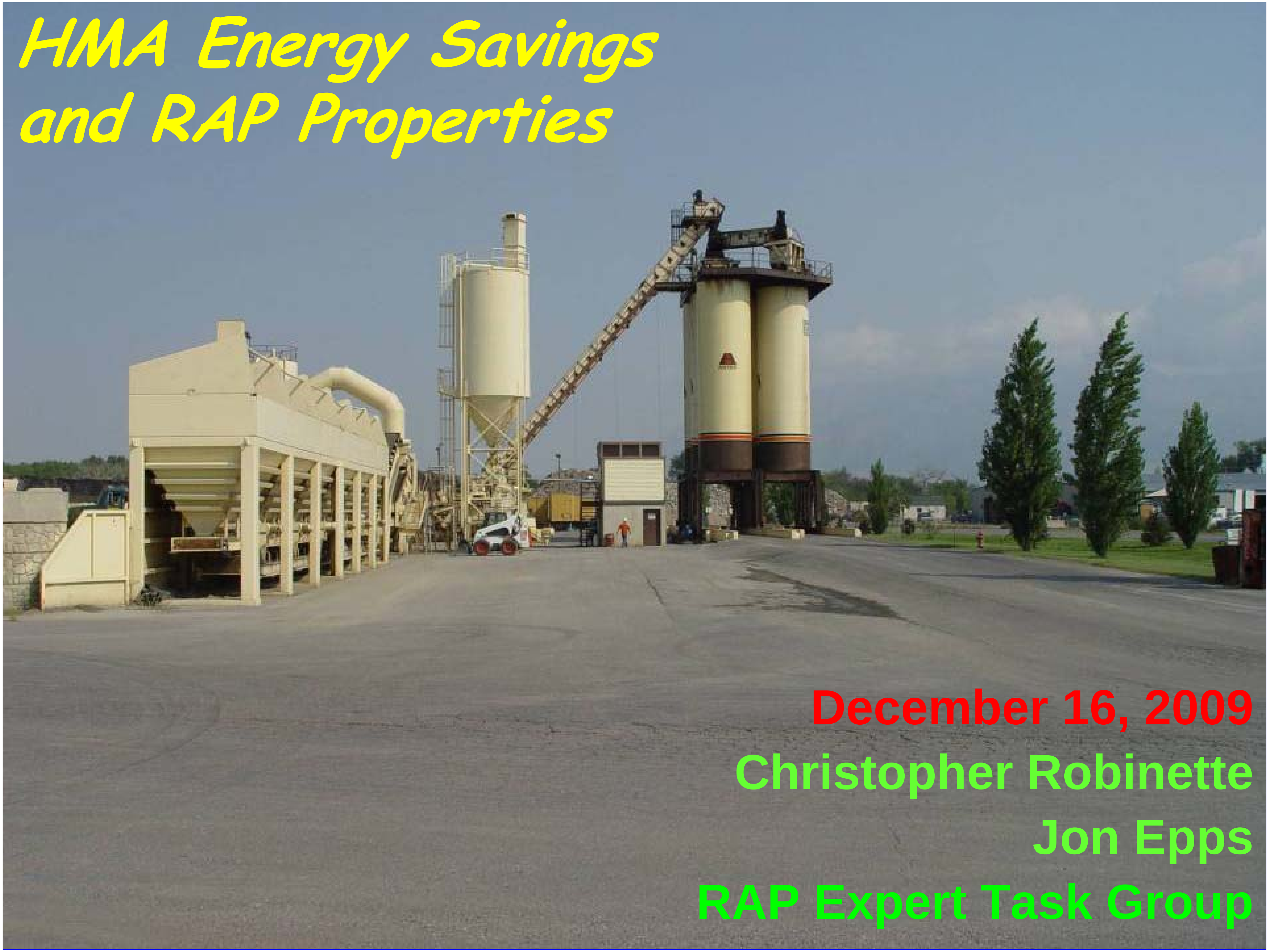
HMA Energy Savings and RAP Properties



December 16, 2009

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RAP Expert Task Group

Outline

- RAP Properties
- Asphalt Shingle Properties
- Energy and Greenhouse Gas
- Life Cycle Assessment
- Summary

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- **RAP Properties**
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Gradation and Asphalt Content

RAP Source	Stat	3/8-in Sieve, % Passing	No. 200, % Passing	Asphalt Binder Content, %DWA
Single RAP Stockpile Poor Control	No.	10	10	10
	Std. Dev.**	5.9	2.0	0.42
Single RAP Stockpile Good Control	No.	4	4	4
	Std. Dev.	1.7	0.9	0.22
Fractionated Coarse RAP	No.	5	5	5
	Std. Dev.	5.3	0.60	0.42
Fractionated Fine RAP	No.	7	7	7
	Std. Dev.	0.0	0.70	0.22

***Test results based on solvent extraction**
****Standard Deviation – measure of variability**

RAP AC Properties

AC-725

PG 83-17

Property	Test Method	Test Temp, C	Coarse RAP			
			No.	Ave.	Std. Dev.	COV
Absolute Viscosity, P	ASTM D2171	60	2	72,443	5,464	7.5
DSR G*/sinδ, kPa	[illegible] T315	60	2	56.76	20.58	36.3
		64	2	31.56	9.15	29.0
		[illegible]	[illegible]	12.98	[illegible]	27.3
		[illegible]	[illegible]	[illegible]	1.18	21.0
		[illegible]	[illegible]	2.2[illegible]	[illegible]	21.3
		[illegible]	[illegible]	1.[illegible]		-
DSR Critical Temp	[illegible] T315	Critical Temp	[illegible]	82.[illegible]	1.1	1.4
BBR, Stiffness, MPa	AASHTO T313	6	-			-
		0	2	99.0	1.4	1.4
		-6	2	156.0	5.7	3.6
		[illegible]	2	220[illegible]	2[illegible]	[illegible]
		-18	-			-
BBR, m-value	AASHTO T313	[illegible]	[illegible]	[illegible]	[illegible]	-
		[illegible]	2	0.36[illegible]	0.00[illegible]	1.7
		-6	2	0.315	0.0057	1.8
		-12	2	0.259	0.0050	1.9
		-18	-			-
BBR Critical Temp	AASHTO T313	Critical Temp	2	-7.6	0.4	-4.7
RTFO Mass Loss	AASHTO T240	Critical Temp	2	-0.340	0.047	-13.7
DSR - RTFO G*/sinδ, kPa	AASHTO T315	64	2	52.9	9.1	17.2
Recycled Asphalt Binder Grade			PG 83-17			

RAP AC Property Variability

Property	Test Method	Test Temp, C	No.	Ave.	Std. Dev.	COV
Absolute Viscosity, P	ASTM D2171	60	2	1,020,651	279,868	27.4
DSR G*/sinδ, kPa	AASHTO T315	60	8	436.01	143.94	33.0
		64	8	216.88	73.73	34.0
		70	8	78.86	27.82	35.3
		76	8	29.27	9.97	34.0
		82	8	11.70	3.95	33.7
		88	8	4.96	1.68	33.8
DSR Critical Temp	AASHTO T315	Critical Temp	8	93.3	2.6	2.7

RAP Binder Grade

	Location 1	Location 2	Location 3
Typical Virgin Grade	PG 64-10	PG 64-22	PG 70-10
RAP Grade	PG 78-24	PG 74-26	PG 89-11

I-19 Project So. Arizona

- Partial depth removal of existing asphalt concrete
- Placement of dense grade asphalt concrete
- Placement of AR-ACFC
- Miscellaneous other work
- Granite's Proposal
  - Use RAP in base course HMA
    - 6% coarse RAP (3/4-in x 3/8-in)
    - 9% fine RAP (3/8-in minus)
  - Note: RAP currently used as shoulder backing and aggregate base on ADOT projects

Granite Test Results – RAP*

Testing Lab	RAP Source	Stat	3/8-in Sieve, % Passing	No. 8 Sieve, % Passing	No. 40 Sieve, % Passing	No. 200, % Passing	Asphalt Binder Content, %DWA
Granite - Arizona	Coarse	No.	10	10	10	10	10
		Std. Dev.**	3.5	2.0	1.1	0.38	0.53
	Fine	No.	11	11	11	11	11
		Std. Dev.	0.0	1.9	1.6	1.17	1.09
Granley		Std. Dev.		2.81		0.94	0.28
Rep. Range		Std. Dev.	2.0 – 4.5	2.0 – 3.5		0.5 – 1.5	0.15 – 0.45
Rep. Value		Std. Dev.	3.30	2.80		0.90	0.30

*Test results based on ignition oven

**Standard Deviation – measure of variability

Granite Test Results – RAP*

Testing Lab	RAP Source	Stat	3/8-in Sieve, % Passing	No. 8 Sieve, % Passing	No. 40 Sieve, % Passing	No. 200, % Passing	Asphalt Binder Content, %DWA
Granite - Arizona	Coarse	No.	5	5	5	5	5
		Std. Dev.**	5.3	3.2	1.5	0.60	0.42
	Fine	No.	7	7	7	7	7
		Std. Dev.	0.0	1.9	1.1	0.70	0.22
Granley		Std. Dev.		2.81		0.94	0.28
Rep. Range		Std. Dev.	2.0 – 4.5	2.0 – 3.5		0.5 – 1.5	0.15 – 0.45
Rep. Value		Std. Dev.	3.30	2.80		0.90	0.30

*Test results based on solvent extraction

**Standard Deviation – measure of variability

Granite/ADOT Test Results - Gradation

- Gradation of aggregate extracted from field mixed samples

		Standard Deviation of Percent Passing Sieve, %			
		3/8-in	No. 8	No. 40	No. 200
Granite		2.95	2.56	1.18	0.57
ADOT		3.22	2.14	0.88	0.46
Granite & ADOT		3.10	2.35	1.04	0.51
Granley			2.81		0.94
NCHRP 455	Rep. Range	2.0 – 4.5	2.0 – 3.5		0.5 – 1.5
	Rep. Value	3.3	2.8		0.9

*Standard Deviation – measure of variability

Granite/ADOT Test Results - Volumetrics

- Volumetric properties of field mixed/lab compacted samples

		Bulk Density, lb/ft^3	Rice Density, lb/ft^3	Air Voids, %	Asphalt Binder Content, %
Granite		0.95	0.58	0.81	0.29
ADOT		0.80	0.49	0.67	0.21
Granite & ADOT		0.88	0.53	0.74	0.25
Granley					0.28
NCHRP 455	Rep. Range			0.3 – 1.2	0.15 – 0.45
	Rep. Value			0.7	0.3

*Standard Deviation – measure of variability

Outline

- RAP Properties
- **Asphalt Shingle Properties**
- Energy and Greenhouse Gas
- Life Cycle Assessment
- Summary

Asphalt Shingle Gradations

	Tear-Off Asphalt Shingles				Manufactured Asphalt Shingles			
	Sample 1	Sample 2	Sample 3	Ave	Manu. 1	Manu. 2	Manu. 2	Manu. 3
3/8-in	100	100	100	100	100	100	100	100
#4	98	100	99	99	100	100	100	100
#8	97	100	99	99	99	100	100	100
#16	79	75	80	78	71	75	75	80
#30	60	59	58	59	53	52	52	64
#50	53	43	51	49	46	45	44	60
#100	37	34	41	37	37	39	38	50
#200	23.4	23.8	29.1	25.4	28.0	29.5	29.2	38.1
AC Content, %	48.1	45.8	43.9	45.9	32.1	21.0	21.2	25.3

Asphalt Shingle Asphalt Binder Properties

High Temperature, PG									
Temp, °C	Tear-Off		Manu. 1		Manu. 2	Manu. 2		Manu. 3	
60	1500		166.1			495.3		56.6	
64	1027		128.6			360.0		40.5	
70	523.6		78.9			222.5		23.4	
76	308.6		47.4		89.6	130.0		13.8	
82	188.7		28.7		59.2	74.9		8.15	
88	112.4		18.0		37.9	44.3		5.07	
Crit. Temp.	133.6		114.4		136.7	122.9		98.7	
Low Temperature, PG									
	Stiffness	m-value	Stiffness	m-value		Stiffness	m-value	Stiffness	m-value
6	47	0.310				29	0.327		
0	79	0.280	28	0.347		45	0.296		
-6	141	0.243	52	0.319					
-12			100	0.296					
-18								106	0.320
-24								159	0.267
Crit. Temp.	+4.0		-11.0			+0.6		-20.3	

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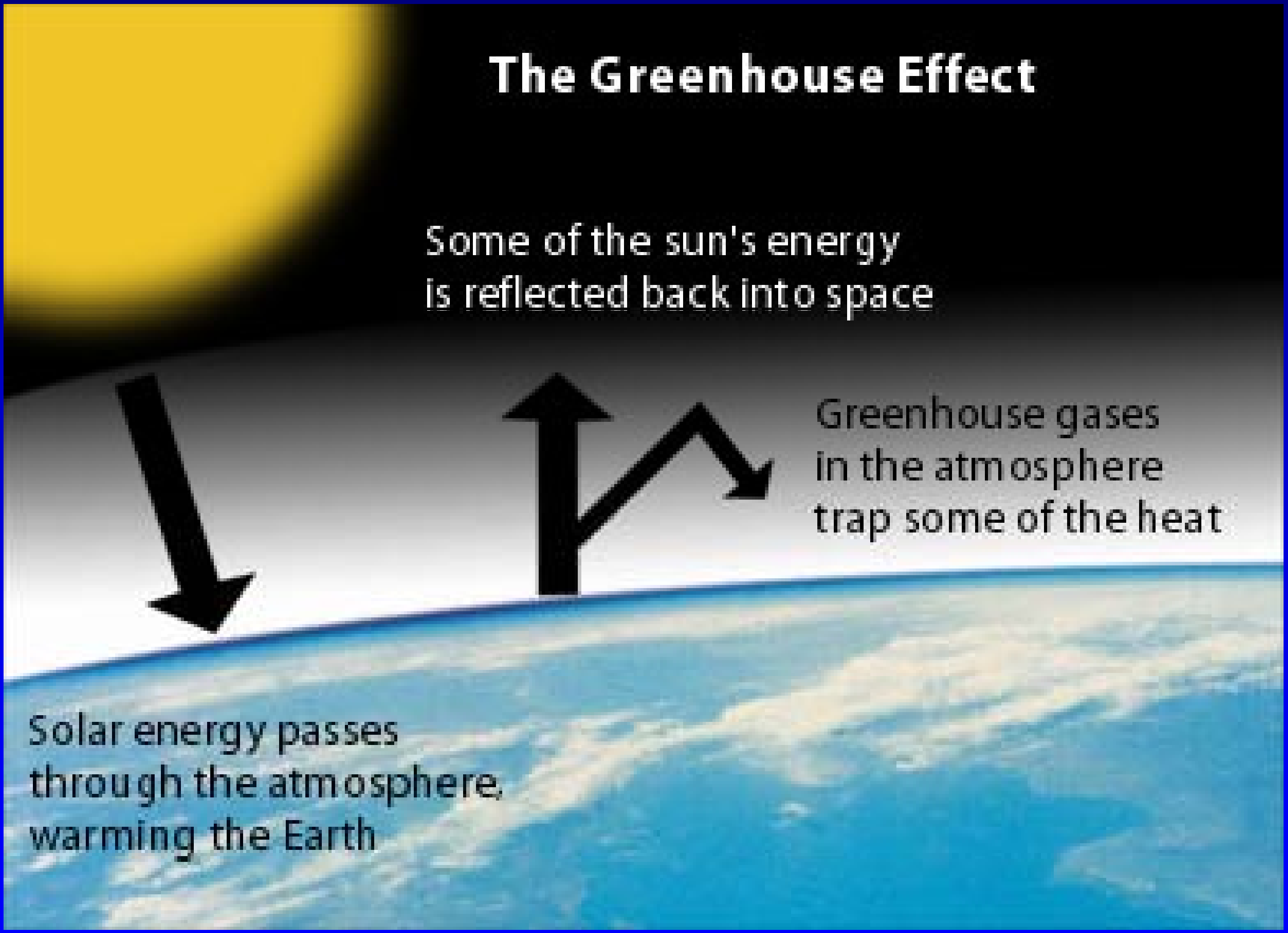
Greenhouse Gases

- By-product of fossil fuel burning

- Carbon Dioxide (CO_2)
- Methane (CH_4)
- Nitrous Oxide (N_2O)
- Others (HFC, PFC, SF_6) – but less significant

- Carbon Dioxide equivalent (CO_{2eq})
  - Global Warming Potential Index (GWPI)
  - $CO_{2eq} = CO_2 + 23 \times CH_4 + 296 \times N_2O$
  - Coefficients may vary

Greenhouse Effect



Life Cycle

- Crude oil extraction and refining
- Aggregate extraction and processing
- Transportation of raw materials
- Plant production
- Transportation of finished product
- Placement

Raw Material Production*

- Asphalt Binder
- 600,000 to 4,200,000-Btu
- 280 to 675-lb CO_{2eq}

- Aggregate
- 15,000 to 52,000-Btu
- 3 to 20-lb CO_{2eq}

*Values based on multiple references

Transportation of Raw Materials and Finished Product

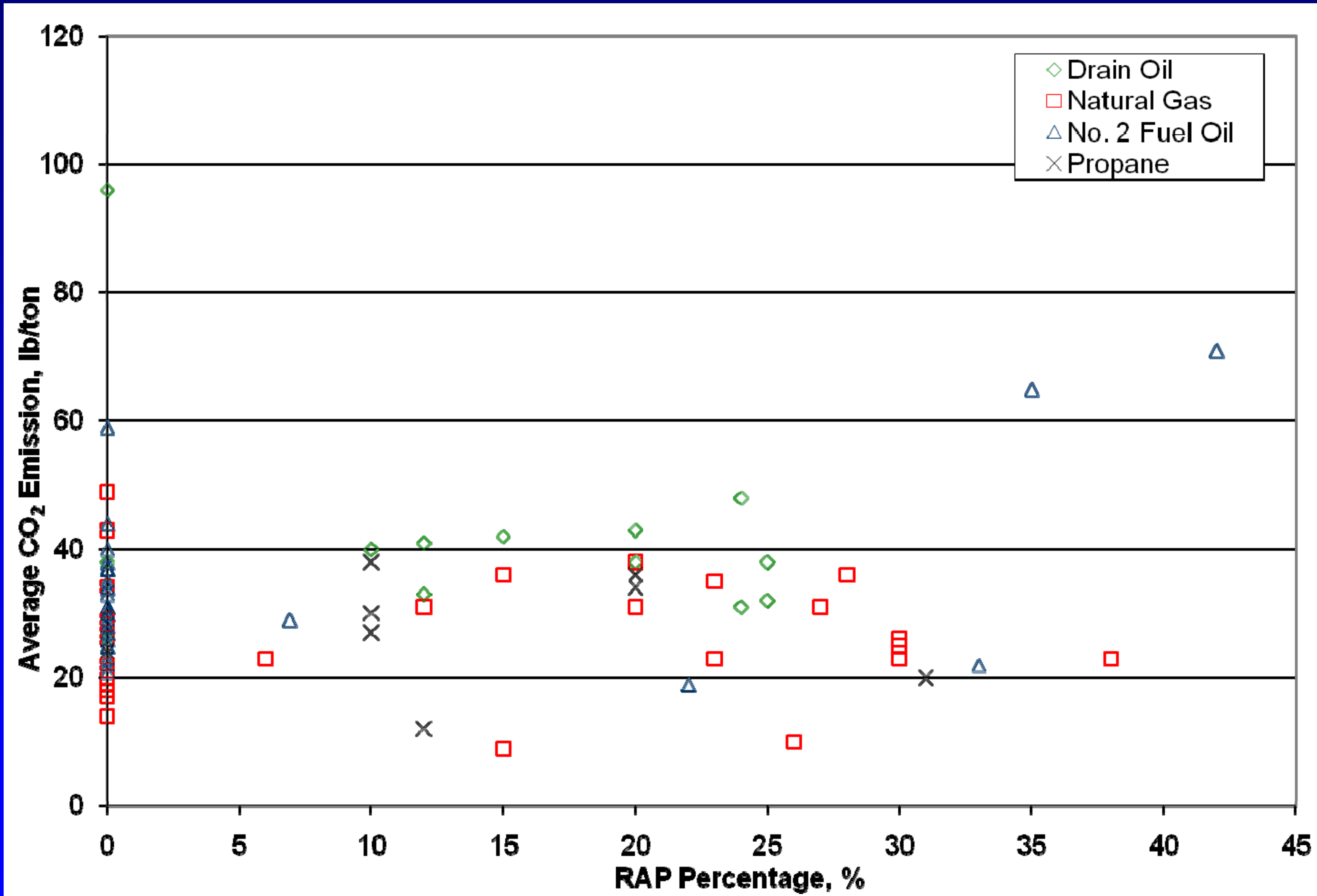
- Haul distance
- Method of transportation
  - Truck – 155-ton-miles/gallon – 25-tons/truck
  - Rail – 436-ton-miles/gallon – 143-tons/car
  - Barge – 576-ton-miles/gallon – 1,500-tons/boat
- Type of fuel consumed
  - Diesel
    - ~139,000-Btu/gallon
    - ~22.6-lbs CO_{2eq}/gallon
  - Gasoline
    - ~124,000-Btu/gallon
    - ~20.0-lbs CO_{2eq}/gallon

Emissions by Fuel Type (EPA AP-42)

	CO_2, lb/ton of HMA		
	No. of Samples	Average	Std. Dev.*
Drum Mix			
Natural Gas	30	26.40	9.11
No. 2 Fuel Oil	44	32.67	11.79
Drain/Waste Oil	22	42.23	13.85
Total	96	32.90	11.55
Batch Plant			
Natural Gas	39	34.56	26.31
No. 2 Fuel Oil	29	38.62	19.70
Total	68	36.29	23.73

*Standard Deviation – measure of variability

Influence of RAP on CO_2 Generation, lb/ton



*Based on EPA AP-42 Emission Factors for a drum mix hot plant

Laydown

- Equipment composition
- Type of equipment engines
- Productivity
- Fuel used

Energy & Emissions Reduction with RAP

Material / Process	Recycled Material Content, %	RAP Asphalt Binder Content, %	Value Per Ton of Mix (% Savings)	
			Energy, Btu	CO_{2eq}, lb
Conventional Hot Mix Asphalt (No RAP)	0.0	N/a	533,333	104.89
			-	-
Reclaimed Asphalt Pavement (RAP)	15.0	4.0	501,778	98.59
			(5.92)	(6.01)
	15.0	5.0	495,544	97.76
			(7.09)	(6.79)
	25.0	4.0	480,741	94.39
			(9.86)	(10.01)
	25.0	5.0	470,352	93.01
			(11.81)	(11.32)

Materials Conservation

Material / Process	Recycled Material Content, %	RAP Asphalt Binder Content, %	Value Per Ton of Mix (% Savings)	
			Asphalt, ton	Agg, ton
Conventional Hot Mix Asphalt (No RAP)	0.0	N/a	0.052	0.948
			-	-
Reclaimed Asphalt Pavement (RAP)	15.0	4.0	0.046	0.804
			(11.54)	(15.19)
	15.0	5.0	0.045	0.806
			(14.42)	(15.03)
	25.0	4.0	0.042	0.708
			(19.23)	(25.32)
	25.0	5.0	0.040	0.711
			(24.04)	(25.05)

Energy & Emissions Reduction with Asphalt Shingles

Material / Process	Recycled Material Content, %	RAP Asphalt Binder Content, %	Value Per Ton of Mix (% Savings)	
			Energy, Btu	CO_{2eq}, lb
Conventional Hot Mix Asphalt (No RAP)	0.0	N/a	533,333 -	104.89 -
Post Industrial Asphalt Shingles	5.0	18.0	493,724 (7.43)	98.94 (5.67)
	5.0	23.0	481,256 (9.76)	97.29 (7.25)
Post Consumer Asphalt Shingles	5.0	32.0	464,633 (12.88)	95.09 (9.34)
	5.0	40.0	448,009 (16.00)	92.89 (11.44)

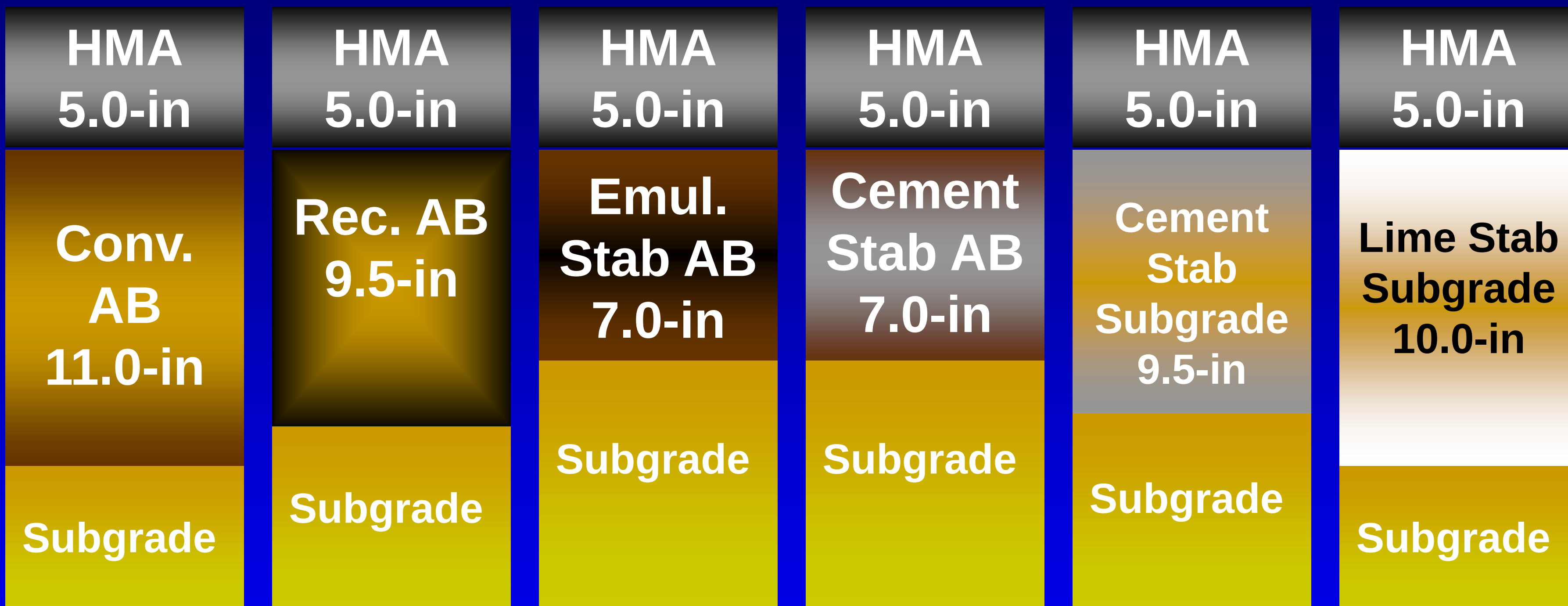
***Effective contribution of asphalt binder from asphalt shingles will influence savings**

Construction Operations – % Savings*

Operation	Energy, Btu/yd^2	CO_{2eq}, Btu/yd^2	Asphalt, ton/yd^2	Aggregate, ton/yd^2
Conventional	-	-	-	-
CIPR – Partial Depth	9	15	2	18
CIPR – Full Depth	29	70	-12	76
HIPR – Remix[1]	30	36	88	83
Overlay[1]	9	8	0	0

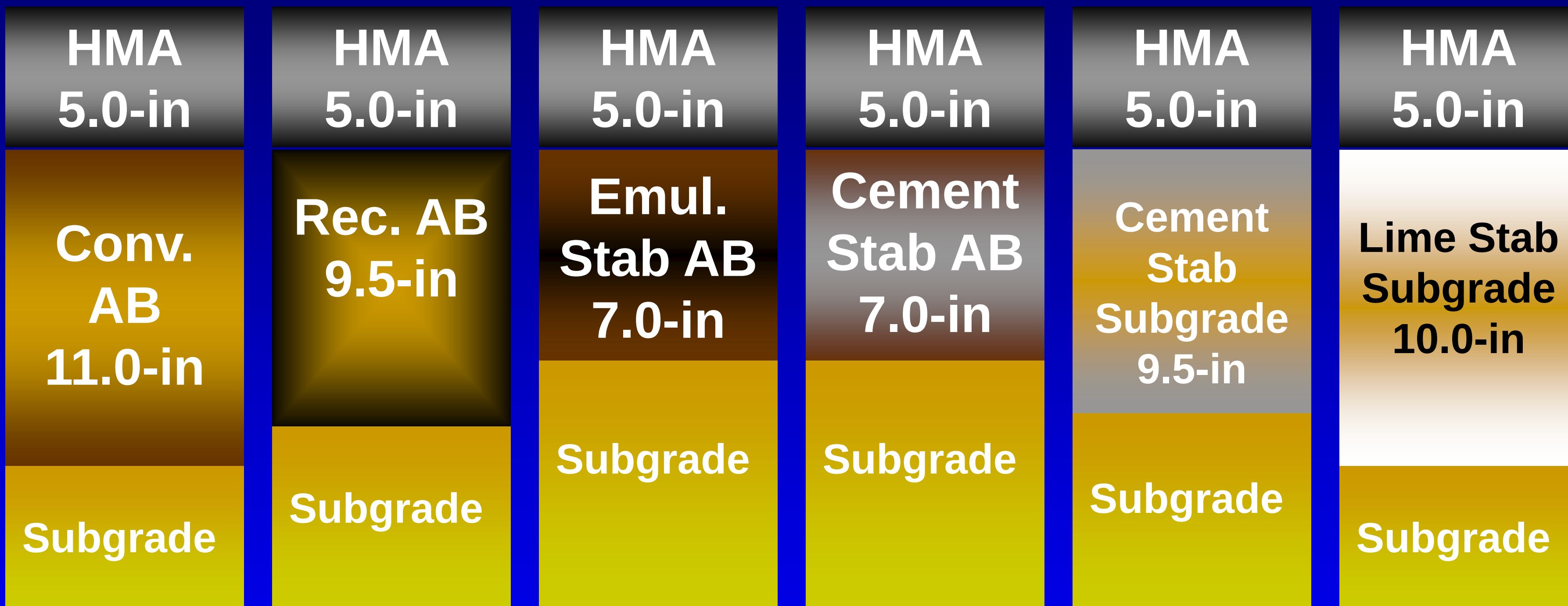
*percent savings in comparison to conventional alternative
[1]Based on project specific parameters

Treatment of Materials – Environmental Analysis



Energy, % Savings (measured in Btu/yd²)					
-	12	6	-8	2	13
Emissions, % Savings (measured in CO_{2eq}/yd²)					
-	7	0	-34	2	6

Treatment of Materials – Natural Resource Analysis



Asphalt Binder, % Savings (measured in ton/yd^2)					
-	0	-53	0	0	0
Aggregate, % Savings (measured in ton/yd^2)					
-	9	26	25	68	68

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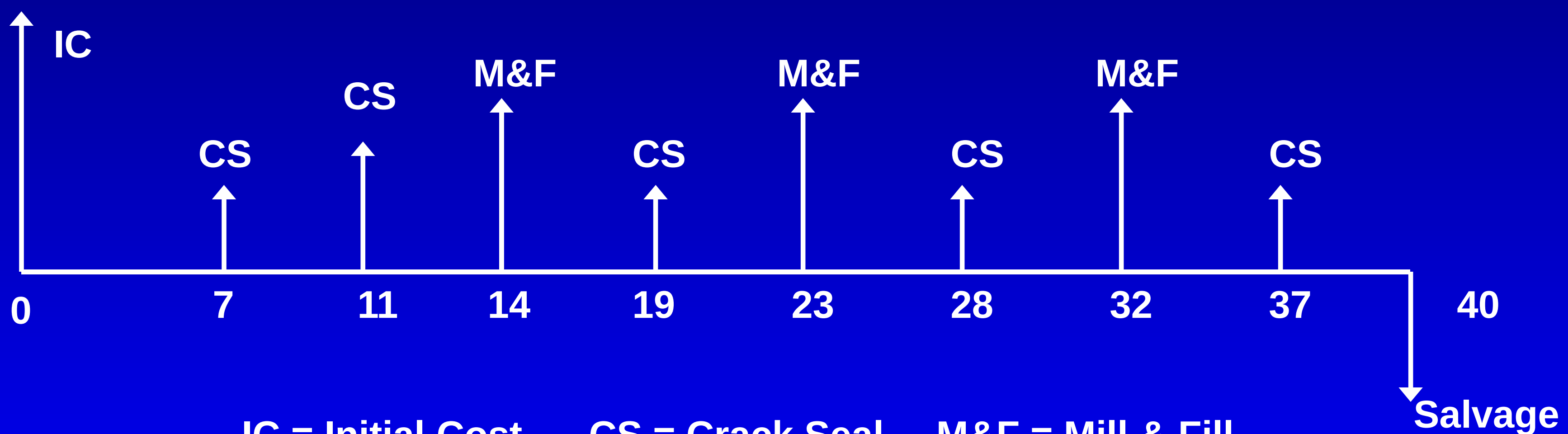
Life Cycle Assessment Format

Reconstruction



IC = Initial Cost CS = Crack Seal M&F = Mill & Fill

Life Cycle Assessment

- Similar approach to previously presented
- Considerations
  - Estimated life
  - Price of rehabilitation/maintenance
  - Discount rate
  - Analysis period
  - Salvage value
- Additional savings seen in LCA

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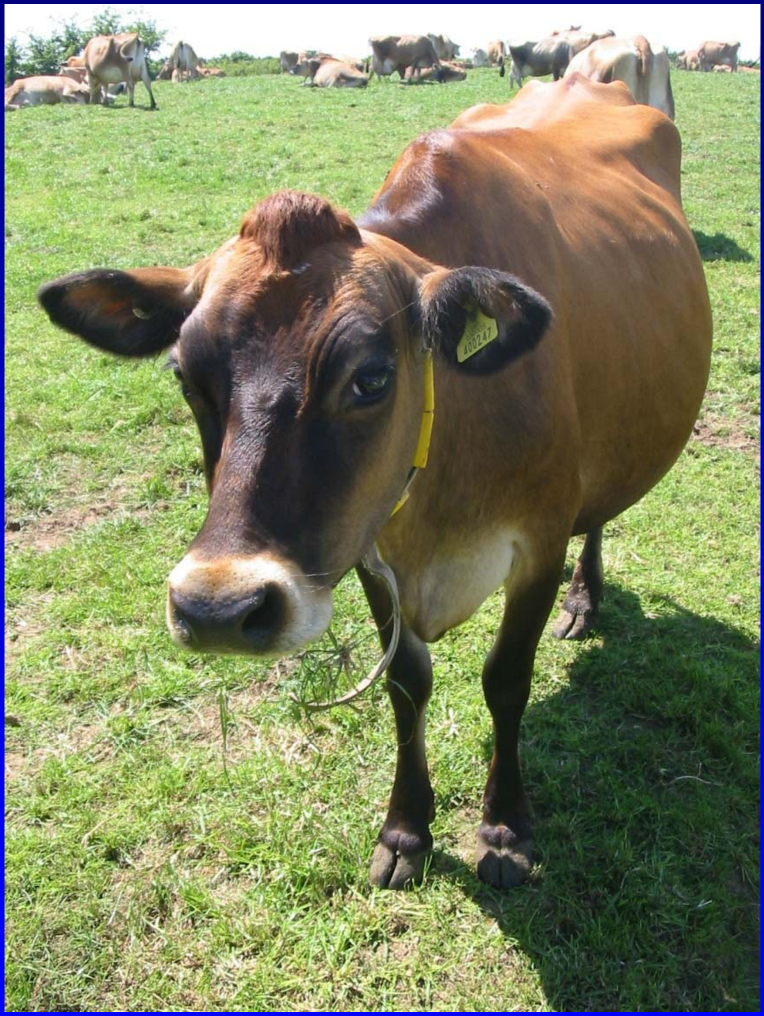
Summary

- Virgin production HMA
  - Consumes ~530,000-Btu/ton
  - Generate ~105-lbs CO_{2eq}/ton
- RAP and asphalt shingles reduce environmental impact
- RAP variability does not impact HMA variability

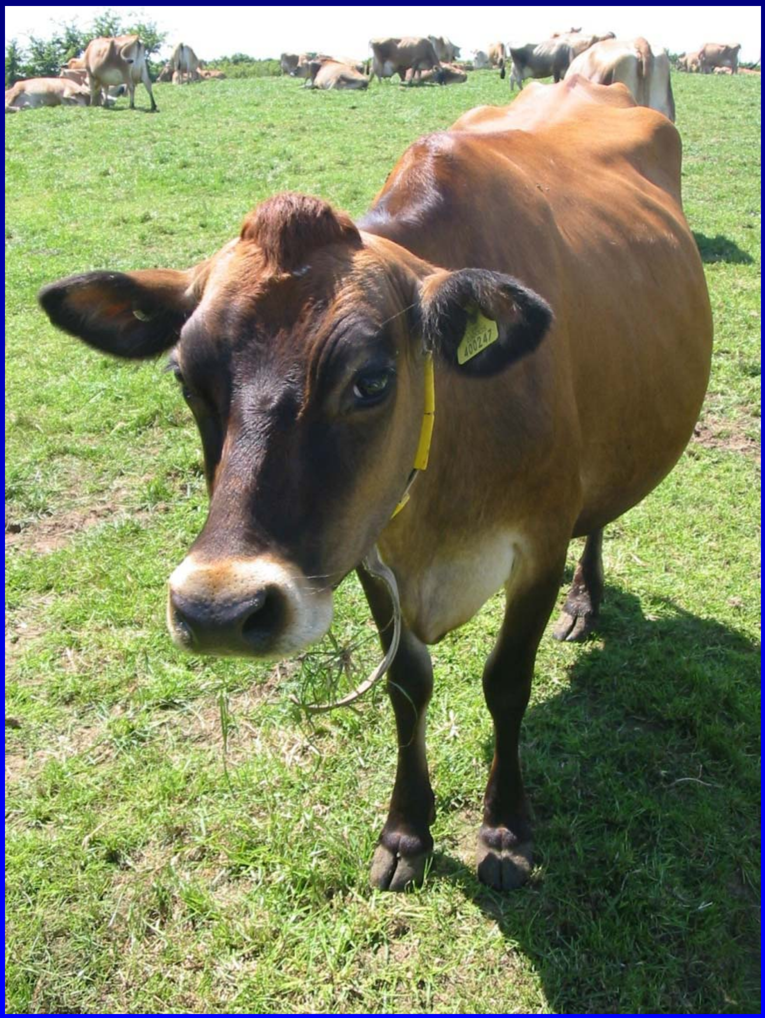
Questions?

?Question?

What does 2,800 represent?



What Produces More CO_2?



VS

US Cattle (Beef & Dairy)

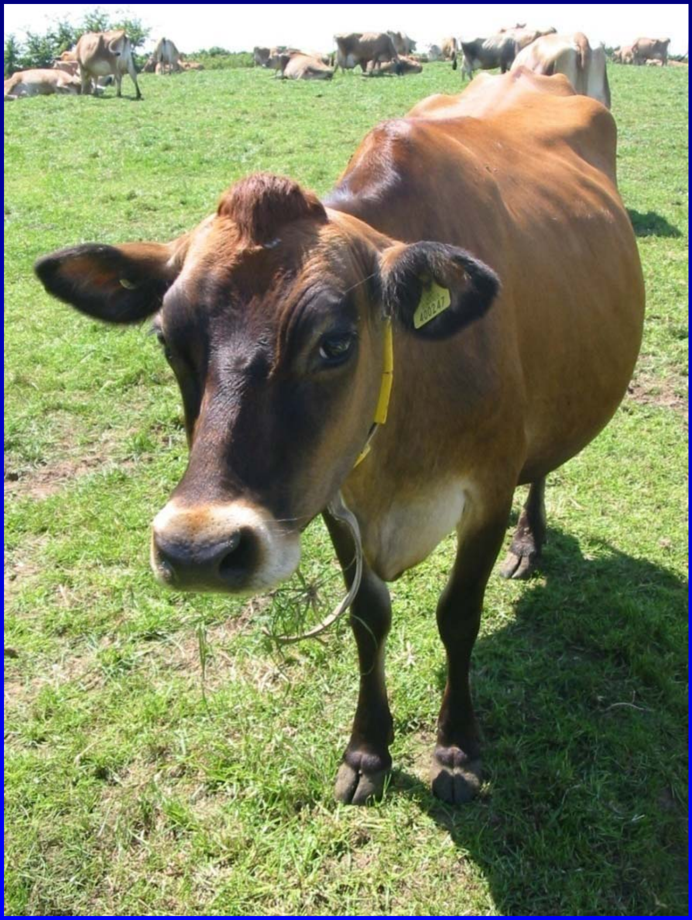
- **104,000,000-head of cattle in US (2007)**
- **145,615,000-tons of CO_{2eq} emitted annually**

University of Missouri - Columbia &

Hot Mix Asphalt

- **Asphalt binder, aggregate, plant production, transportation and laydown**
- **~105-lbs CO_{2eq}/ton**
- **~550-MM tons HMA produced in 2007**

Tale of the Tape



VS

145,615,000-tons CO_{2eq}/year

28,875,000-tons CO_{2eq}/year
Assumes no RAP

Difference of 116,740,000-tons CO_{2eq}/year

What Can We Do to Reduce Global Warming?