Solstice: High Performance LGWP Products

November, 2012

Honeywell

Honeywell: A History of Innovation

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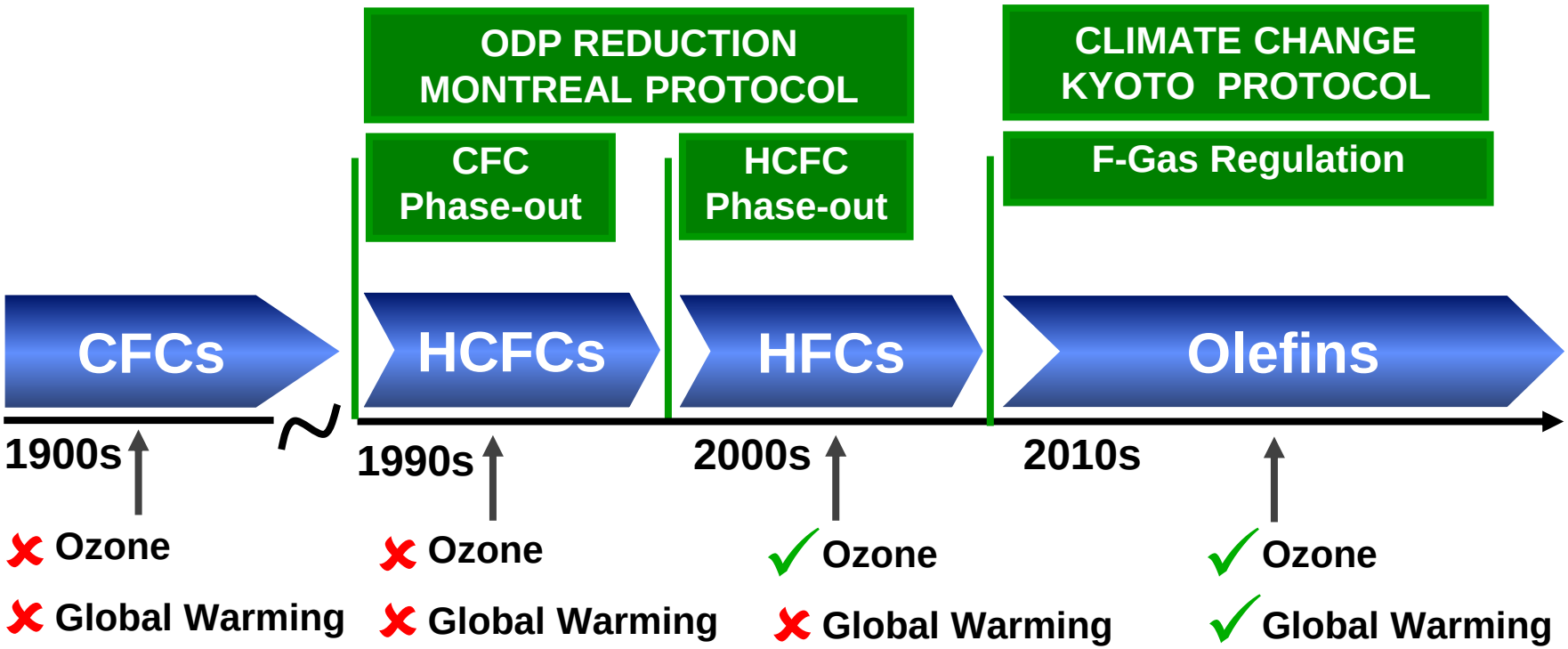

Energy Efficiency + Environmental Compliance + Safe To Use + Cost To Serve

Markets Served: Stationary Air conditioning**,** Auto air conditioning, Refrigeration, Insulation Foam for Buildings & Electrical Appliances, Cleaning Solvents , Aerosols, Fire Suppression, Heat Pumps, Geothermal/Solar Renewables

Enabling Customers to Comply with Regulation

Low Global Warming Options from Honeywell

Honeywell

	HONEYWELL OPTIONS	
	Low Global Warming Products	**GWP_{100}**
Foams	Solstice GBA	<5
	Solstice LBA	<5
Refrigerants	Solstice L-41	<500
	Solstice L-40	200-300
Solvents	Solstice Performance Fluid	<5
Aerosols	Solstice Propellant	<6

Today's Focus

Low GWP Solutions for Foam, Refrigerant, Solvent, Aerosols

Comparative Physical Properties – Solstice LBA

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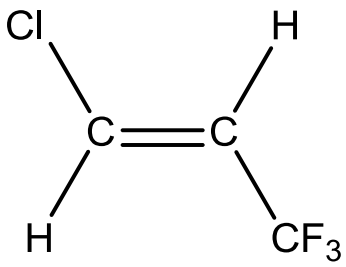

- **(E) 1-chloro-3,3,3-trifluoro-propene**
- **Trans isomer**

	Solstice LBA	245fa	Cyclopentane
Mol. Weight	130	134	70
Boiling Point			
°C	19	15.3	49.3
°F	66	59.5	120.7
Flashpoint			
°C	None	None	-7
°F	None	None	19
LFL / UFL (Vol % in air)	None	None	1.5-8.7
ODP	~0(1)	~0	~0
GWP, 100 yr	< 5(2)	1030(3)	<25(6)
OEL(5) (PEL)	300 (4)	300	600

1. No impact on ozone layer depletion and is commonly referred to as zero, Reference: Preliminary report: Analyses of tCFP's potential impact on atmospheric ozone**;** Dong Wang, Seth Olsen, and Donald Wuebbles Department of Atmospheric Sciences University of Illinois, Urbana, IL
2. Reference (Private Correspondence with Donald Wuebbles)
3. 2007 Technical Summary. Climate Change 2007: They Physical Science Basis. Contribution of Working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.
4. Honeywell Internal OEL
5. Manufacturers' literature except where noted
6. UNEP Rigid anf Flexible Foams Technical Options Committee 2010 Report

Note: Physical properties are one of a mosaic of attributes that must be assessed to determine the suitability of any material as a blowing agent.

Solstice LBA has excellent blowing agent properties

Safe for Users and the Environment

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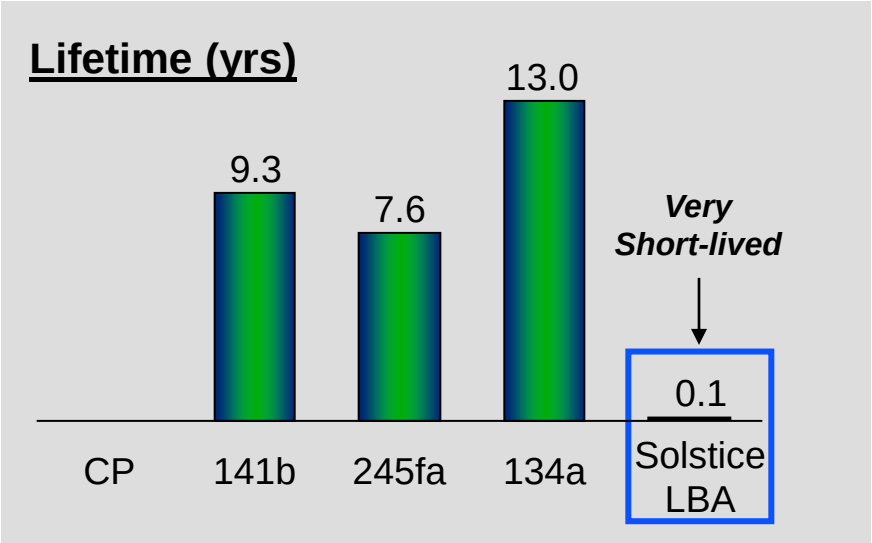

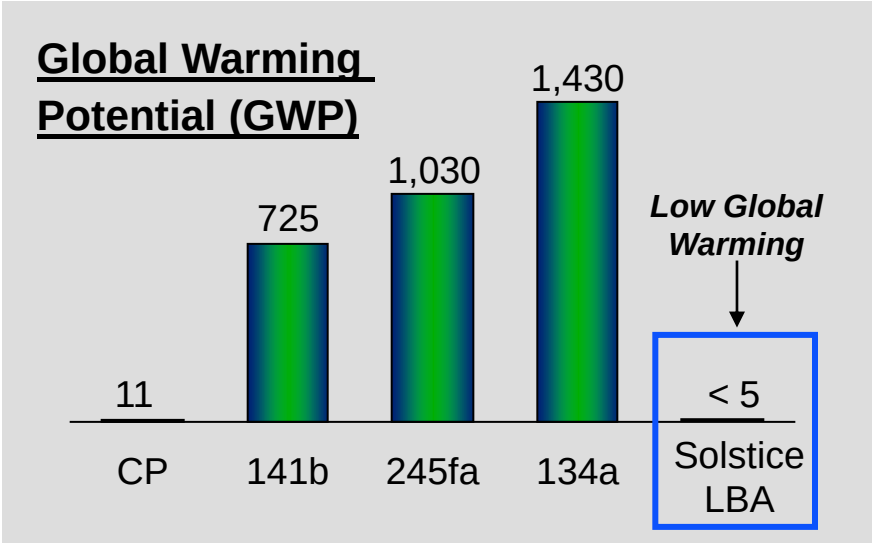

FLAMMABLE

- Cyclopentane
- 365mfc

Higher Cost/Risk

NOT FLAMMABLE

- 141b
- 245fa
- 134a
- Solstice™ LBA

VOC/ High POCP

- Cyclopentane

Permitting Issue Higher Cost

NOT VOC/Low POCP

- 141b
- 245fa
- 134a
- 365mfc
- Solstice™ LBA*

Superior safety and Environmental Performance

Transitioning from Blowing Agent 141b

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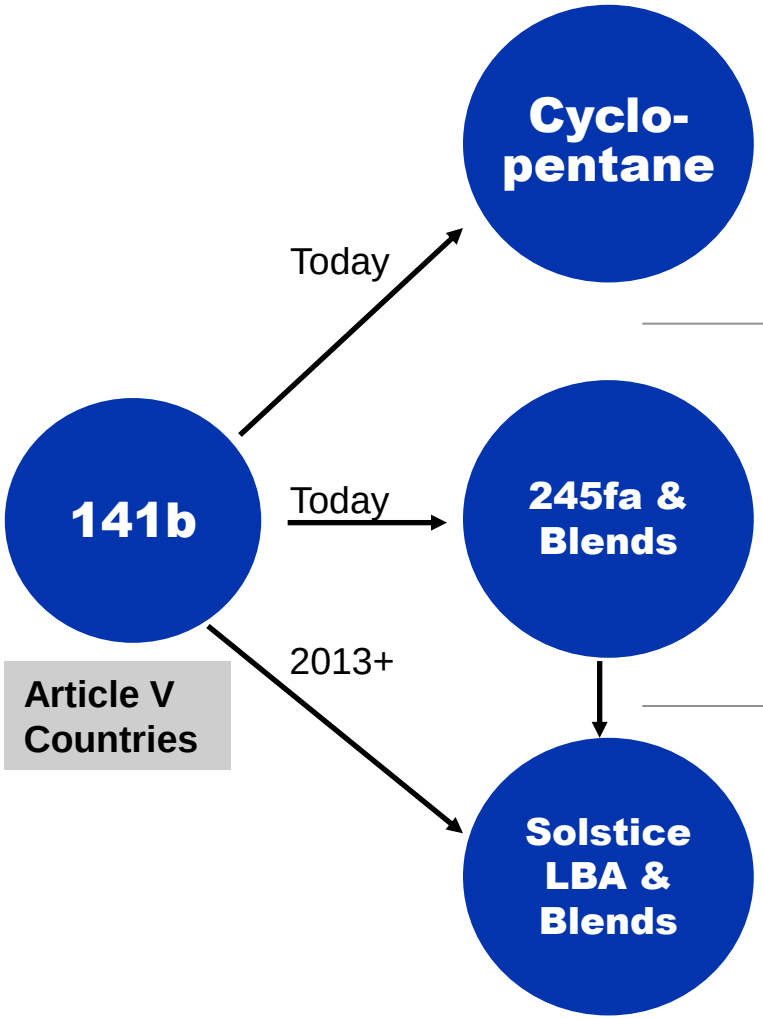
Current: | **Transition to:** | **Assessment** | **Future Impact**



Cyclo-pentane

Assessment: Performance (red), Cost-effective (red), Environment (yellow), Safety (red)

- May not meet emerging energy standards and may ***require a 2nd transition*** to 245fa or Solstice LBA

245fa & Blends

Assessment: Performance (green), Cost-effective (green), Environment (yellow), Safety (green)

- Solution available today
- Will meet energy efficiency standards
- Can transition to Solstice LBA in future to meet GWP standards

Solstice LBA & Blends

Assessment: Performance (green), Cost-effective (green), Environment (green), Safety (green)

- Most energy efficient blowing agent with very low GWP (<5) puts you in the ***best position now and in the future***

245fa, Solstice LBA & Blends: Low Capital and Cost Transitions

Regulatory and Commercialization Status

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- **Regulatory:**
  - US EPA approval
  - EU: Registered up to 10MT, additional filings in place
  - No limitations on sales in: India, Indonesia, remaining A/P, Mexico, **Brazil**, S. America, Central America, M. East, Africa
- **Commercial trials on-going across multiple applications**
  - Appliance
  - Spray foam
  - Panel (continuous and discontinuous)
- **Commercialization status:**
  - Today: Trial quantities available
  - 2013: Semi-commercial
  - 2014: Commercial; multiple sources

Commercialization on Track

Summary

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- **245fa is available and viable today**
  - Fully registered, available in Brazil, 2% import tax
- **Solstice LBA commercializing now**
  - No chemical registration requirements
  - Semi-scale available in 2013, full commercial in 2014
- **Solstice LBA offers superior environmentally properties, safety and performance**
  - GWP < 5, No impact on the Ozone Layer
  - Non-flammable
  - Great insulation performance – Lowest thermal conductivity
- **Transition from 141b > 245fa > Solstice LBA**
  - Brazilian HPMP permits 245 as step to LGWP product
  - Minimizes equipment modifications

A smooth transition: 141b > 245fa > Solstice LBA

Solstice LBA

Appliance Foam Applications

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Liquid Blowing Agents Comparison (PU Foam Appliances)

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		HCFC 141b	Hydro Carbons	245fa	Solstice LBA / Blends
Performance	Energy Efficiency				
Cost effective	Adoption Capital / Ease				
	Lower Cost / Unit*				
Environment	Global Warming Impact				
	Ozone Depletion Impact				
	Volatile Organics				
Safety	Flammability				

In-Place λ
(mW/m-K)
- 141b 17
- c-pentane 20-21
- 245fa 18-19
- LBA 17

* Specifics will vary by energy efficiency standards and type of refrigerator

Solstice LBA: Lower Total Cost to Meet Energy Standards, Most Efficient and Great Environmental Properties

** Comparison based on future increasing energy standards, reflects total cost to produce refrigerator / freezer*

Refrigerator Trials

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- Commercial manufactured refrigerators, 200-710 liter
- Major appliance OEMs and major global polyurethane system houses performed trials
- Conducted trials in NA/EU/Asia
- State of the art appliance polyurethane system utilized
- Benchmarked performance versus cyclopentane and 245fa
- Multiple trials: 100’s units total on Multiple refrigerator platforms
- Long term performance assessment continues: initial refrigerators manufactured in 2009
- Demonstrated comparable / improved process conditions
- Demonstrated HIPS liner computability

Solstice LBA Refrigerators Benchmarked to Commercial 245fa or cyclopentane Refrigerators

Solstice LBA- More Energy Efficient

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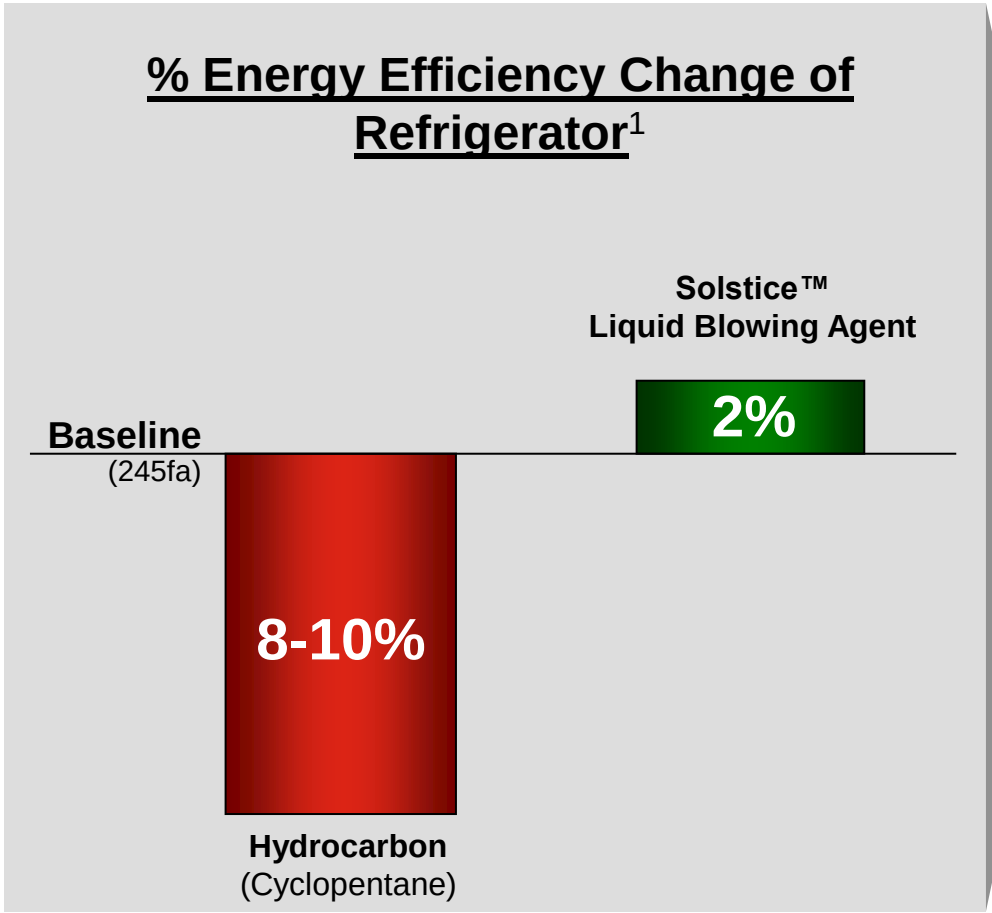

- **In refrigerator trials, Solstice LBA saves costs:**
  - 10-12% more efficient than cyclopentane
  - 2% more efficient than 245fa
- **Results proven with OEMs in US, China, Korea, Europe, M. East**
- **Similar performance for spray and panel foam**

10-12% More Energy Efficient than Cyclopentane

1) Commercial refrigerator trials; unoptimized formulation of Solstice LBA; Cyclopentane vs. 245fa from AHAM trials

Solstice LBA versus 141b

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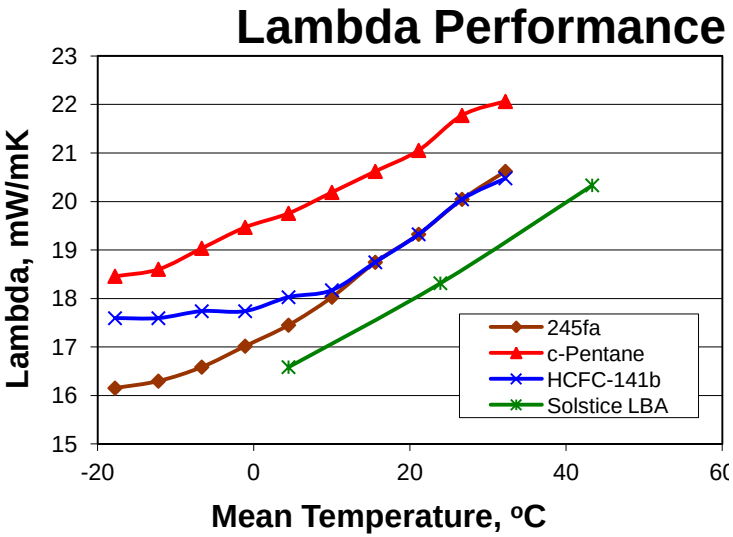
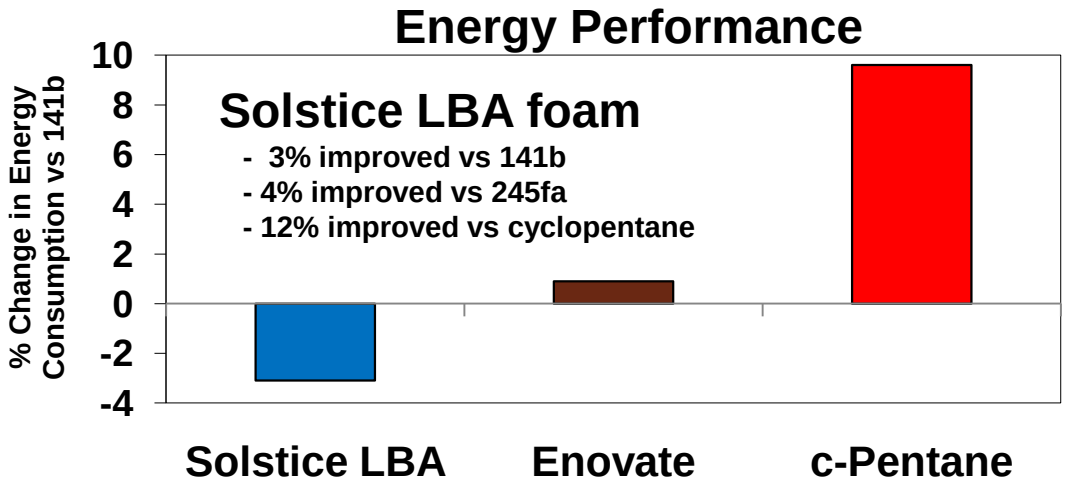
Foam performance of Solstice LBA

- Polyol miscibility equal to 141b, improved versus Enovate Blowing Agent (245fa)
- Similar strength properties to Enovate, improved compared to 141b at equal density
- Improved k-factor than Enovate foams
- Improved k-factor compared to c-pentane foams





Source: AHAM 3rd Gen BA study plus Hon data on Solstice LBA

Lambda and Energy Performance Superior to 141b, CP, and 245fa

Summary: Solstice LBA In Appliances

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- **Refrigerator finished product energy efficiency performance…**
  - 3% improvement vs. 141b
  - 2-4% improvement to 245fa
  - 8-12% improvement to cyclopentane
- **Lower cost solution (capital and manufacturing costs)**
  - Dependent upon energy efficiency standard, refrigerator platform:
    - Avoid spending capital to mitigate flammability
    - Opportunity to take out costs for VIP, variable speed compressors etc…
  - Lower capital and cost/ refrigerator than flammable blowing agents
- **Best environmental balance**
  - Low GWP (<5)
  - Low POCP / Non-VOC (anticipated classification relative to MIR)
- **Safety: non flammable**

Solstice LBA – The Best Global Solution

Solstice LBA

Spray Foam Applications

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Spray Program Status and Direction

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- **Engaging System Houses Globally**
  - Samples provided
  - Multiple lab assessments in Japan and US
  - Multi-season trials conducted
    - Favorable results and ongoing work with partner companies
- **Engaging other raw material suppliers**
  - Polyol, PMDI, surfactant, catalyst, flame retardant suppliers engaged
  - Work initiated to identify or develop optimum raw materials and additives for use with Solstice LBA
- **Joint Evaluation with Industry Associations**
  - Honeywell recommended formulation evaluated
  - Feasibility demonstrated
  - Foam meets current code requirements
  - Individual systems houses developing commercial systems based on demonstrated formulation

Commercial demonstration project this month in USA

Polyol Miscibility Evaluations

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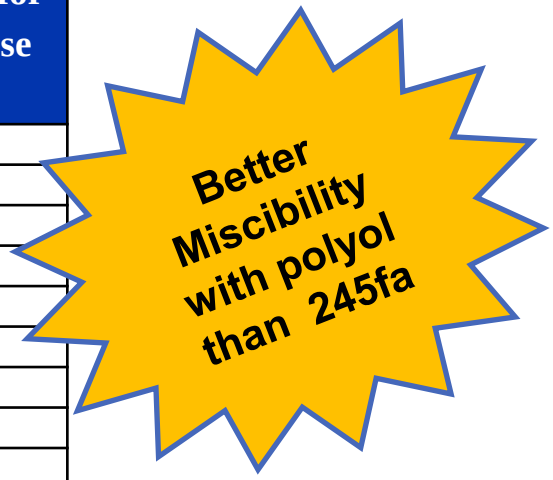
Polyol	Max. Wt% for Single Phase		Polyol	Max Wt% for Single Phase
Polyether			**Polyester**	
Carpol® GSP-280[1]	>40		Phantol® SV-298[10]	35
Jeffol® A630[2]	>40		Phantol® JP-733[10]	29
Multranol® 3901[3]	>40		Phantol® 6300[10]	44
Pluracol® 824[4]	>40		Phantol® 6301[10]	35
Voranol® 270[5]	>40		Phantol® 6305[10]	>50
Voranol® RH360[5]	>40		Stepanol® 2352[6]	>40
Voranol® 350X[5]	>40		Terate® 2031[7]	~11
Voranol® 470X[5]	>40		Terate® 2540[7]	40
Voranol® 490[5]	>40		Terate® 4020[7]	~20
Voranol® 800[5]	>40		Terol® 198[8]	40
			Terol® 250[8]	40
Polyester			Terol® 256[8]	25
Maximol® RDK-133[9]	25		Terol® 305[8]	26
Maximol® RDK-121[9]	25		Terol® 352[8]	23
Maximol® RDK-142[9]	25		Terol® 925[8]	21
Phantol® PL-272[10]	24		Terol® 1254[8]	39
Phantol® PL-306[10]	16		Terol® 1304[8]	47
Phantol® PL-405[10]	19		Terol® 1465[8]	25
Phantol® SV-208[10]	37		Terol® 1481[8]	30
PMDI				
Luprinate M20s[4]	>10			



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[2]Trademark of Huntsman
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[6]Trademark of Stepan
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[8]Trademark of Oxid L.P. / Data provided by manufacturer
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[10] Trademark of Hitachi Kasei Polymer Co. Ltd./ Data provided by manufacturer

Excellent Miscibility in Polyether and Polyester Polyols & PMDI

System Properties- Vapor Pressure

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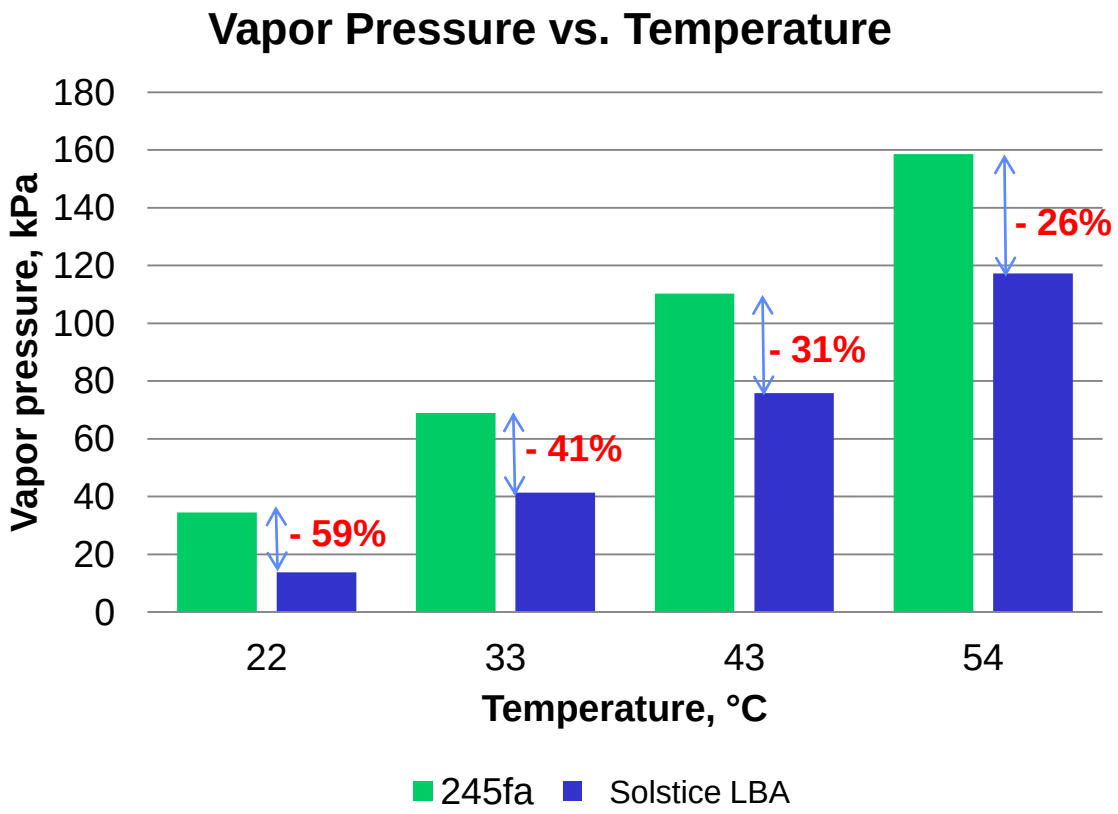

Lower Vapor Pressure Means:

- Less potential for bulging drums
- Potential to use lower gauge (thinner) drums
- Less potential for blowing agent loss from system

Solstice LBA Has Lower Vapor Pressure at All Temperatures

System Properties-Formulation Stability @ RT (room temp)

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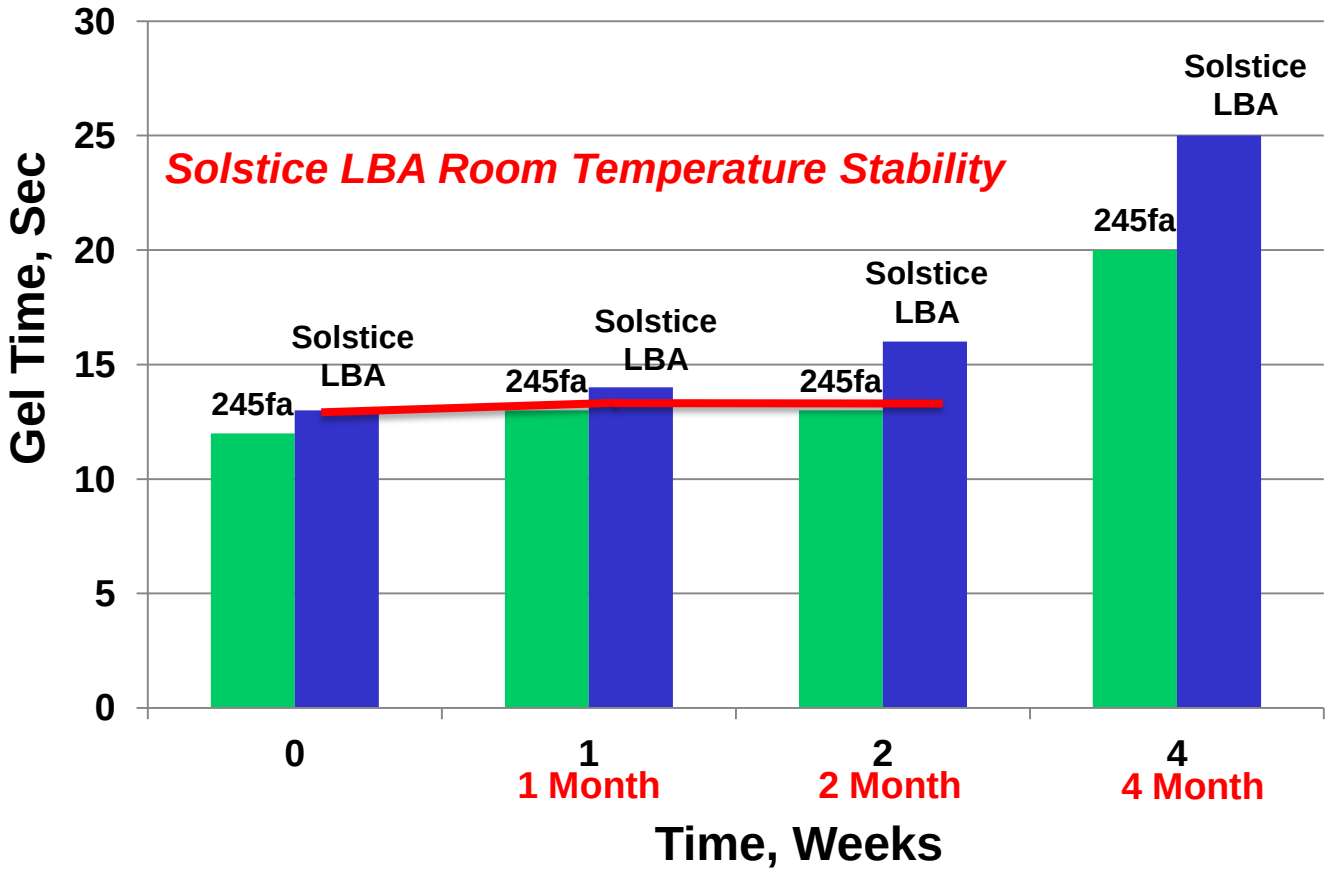

Conclusion:

- Accelerated 54°C test – produces results not seen at RT
- Solstice LBA formulation shows no gel time variation at RT

Solstice LBA Formulation Has Acceptable Stability

Physical Properties

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System		245fa	Solstice LBA
Tests	Units		
Gel time	sec	5.00	8.00
Density	kg/m^3	32.60	32.60
Compressive strength, Perpendicular	mPa	0.07	0.07
Compressive strength, Parallel	mPa	0.18	0.20
Initial Thermal conductivity @24°C	mW/mK	20.40	19.30
Closed cell content	%	92	90
Dimensional stability -30C @ 28 days	Vol %	-0.58	-0.58
Dimensional stability 70C @ 28 days	Vol %	5.54	0.48
Dimensional stability 70C/ 95% humidity @ 28 days	Vol %	15.80	4.90

Solstice LBA Foams Equal or Better than 245fa- Further System Optimization In Progress

Foam Quality

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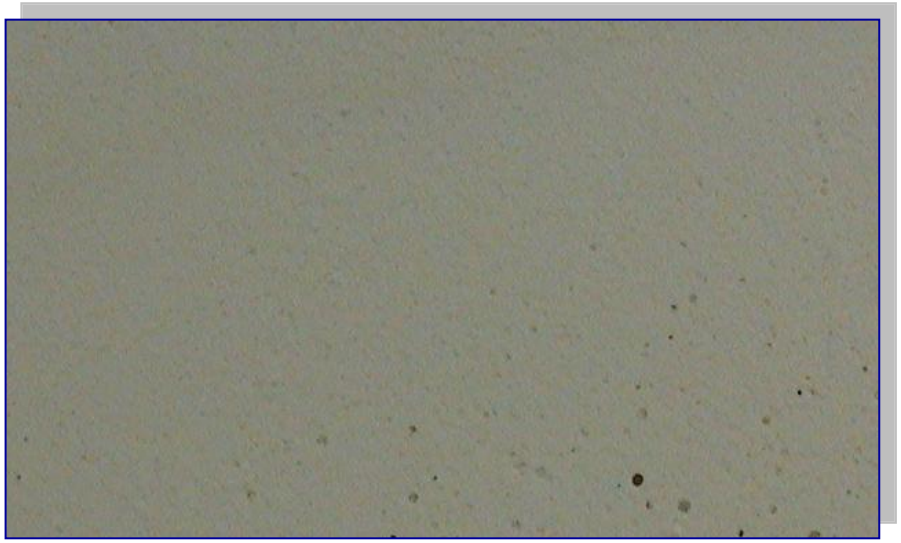
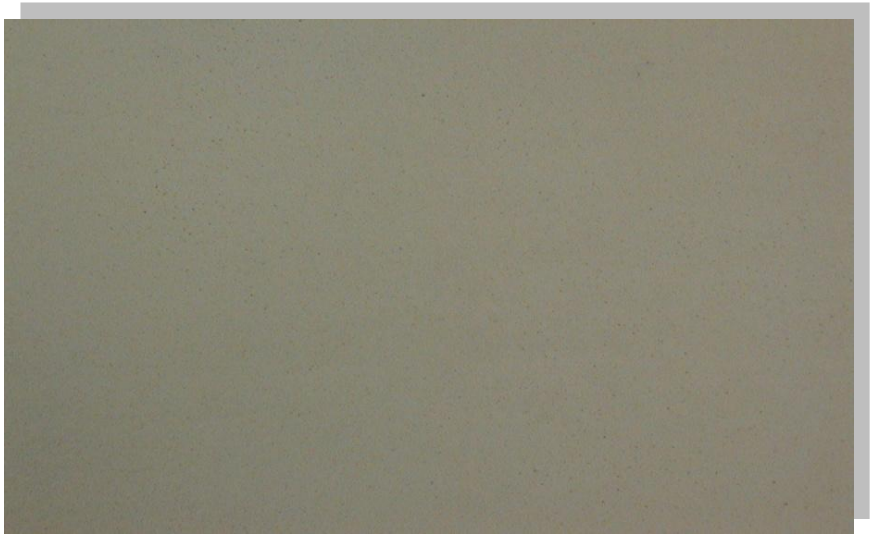
245fa



Solstice LBA



Fine Cell Size – Uniform Cell Structure – Smooth Surface

Solstice LBA Versus 141b in Spray Foam

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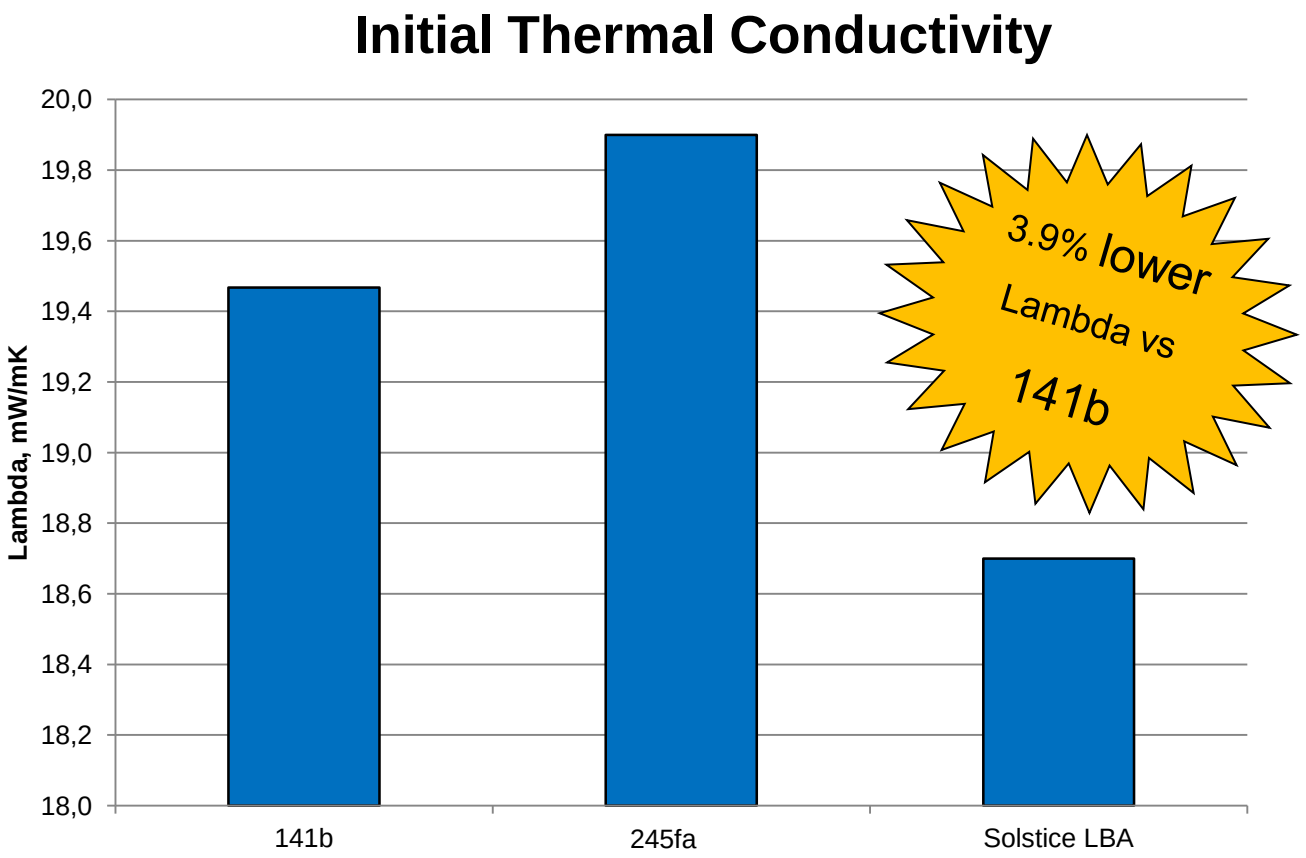

Solstice LBA shows superior performance to 141b and 245fa

Summary: Solstice LBA In Spray Foam

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- **Excellent Insulation Performance**
  - 4% improvement vs 141b
  - 5-6% improvement vs 245fa
- **Safe and effective solution**
  - Non-flammable
  - Highly miscible in commonly used polyols
  - Reduced vapor pressure
    - Reduces risk is packaging, shipping, and storage
  - Excellent processing characteristics
- **Best environmental balance**
  - Low GWP (<5)
  - Low POCP / Non-VOC (anticipated classification relative to MIR)

Solstice LBA – The Best Global Solution

Solstice LBA

Panel Foam Applications

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Discontinuous Panel Generic Formulations

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Polyol Blend (B-side)				
Components (php)	Solstice LBA	245fa	C-C5	141b
Polyether Polyol	65.0			
Polyester Polyol	35.0			
Catalyst	2.0			
Surfactant	1.5			
Flame Retardant	22.0			
Water	2.0			
Blowing Agent	23.3	24.0	12.5	21.0
Isocyanate (A-side)				
Isocyanate	143.6			

A Blowing Agent "Drop-in" Replacement Study

Comparison of Physical Properties

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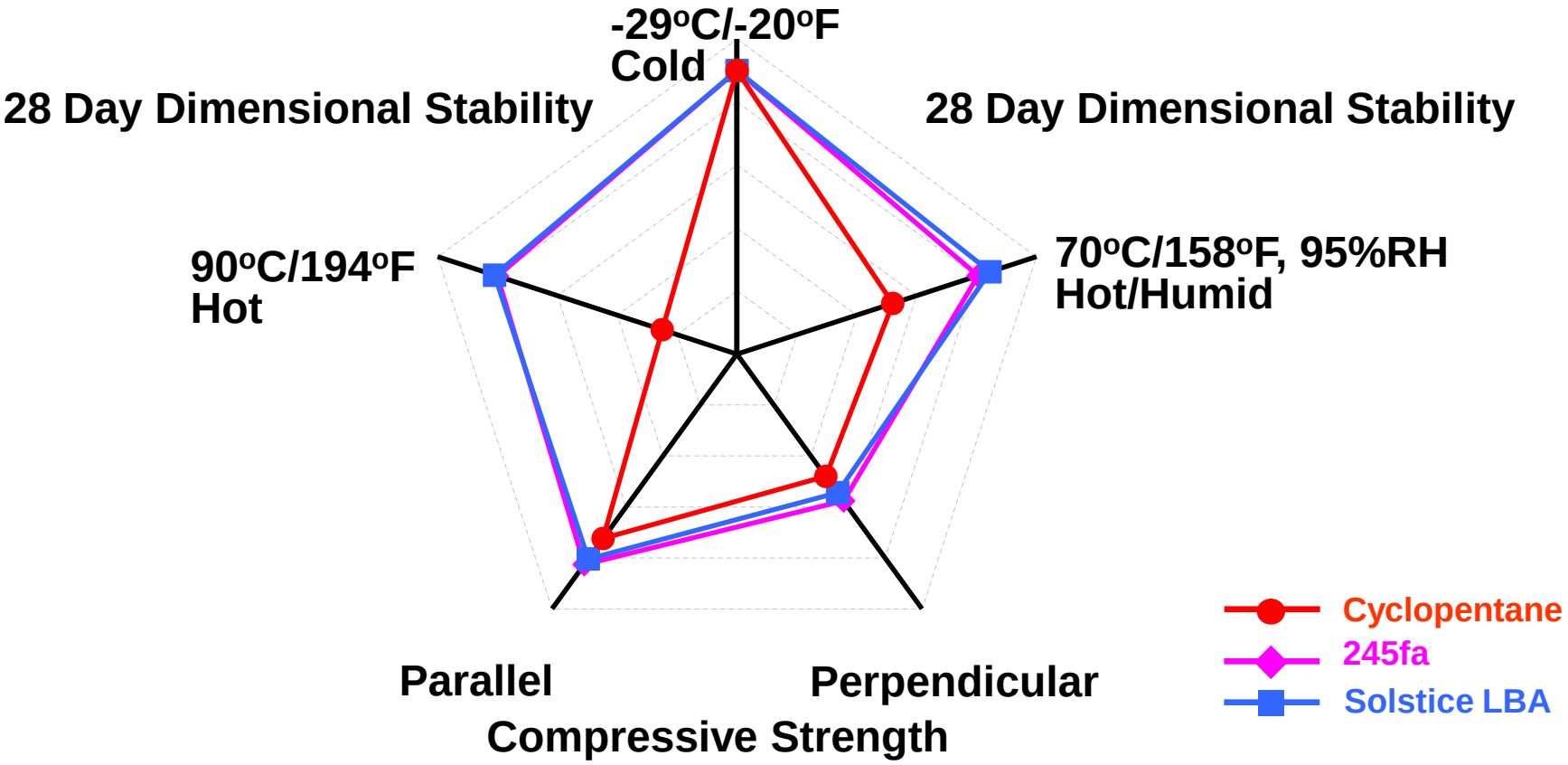
Liquid Blowing Agents



Comparable Properties to 245fa, Better Properties than Cyclopentane

Initial Thermal Conductivity

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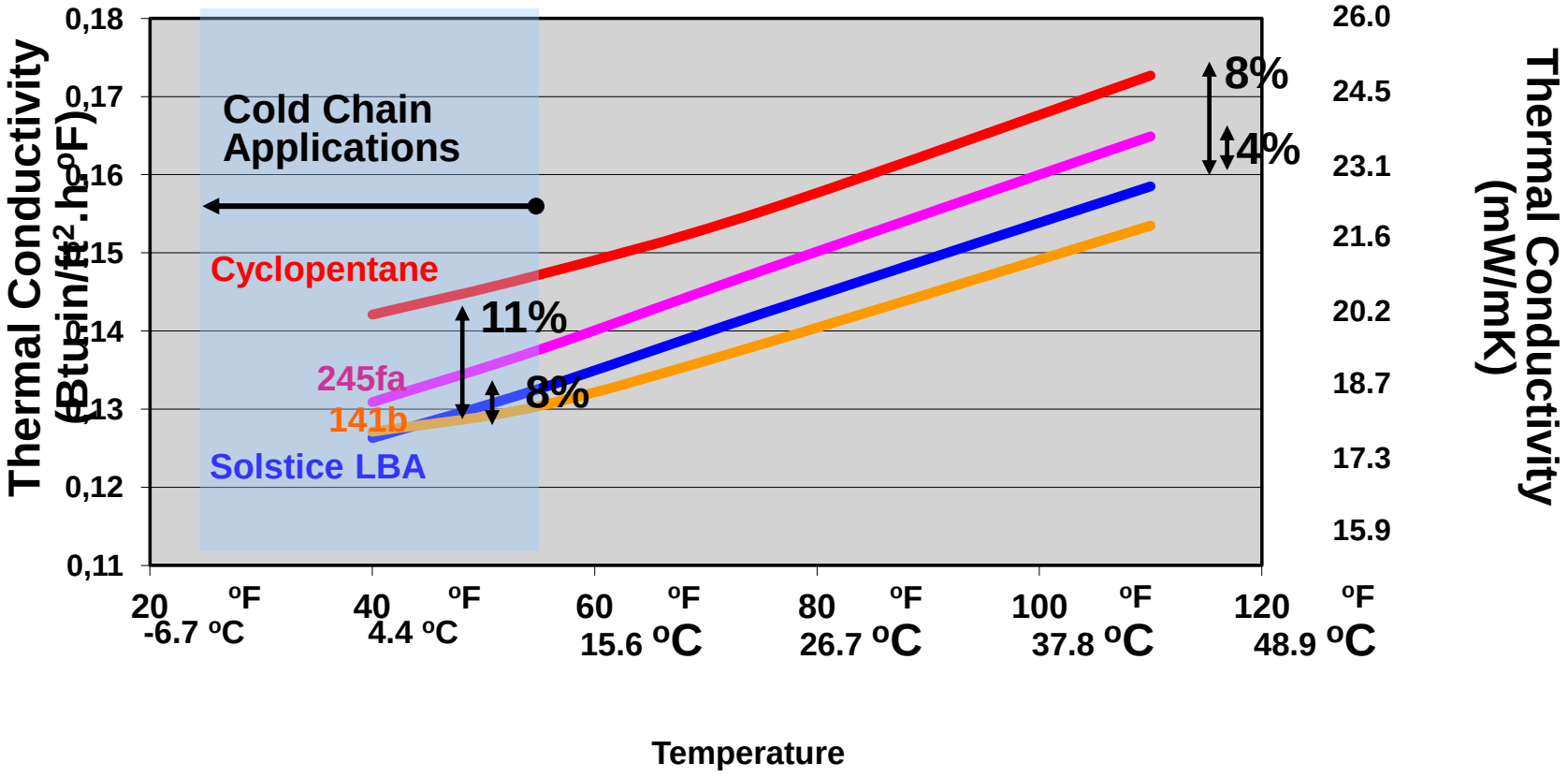

Best Thermal Insulation Performance for Cold Chain Applications

28 Day Aged Thermal Conductivity

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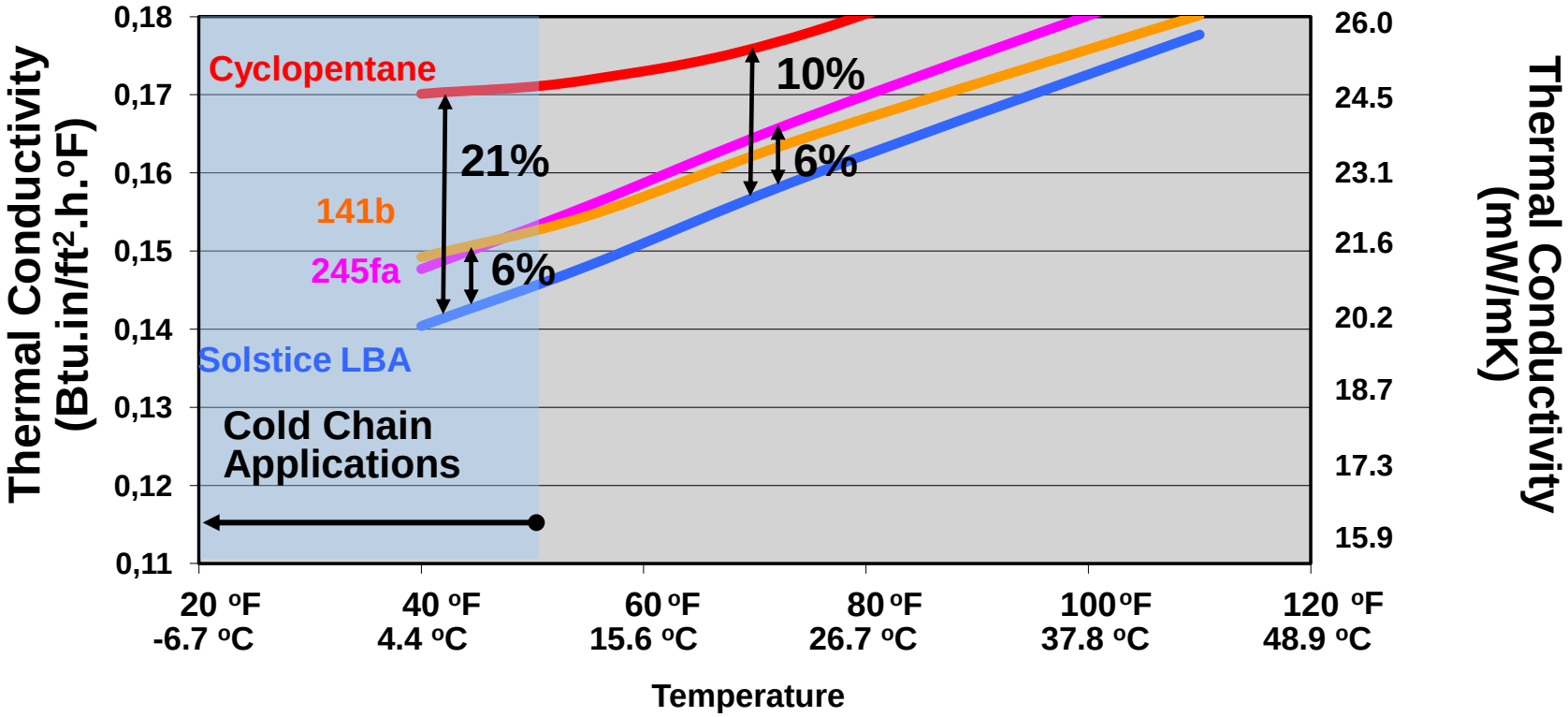

Best Thermal Insulation Retention at All Evaluated Temperatures

Solstice LBA / Cyclopentane Mixtures for Panel Foam Applications

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Comparison of Physical Properties

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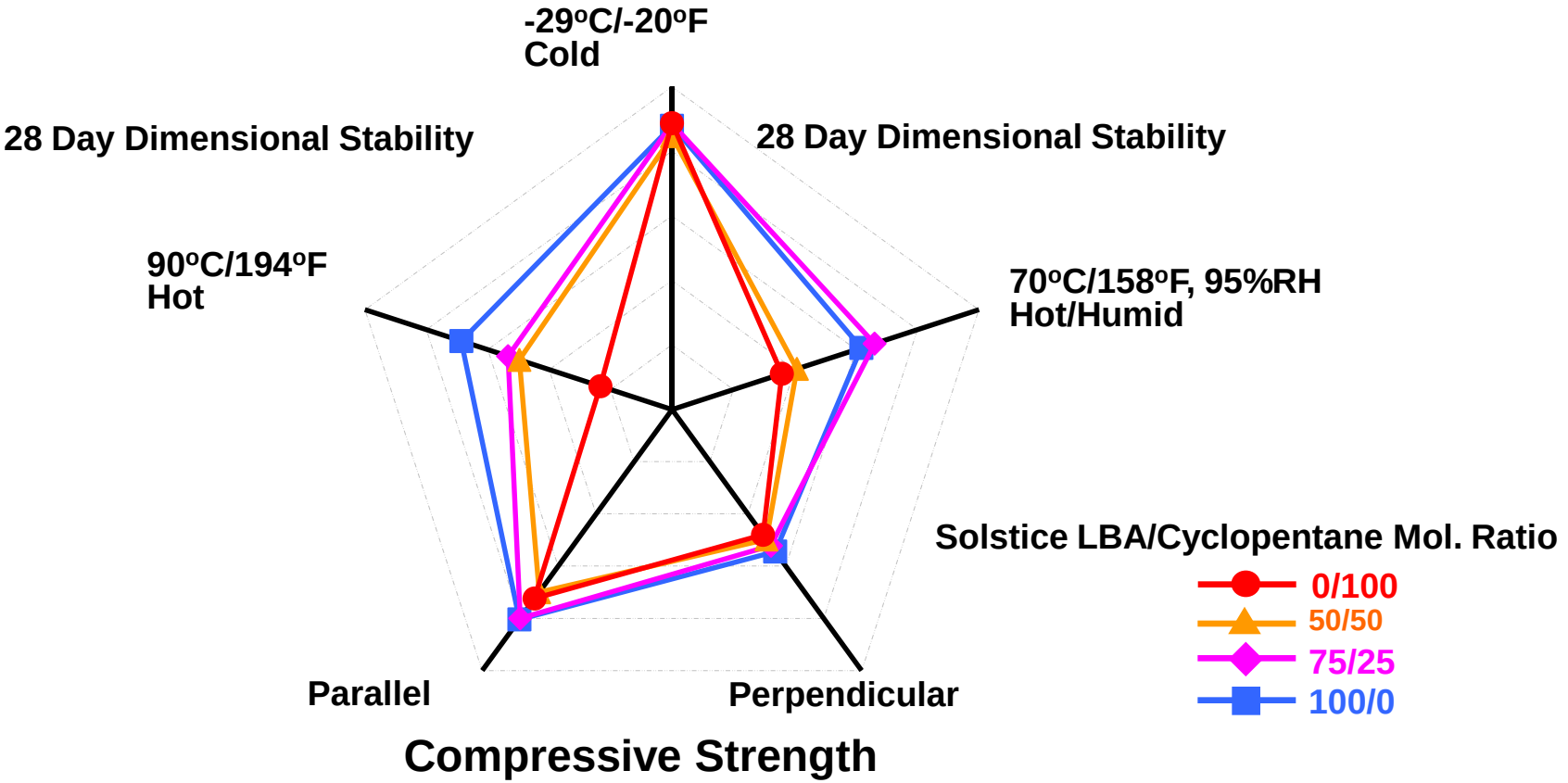
Solstice LBA/Cyclopentane Blends



Solstice GBA/C-C5 Blend: Balanced Solution for Cost and Physical Properties

Initial Thermal Conductivity

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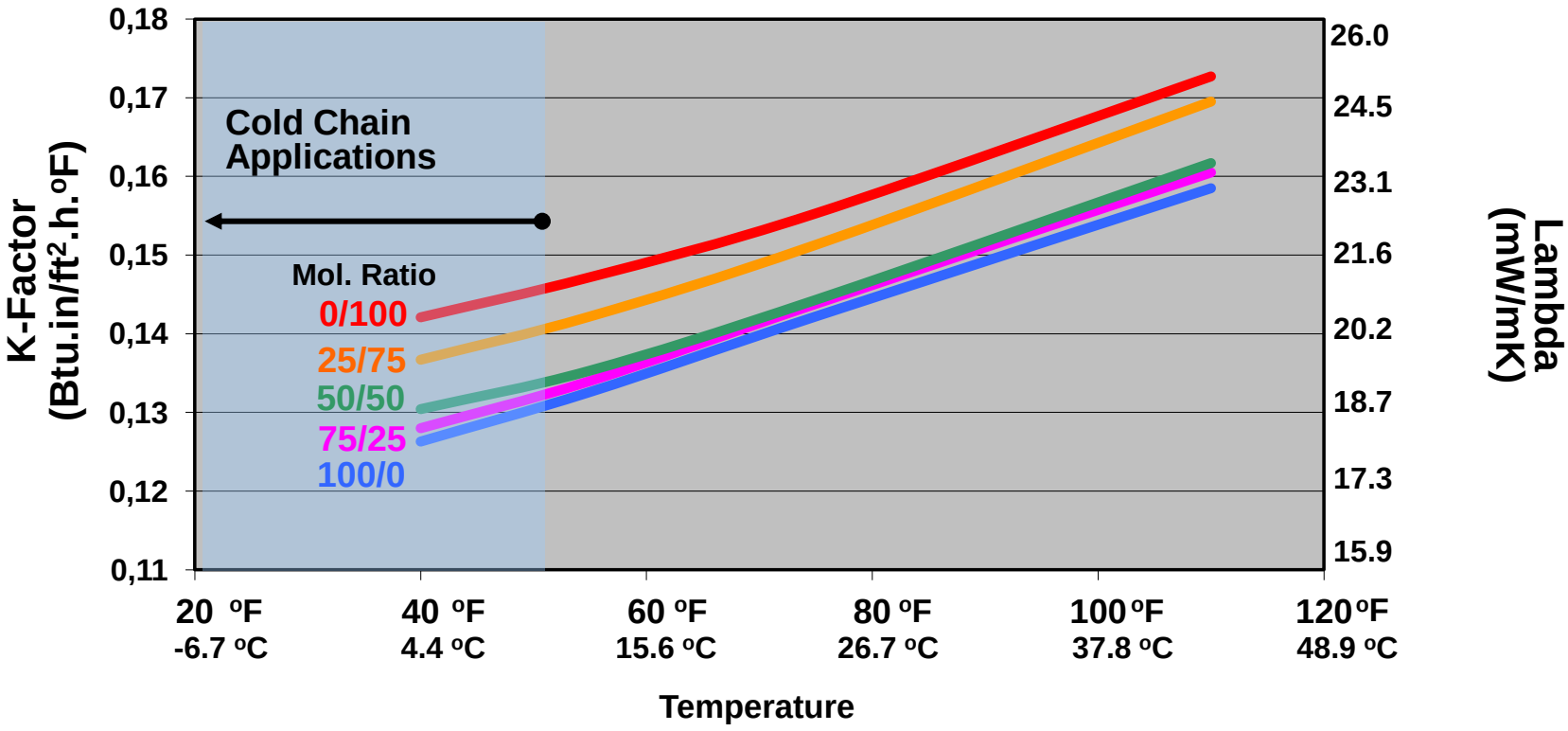
Solstice LBA/Cyclopentane Blends



Solstice LBA/Cyclopentane Blend:
Balanced Solution of Desired Properties

28 Day Aged Thermal Conductivity

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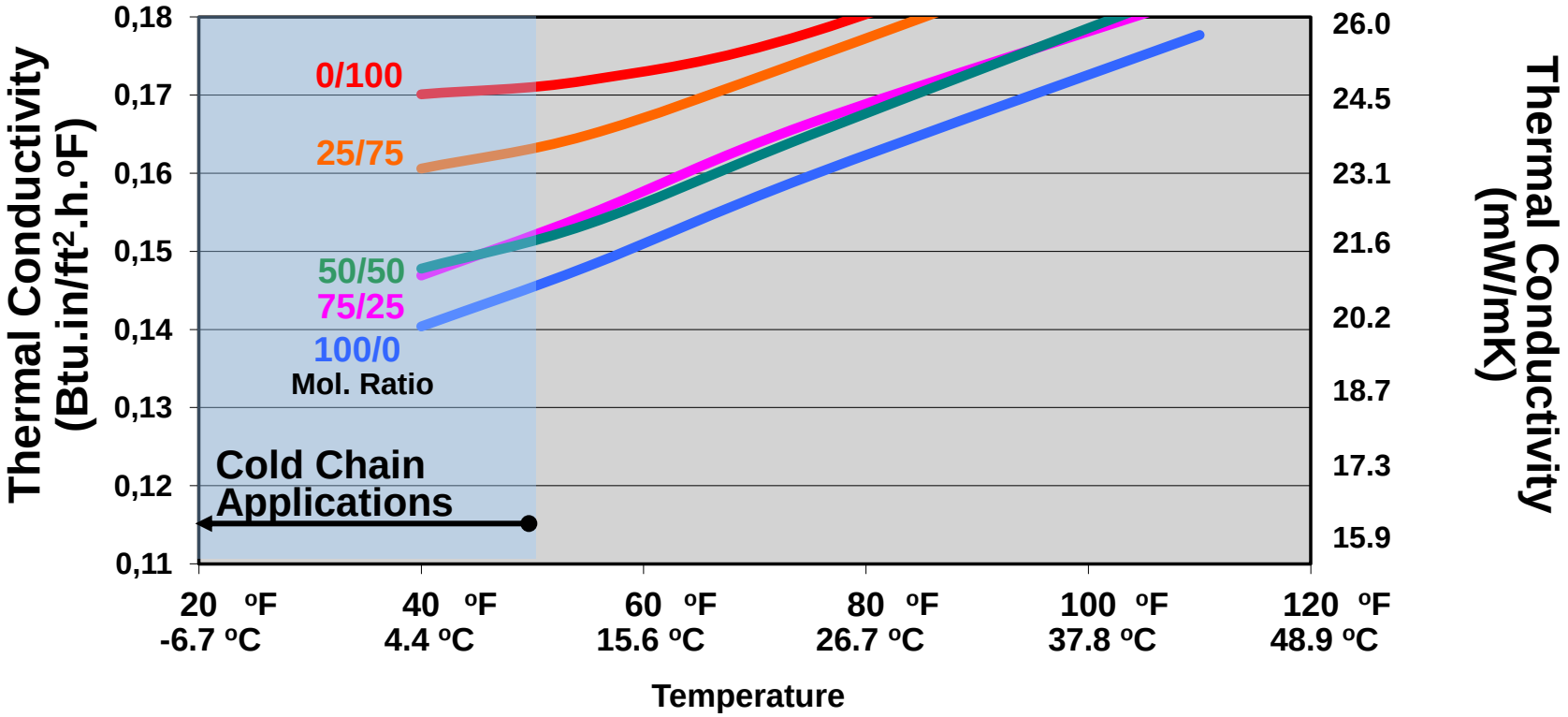
Solstice LBA/Cyclopentane Blends



Addition of Solstice LBA Enhances Thermal Insulation Retention

Foam Flammability Evaluations

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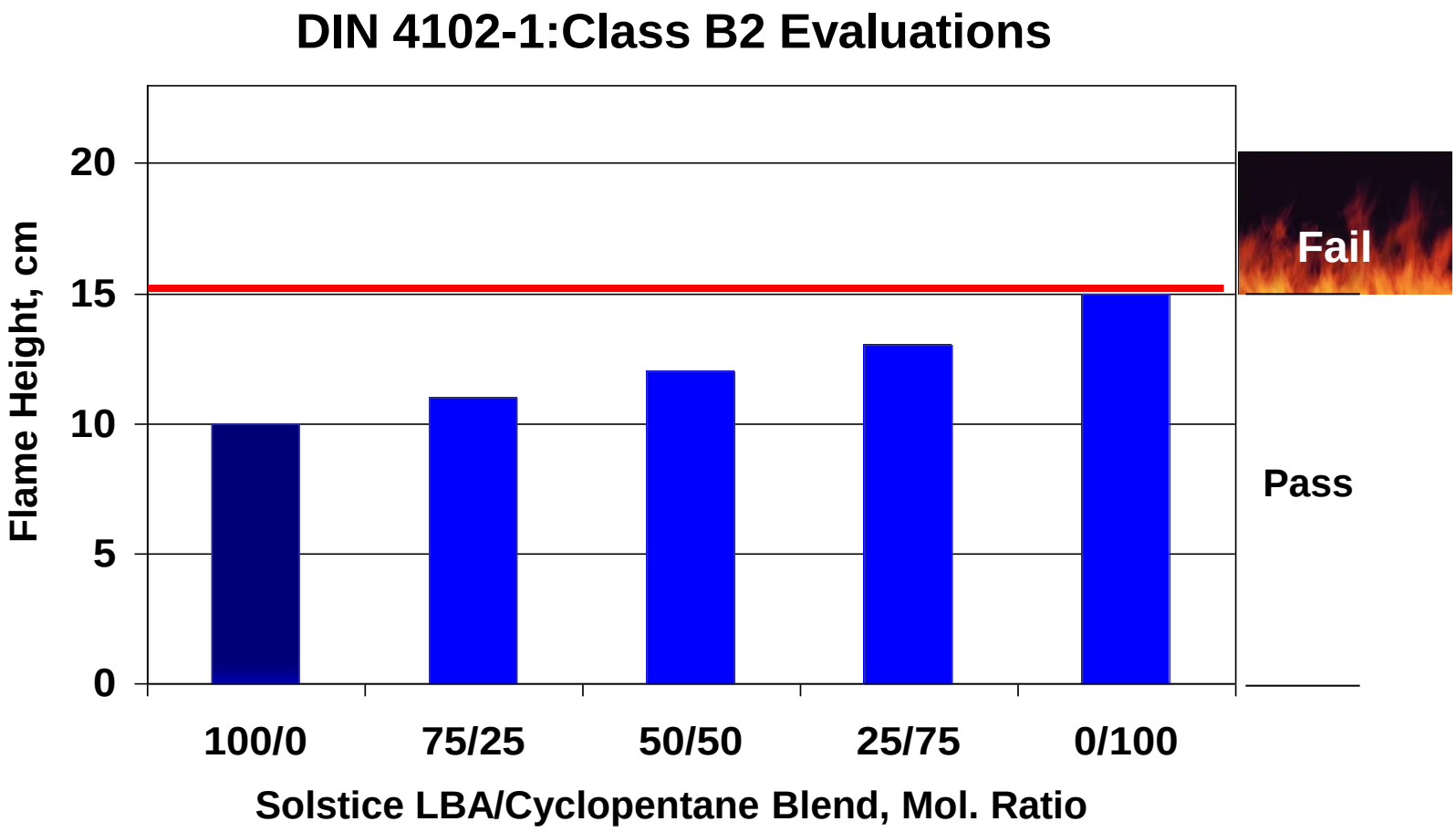

Solstice LBA: Enhanced Foam Fire Retardancy

Summary: Solstice LBA In Panel Foam

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- **Excellent Insulation Performance**
  - 4% improvement vs 245fa
  - 8% improvement vs cyclopentane
  - Superior thermal conductivity retention vs other alternatives
- **Safe and effective solution**
  - Non-flammable
  - Highly miscible in commonly used polyols
  - Physical properties similar to HFC-245fa foam
  - Improved dimensional stability compared to cyclopentane
- **Potential blend options**
  - Blends of Solstice LBA and cyclopentane offer effective strategy to balance performance and cost
- **Best environmental balance**

Solstice LBA – The Best Global Solution

Converting From HCFC-141b or Pentane to HFC -245fa and Solstice LBA

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Blowing Agent: Properties Comparison

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	HCFC-141b	245fa	Solstice LBA	Cyclopentane
Molecular Weight	117	134	130	70
Boiling Point				
°C	32.0	15.3	19.0	49.3
°F	89.6	59.5	66.0	120
Flashpoint				
°C	None	None	None	-7
°F	None	None	None	19
Flammability Limits (Vol % in air)	7.4-15.5	None	None	1.5-8.7
GWP, 100yr[1]	725	1030	<5[4]	<25[5]
PEL[3]	500	300	300	600

[1] 2007 Technical Summary. Climate Change 2007. The Physical Science Basis. Contribution of working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. (Except where noted)
[2] Measured Value
[3] Manufacturers' literature where noted
[4] Private Communication, Prof. D. Wuebbles, University of Illinois, Dept. Atmospheric Sciences
[5] UNEP Rigid and Flexible Foam Technical Options Committee 2010 Report

Most 141b Equipment is Compatible with 245fa and Solstice LBA

Pressure Considerations - Tanks

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Blowing Agent	Vapor Pressure @120 °F (49°C) + 10% factor	Recommended Tank Design Pressure (minimum)
HCFC-141b	11.8 psig (81.5 kPa)	50 psig (345 kPa)
245fa or LBA	36.3 psig (250 kPa)	50 psig (345 kPa)
HFC-134a	188.2 psig (1300 kPa)	250 psig (1725 kPa)
c-Pentane		Pressure Vessels

Pressure vessels preferred in hot climates: 150 psig (1000 kPa)

Temperature Considerations

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- 245fa & Solstice LBA have near room temperature boiling points
- Polyol blend vapor pressure is formulation dependent
- Inert loading affects blend tank system pressure
- Polyol blend vapor pressure is reduced with water as a co-blowing agent (lower levels of 245fa or Solstice LBA)
- 245fa/Solstice LBA Blowing Agent / Polyol Blend Operations
  - Polyol temperature is usually higher than boiling point of blowing agent
  - Addition rate should not exceed 245fa or Solstice LBA dissolution rate
  - Preferred to add blowing agent at bottom of vessel with agitation
  - Inert loading affects the blend system pressure
  - Frothing can be an artifact of these conditions

245fa and Solstice LBA can be managed above boiling point

Materials Compatibility

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- 245fa and Solstice LBA is non-reactive and non-corrosive toward all commonly used metal in PU equipment
  - Carbon steel, stainless steel, copper, and brass
- 245fa and Solstice LBA have generally good compatibility toward plastics and elastomers used in PU industry.

<u>Process Application Considerations</u>

- Risk Exposure of Failure
  - Safety, environmental, and economics
- Polyol Blends with 245fa or Solstice LBA
  - Compatibility cannot be predicted based on neat blowing agent data
- PTFE is best choice
- Detailed compatibility available from Honeywell

245fa and Solstice LBA are compatible with a variety of materials

Storage Tank Conversion Checklist

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- ✓ Assess tank suitability for HFC-245fa or Solstice LBA
- ✓ Inspect tank – externally for corrosion: nozzles, shell, etc.
- ✓ Remove liquid HCFC-141b (or c-pentane) to drums or auxiliary tank
  - Caution: c-Pentane is flammable material
- ✓ Vapor removal with vacuum pump to 29" Hg
- ✓ Introduce dry air to atmospheric pressure
- ✓ Internal tank inspection – SAFETY CAUTIONS APPLY
- ✓ Change all gaskets to compatible gasketing materials
- ✓ Change all valves as indicated by compatibility assessment
- ✓ SRV : Preventative maintenance and test
- ✓ Pressure tank to 50 psig – leak check
- ✓ Evacuate tank to 29" Hg vacuum
- ✓ Bulk tank is ready for HFC-245fa or Solstice LBA delivery
- ✓ Change pump seal if indicated by compatibility
- ✓ Change deficient gaskets from pump suction to polyol blend tank
- ✓ Repair / replace all grounding straps through the system
- ✓ Bulk storage system is converted … to polyol blend tank (system)

Good Engineering Practice will Ensure Success

Polyol Blending Conversion

Honeywell

Master batch Blend Tank

- Determine suitability of tank for 245fa or Solstice LBA and other raw materials
  - Correct sizing
  - Material compatibility
  - Vapor pressure of system
  - Other factors
- Inspect tank internally & externally for corrosion
  - Inspect internal liner if applicable for repair –CAUTION APPLIES
  - Determine that 245fa or Solstice LBA will be introduced below liquid level (master batch tank utilized for blowing agent mixing)
- Assess gaskets and valves for compatibility of the blend
- Inspect polyol cooling / heat exchanger (gasket compatibility)
- Service and test safety relief system

Blowing Agent Blender (c-pentane type)

- Assess gaskets and other elastomers for compatibility
- Re-calibrate for 245fa or Solstice LBA (density / flow rates)
  - Consult blender manufacturer for detail

Conversion Summary

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245fa and Solstice LBA Blowing Agents:

- Can be handled as a liquid
- Are manageable above ambient temperatures
- Exhibit wide compatibility with materials
- Are suitable to be used in most HCFC-141b tanks
  - Are suitable in c-pentane tanks (pressure vessels / explosion proof is typical design)
- Does not require extensive conversion effort

245fa and Solstice very compatible with 141b and CP equipment

Honeywell

www.honeywell-solsticelba.com