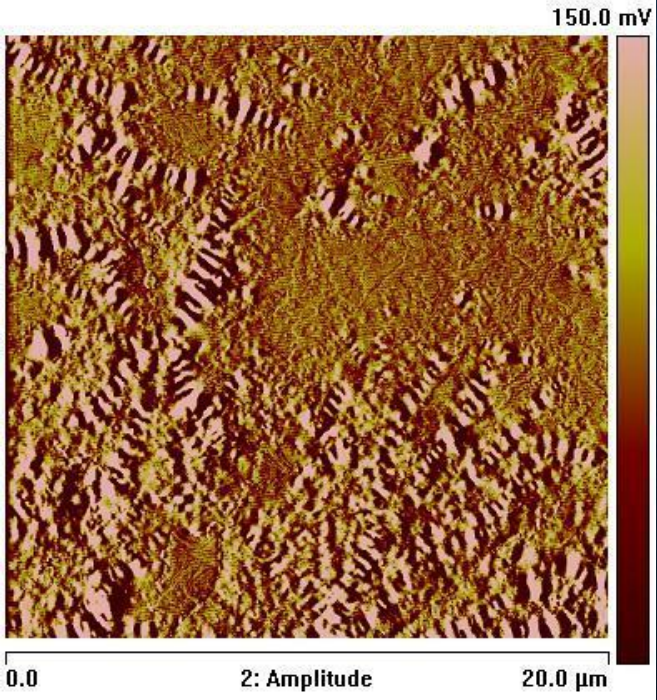
- Control



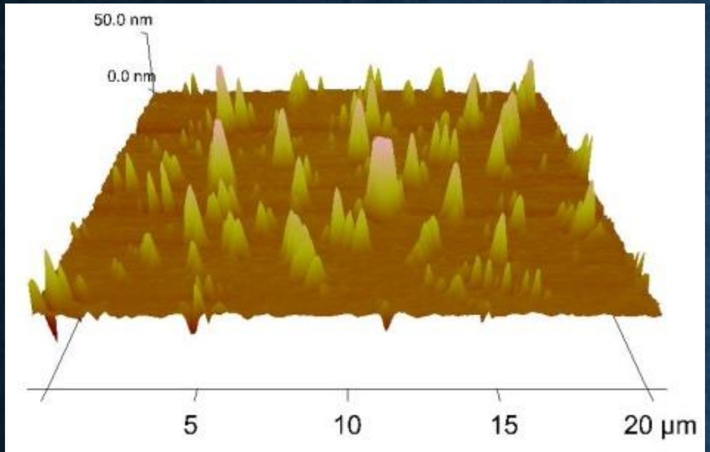
- Aspha-min



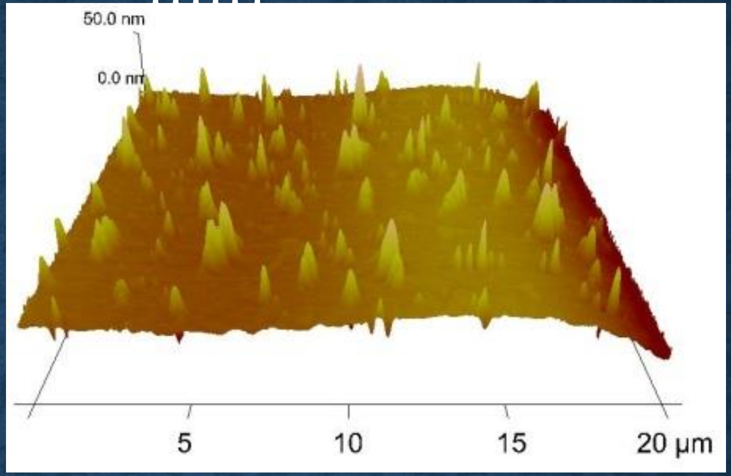
- Sasobit



Control



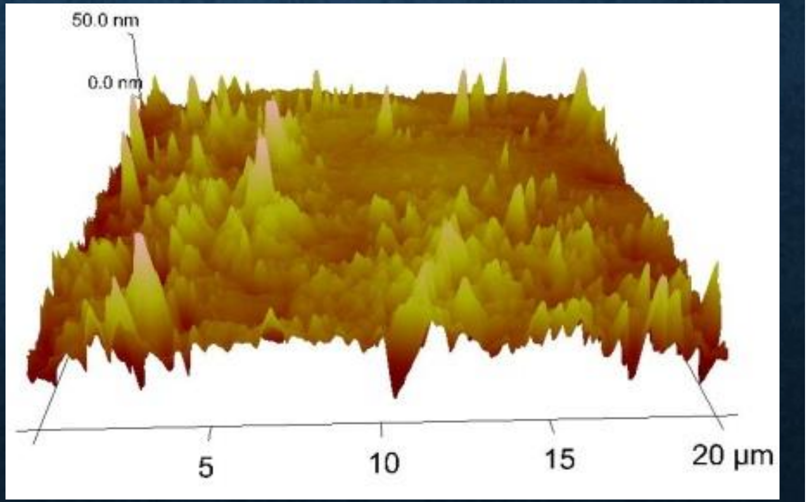
Aspha-
min



AFM Images 3D

Binder I

Sasobit



Conclusions

- Binder Analysis

WMA additives generally helped the performance properties of SBS modified binders at the temperature range of 76 to 135°C.

The addition of Sasobit significantly decreased the viscosity of the binders at 135°C due to the wax dissolution that acted like a flow improver, while the addition of Aspha-min increased the viscosity of the binders due to the remained zeolite particles after the micro water evaporated..

Its binder viscosity results may not be truly appropriate since the benefit of Aspha-min commonly appears during mixing with aggregates and not with simply binder.

Conclusions

- Oxidative Aging Analysis

Aging levels showed a general trend that depended on time and temperature through both aging procedures (STOA and RTFO) based on LMS values using GPC method.

These trends were also consistent regardless of WMA additives and SBS modified binder sources. In particular, the asphalt mixtures by the STOA procedure resulted in a higher level of aging than the asphalt binder by the RTFO methods

The thinner binder film thickness coating aggregates is thought to be a contributing factor.

Conclusions

Mixture Performance Analysis

Irrespective of WMA additives, the ITS and TSR values of SBS modified asphalt mixtures were higher than the specification set forth by the SC DOT (minimum 448 kPa of wet ITS and 85% of TSR).

In most cases, there was no significant difference of the ITS values between HMA and WMA mixtures.

The final rut depths of all the SBS modified mixtures were much lower than the requirements specified by the SC DOT (3mm).

In particular, SBS modified asphalt mixtures made with Sasobit were observed to have lesser rutting potential, while there was no significant difference between HMA and WMA mixtures made with Aspha-min..

RESEARCH PROJECT: SUMMARY AND CONCLUSIONS

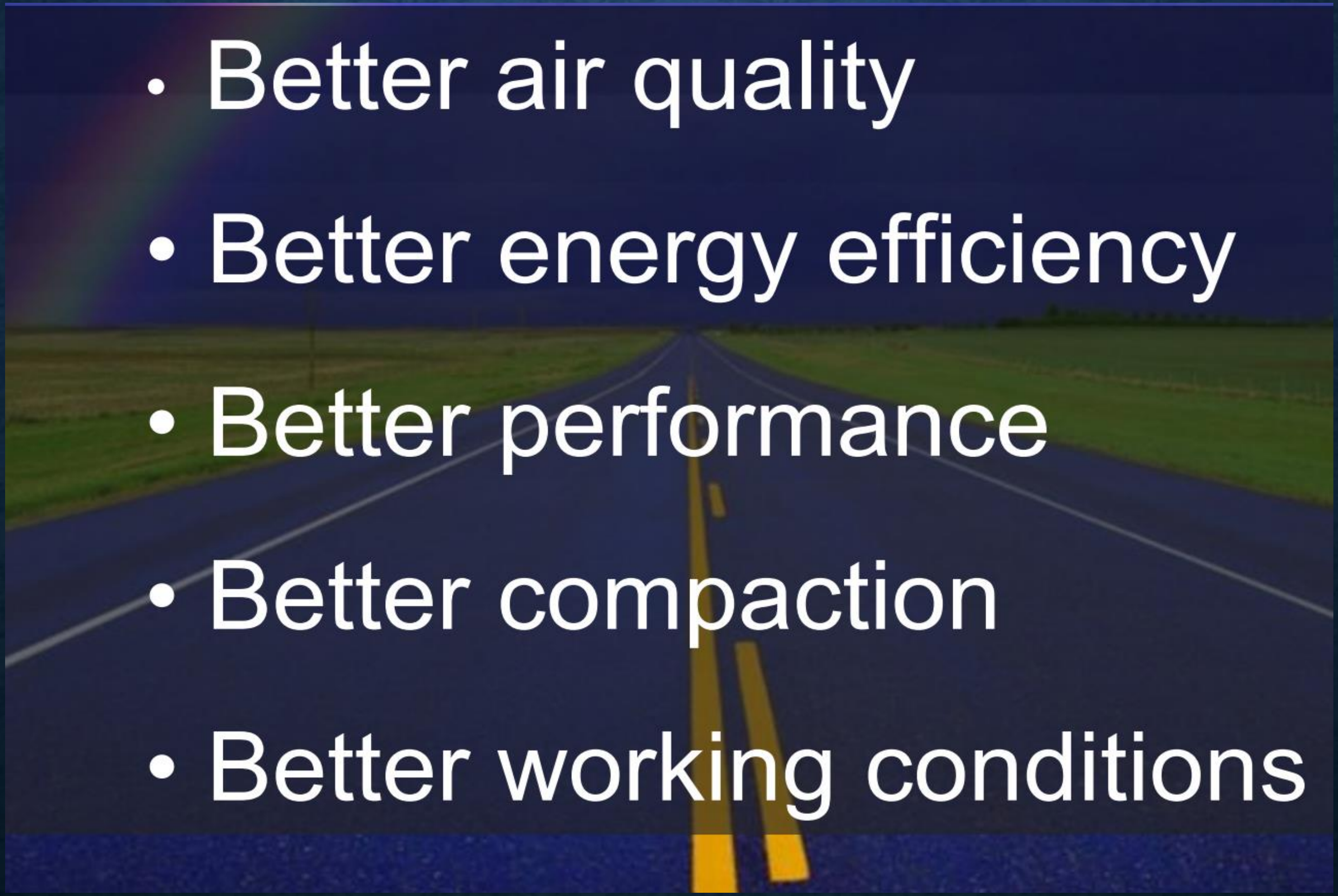
- ✓ Pavement is expected to perform better because the asphalt is not aged.
- ✓ Working environment will be better for construction workers with a lower amount of asphalt fumes.
- ✓ Based on the limited test results, Sasobit®, Evotherm J1, and RedisetTM WMX additives are effective in producing WMA mixtures in the laboratory that are comparable to HMA mixtures.
- ✓ In the future, the majority of asphalt mixtures will be produced at a lower temperature than today.

ADVANTAGES OF LOWER TEMPERATURES

- Lower fumes and emissions (~30-90%)
- Lower energy consumption (~30%)
- Lower plant wear
- Decreased binder aging
- Early site opening
- Cool weather paving
- Compaction aid for stiff mixes
- Cooler working conditions
- Edge of mat is more vertical, making a better joint
- Eliminates bump at joint when overlaying concrete
- Eliminates the need for fume evacuation equipment on plant and paver

APPLICATIONS

THE NEED FOR WARM MIX



GENERAL TRENDS AROUND THE WORLD

- Regulations
- Activism
- Higher Production Temperatures
- Increasing Energy Costs

REDUCED EMISSIONS (DATA SUPPLIED BY THE SUPPLIERS)

- Aspha-min – North Carolina – 265°F
  - 17.6% decrease in SO_2
  - 3.2% decrease in CO_2
  - 35.3% decrease in total hydrocarbons
  - 6.1% decrease in NO_x
- Evotherm – Canada – 140°F
  - 45.8% decrease in CO_2
  - 63.1% decrease in CO
  - 41.2% decrease in SO_2
  - 58% decrease in NO_x
- Direct comparisons are discouraged – different plants, different weather, different temperatures

2017 DATA

- 147.4 million tons of warm-mix asphalt was produced
- ~ 39% of total asphalt pavement mix production
- 777% increase since 2009
- 42% of the asphalt pavement mixture produced for DOTs was produced with WMA
- > half of all asphalt pavement mixtures in 16 states : WMA
- 8 of those states, more than 75% of the mixtures were WMA

CONCLUSIONS

- Warm Mix is the Future of Asphalt Mixtures.
- Technology providers coming forward.
- Industry and agencies must work together to make it happen.
- Advantages outweigh concerns.
- Will add to versatility of the material.

THANK YOU