

**Further Development of a Low GWP Foam Expansion Agent with Improved Insulation Performance vs. Commercially Available Options Today**

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**Blowing Agents & Foaming Processes  
2010**

**Cologne, Germany**

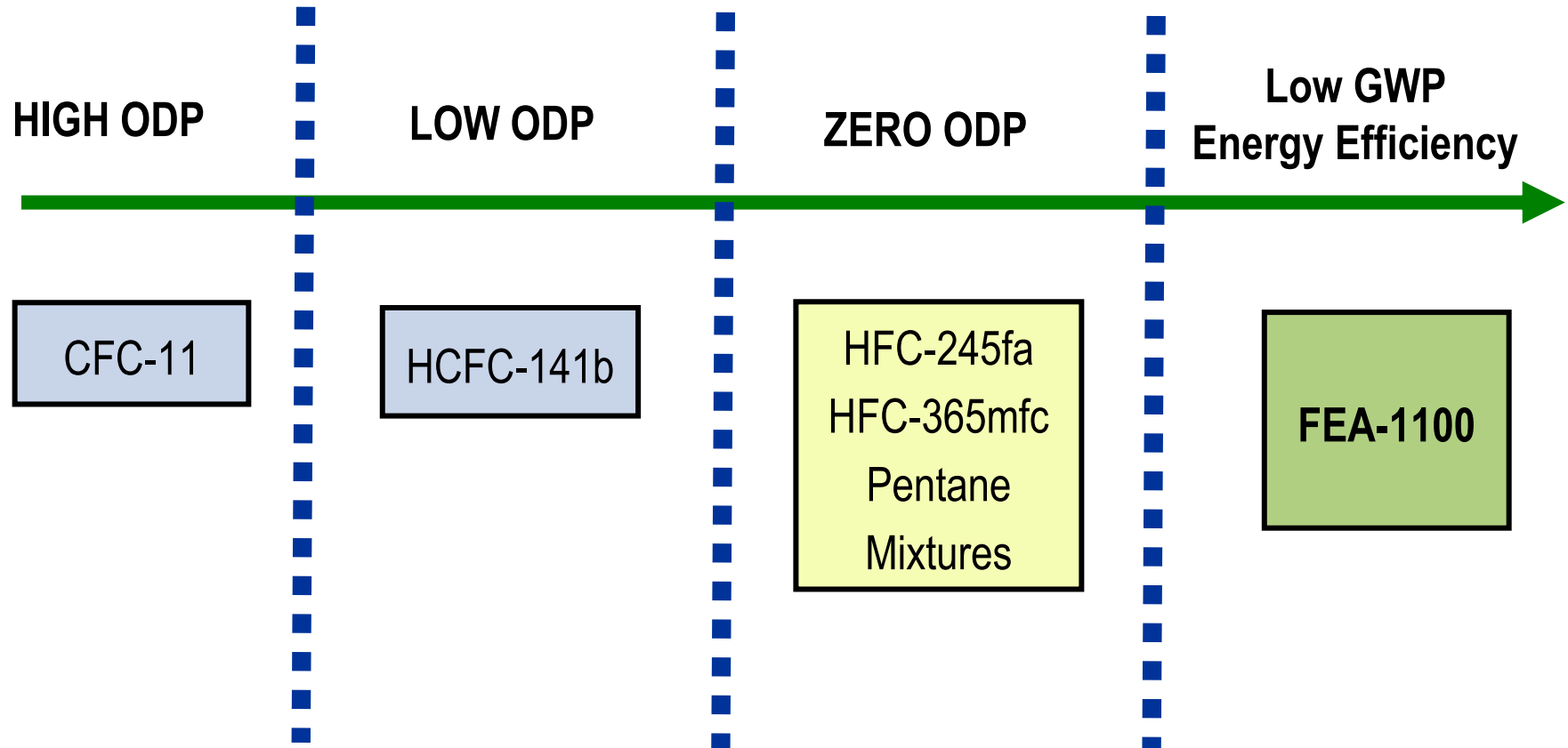


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# Presentation Outline

- **DuPont next gen FEA program**
- **FEA-1100 Properties**
- **Physical and Chemical Stability Evaluation**
- **Performance in Major Types of Polyols**
- **Material Compatibility**
- **Summary**

# Foam Expansion Agents (FEAs or Blowing Agents)



# Next Generation FEA Program Current Status

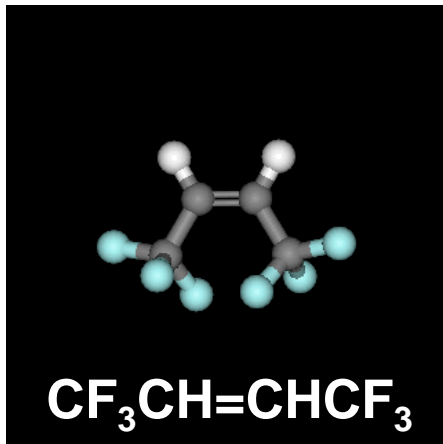
## Criteria

## Attributes

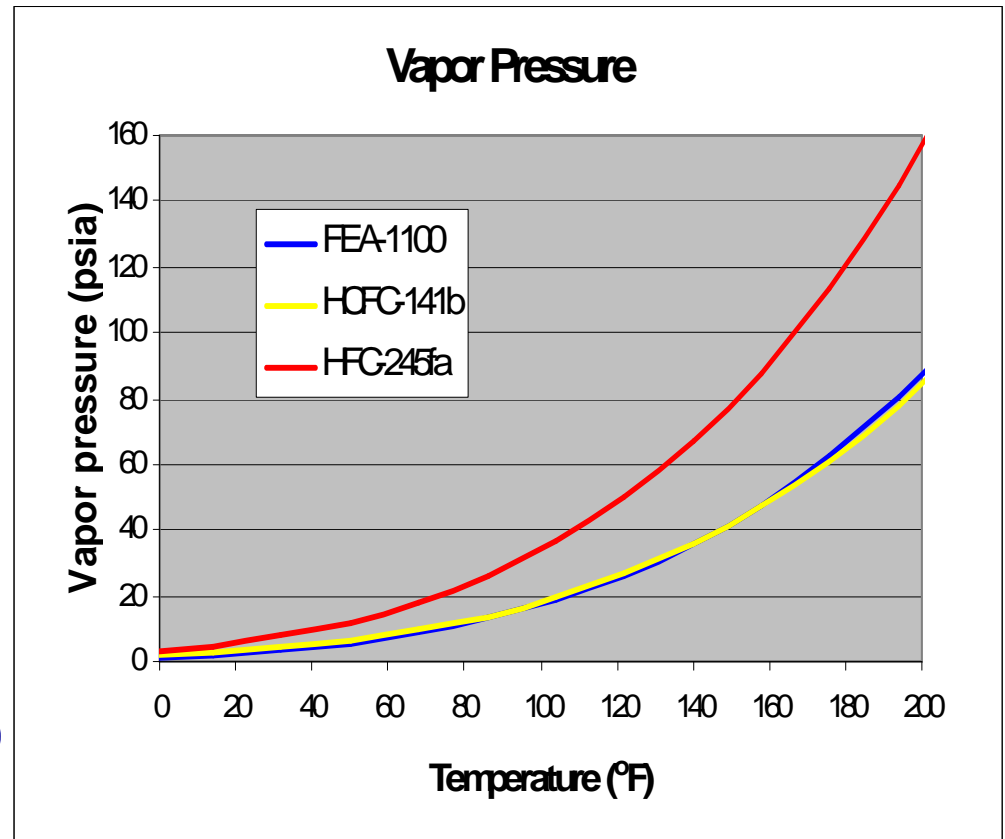
## Status



# FEA-1100



- $GWP_{100\text{ yr ITH}} = 9.7$  (NOAA)
- ATM lifetime: 24 days (NOAA)
- Nonflammable (E 681 at 60°C & 100°C)
- b.p = 33 °C



# FEA Property Comparison

Property	CFC-11	HCFC-141b	HFC-245fa	HFC-365mfc	Isopentane	FEA-1100
Chemical Formular	$\text{CFCl}_3$	$\text{CCl}_2\text{FCH}_3$	$\text{CF}_3\text{CH}_2\text{CHF}_2$	$\text{CF}_3\text{CH}_2\text{CF}_2\text{CH}_3$	$\text{CF}_3\text{CH}(\text{CH}_3)\text{CH}_2\text{CH}_3$	$\text{CF}_3\text{CHCHCF}_3$
ODP	1	0.12	0	0	0	0
GWP (100 year ITH)	4750 <sup>a</sup>	725 <sup>a</sup>	1030 <sup>a</sup>	794 <sup>a</sup>	11 <sup>b</sup>	9.7 <sup>c</sup>
Vapor Thermal Conductivity (mW/mK at 25 °C)	8.4	9.7	12.7	10.5	13.3	10.7
Flash Point (°C)	none	none	none	-25	-51	none
Boiling Point (°C)	24	32	15	40	28	33

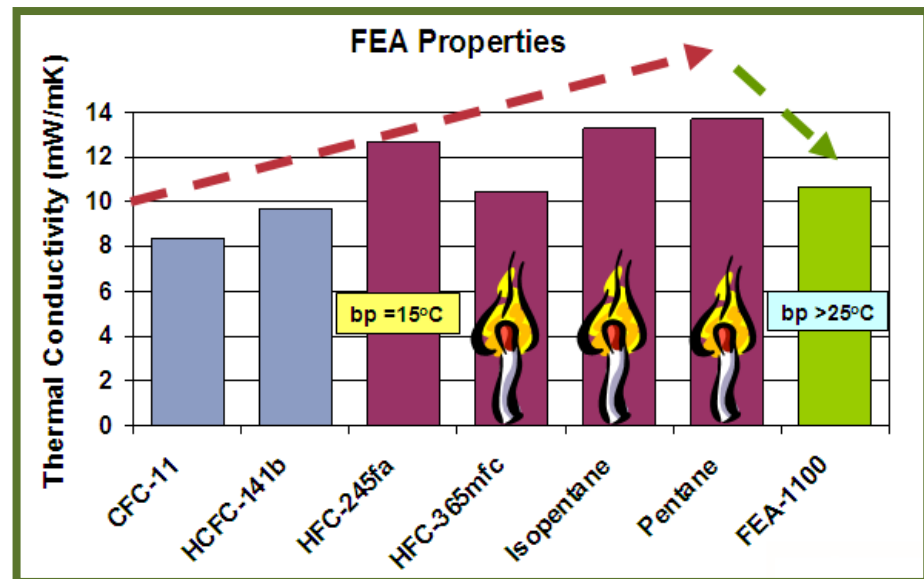
a: IPCC/TEAP (2005)

b: Klempner, D., et al., *Polymeric Foams & Foam Technology*, 2004; p 545

c: NOAA (2010)

## FEA-1100

- Zero ODP (Chlorine-free)
- Low GWP (GWP = 9.7)
- Nonflammable
- Low thermal conductivity
- Stable liquid (b.p close to HCFC-141b)



# Toxicity Assessment

## Clean data so far

- **4-hr LC50:** Very Low acute toxicity
- **Skin Irritation:** Non - irritating
- **Ames Test:** Non - mutagenic
- **Chromosomal Aberration:** No genetic material damage
- **Cardiac Sensitization:** Favorable cardiac sensitization potential profile
- **28-Day Repeat Inhalation:** Favorable repeated inhalation profile
- **90 Day/ developmental:** **Verbal results received; favorable repeated inhalation profile consistent with 28-day test**

## Chemical Stability – Polyether at 50 °C for 6 months

**FEA-1100 is stable in a generic polyether formulation after 6 months storage at 50 °C**

B-side ingredients	pbw
Polyether (TDA)	100
Silicon Type Surfactant	2.0
Amine-based Catalyst	3.0
Co-catalyst	1.0
Water	1.0
FEA-1100	29.4
Foam index	1.2

Days at 50°C in Oven	Cream time (seconds)	Tack free (seconds)	Ratio (Tack free /Cream time)	Foam density (pcf)
0	25	90	3.6	2.1
4	20	90	4.5	2.2
21	21	110	5.2	2.2
53	23	100	4.3	2.4
89	25	75	3.0	2.6
122	27	120	4.4	2.6
150	28	100	3.6	2.2
187	28	100	3.6	1.9

## Chemical Stability – Polyester at 50 °C for 6 months

FEA-1100 is stable in a generic polyester formulation after 6 months storage at 50 °C

B-side ingredients	pbw
Aromatic Polyester	100
Silicon Type Surfactant	6.2
Potassium Catalyst	2.8
Amine-based Catalyst	0.7
FEA-1 100	39.7
Foam index	2.5

Days at 50°C in Oven	Cream time (seconds)	Tack free (seconds)	Ratio (Tack free /Cream time)	Foam density (pcf)
0	25	90	3.6	2.5
15	30	110	3.7	2.4
47	20	130	6.5	2.3
83	25	135	5.4	2.6
116	27	120	4.4	2.2
144	30	100	3.3	2.4
181	30	100	3.3	2.2

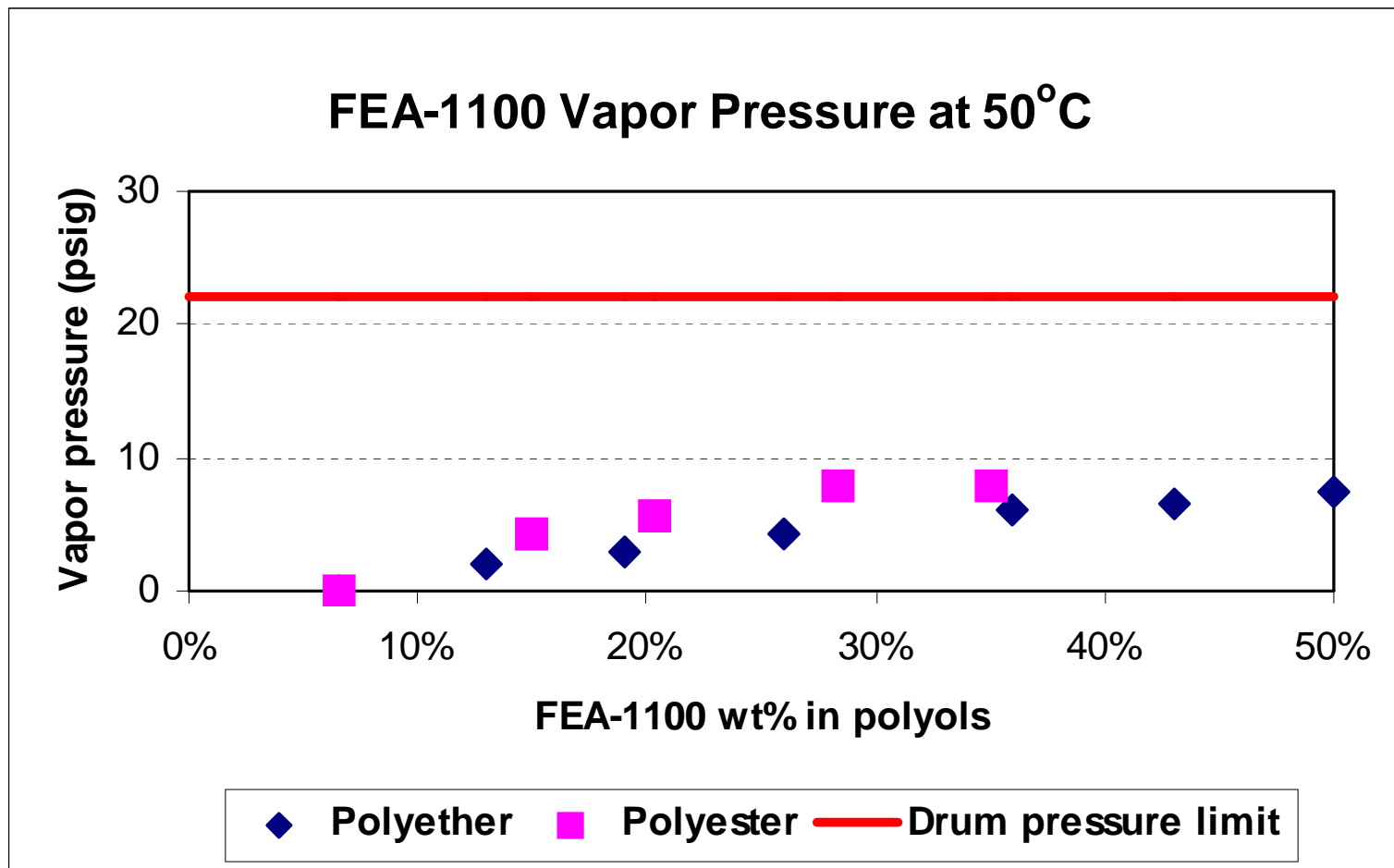
# Polyol Solubility

**FEA-1100 is soluble in commonly used polyols**

Polyol Type	OH# (mg KOH/g)	Weight% in Polyols for Single Phase Mixture (21 °C)	Weight% in Polyols for Single Phase Mixture (50 °C)
<b>Polyethers</b>			
Amine	391-800	5-50+	40-50+
Sucrose/amine	400-499	50+	50+
Sucrose/glycol	440	50+	50+
Sucrose/glycerine	280-520	50+	50+
Sorbitol	490	50+	50+
Mannich-base	300-390	5-50+	29-50+
<b>Polyesters</b>	240-307	5-30	23-35

# Vapor Pressure at 50 °C

Vapor pressure at 50°C is well below the drum pressure rating



# Generic Formulation- Manich base polyol

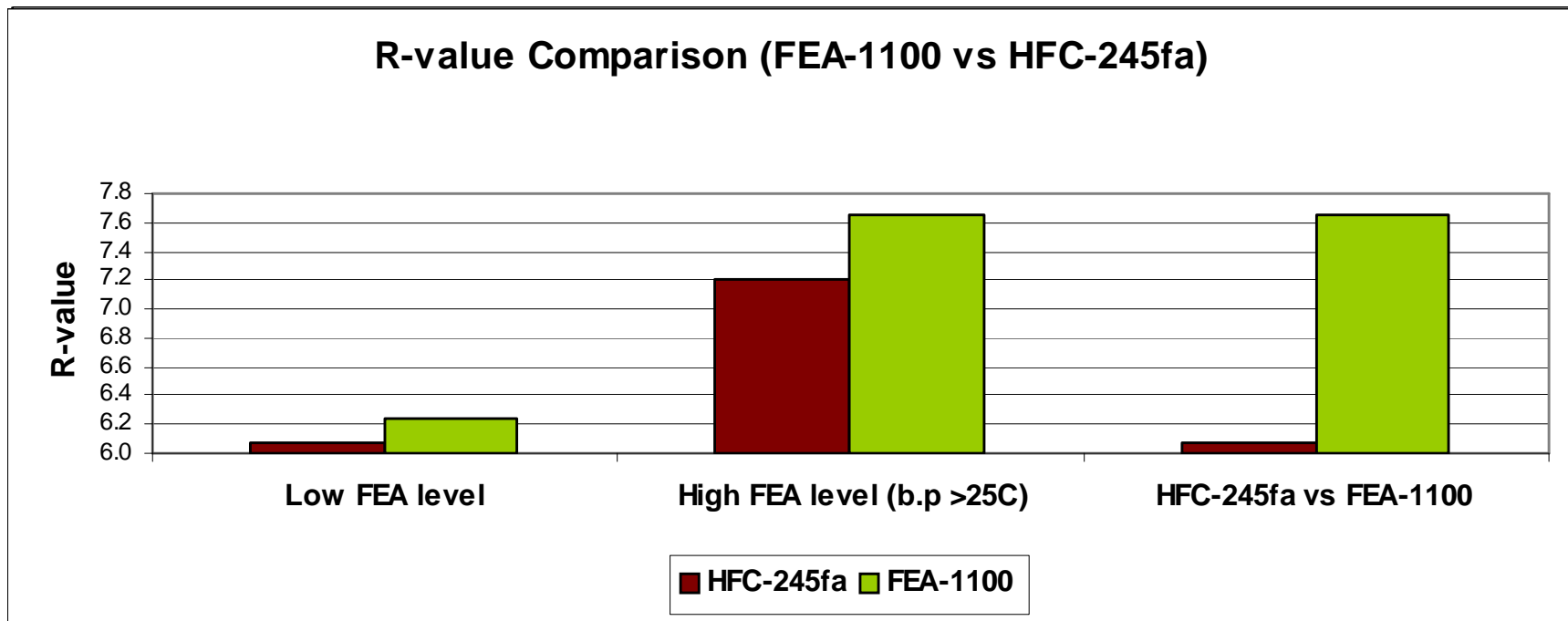
- Drop-in to a HFC-245fa formulation with low FEA levels
- Increase to high FEA levels typically used in HCFC-141b formulation

Ingredients (pbw)	HFC-245fa (low FEA level)	FEA-1100 (low FEA level)	HFC-245fa (high FEA level)*	FEA-1100 (high FEA level)
Mannich polyol	50	50	50	50
Polyester polyol	50	50	50	50
Surfactant	0.25	0.25	0.25	0.25
Flame retardant and additives	24.50	24.50	24.50	24.50
Catalysts	1.22	1.22	1.22	1.22
<b>FEA (moles)</b>	<b>0.045</b>	<b>0.045</b>	<b>0.179</b>	<b>0.179</b>
<b>Water (moles)</b>	<b>0.169</b>	<b>0.169</b>	<b>0.035</b>	<b>0.035</b>
Isocyanate	138	138	97	97
Foam index	1.1	1.1	1.1	1.1
<b>Reaction Profile</b>				
Cream time(s)	8	8	7	7
Rise time(s)	70	67	85	71
Tack free time(s)	70	70	90	85
<b>Foam Initial properties</b>				
Sample density (pcf)	2.6	2.6	2.5	2.8
<b>R-value (ft<sup>2</sup>.h.°F/Btu.in) @ 75°F</b>	<b>6.1</b>	<b>6.2</b>	<b>7.2</b>	<b>7.7</b>

\* Pressure may exceed drum rating

## FEA Level & R-value (FEA-1100 vs HFC-245fa)

- Better insulation performance than HFC-245fa at low and high FEA levels
- Superior insulation performance at high level of FEA-1100



\* High level of HFC-245fa may cause pressure exceed drum pressure rating

# Generic Formulation - Sucrose-based Polyol

Superior insulation performance compared to HCFC & HFCs

Ingredients (pbw)	FEA-1100	HCFC-141 b	HFC-245fa	HFC-365mfc
Sucrose- based polyol	100	100	100	100
Surfactant	2.00	2.00	2.00	2.00
Catalysts	4.00	4.00	4.00	4.00
water (moles)	0.08	0.08	0.08	0.08
<b>FEA (moles)</b>	<b>0.20</b>	<b>0.20</b>	<b>0.20</b>	<b>0.20</b>
Isocyanate	121	121	121	121
Foam Index	1.1	1.1	1.1	1.1
<b>Reaction Profile</b>				
Cream time(s)	7	6	6	7
Rise time(s)	120	120	120	130
Tack free time(s)	140	150	140	140
<b>Foam Initial Properties</b>				
Foam density(pcf)	1.9	2.0	2.0	1.9
<b>R-value (ft<sup>2</sup>·h.° F/Btu.in) @ 75° F</b>	<b>7.0</b>	<b>6.7</b>	<b>6.5</b>	<b>6.5</b>

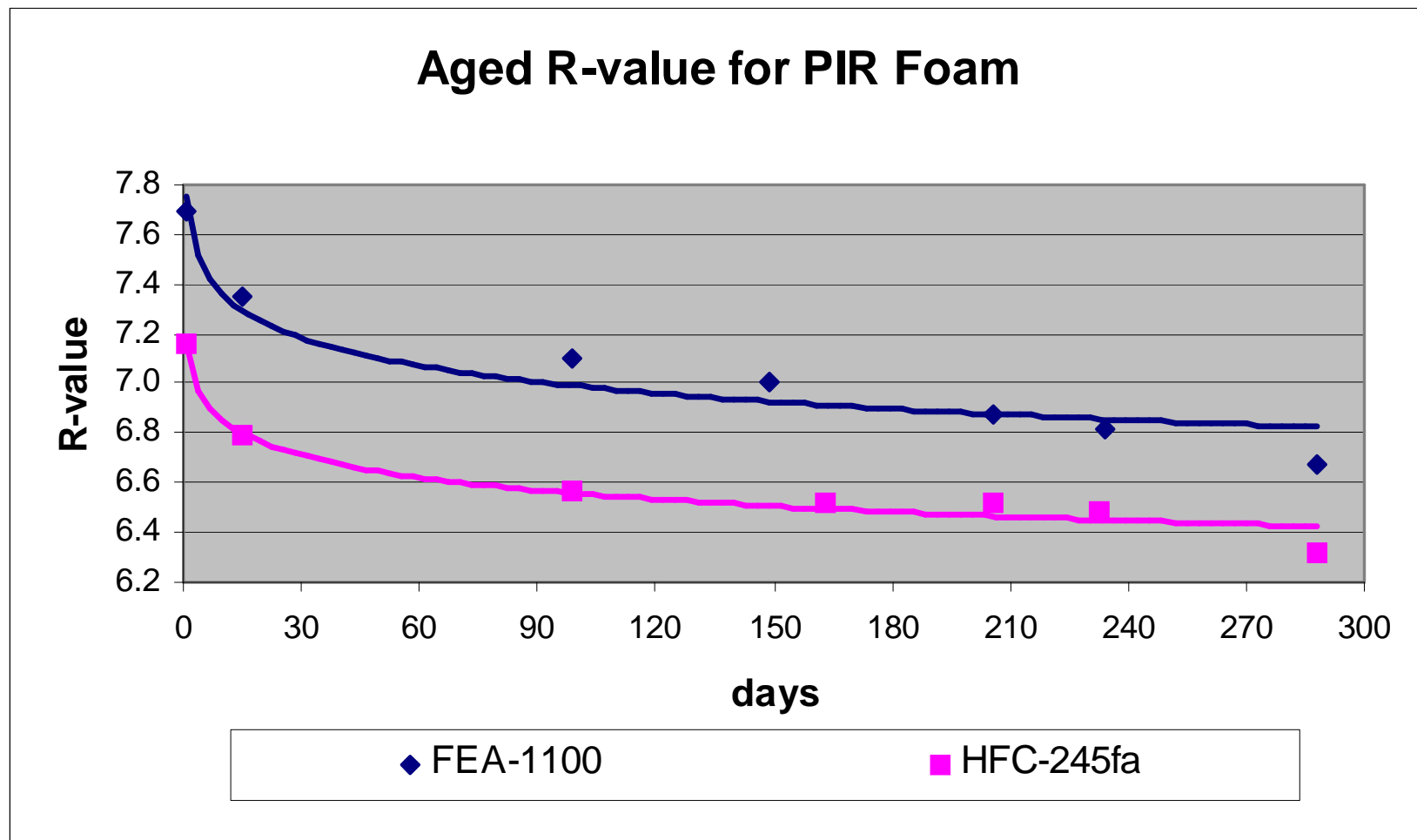
# Generic Formulation - Polyester Polyol

Superior insulation performance compared to HFC-245fa

Ingredients (pbw)	FEA-1100	HFC-245fa
Aromatic polyester	100	100
Surfactant	6.17	6.17
Catalysts	3.43	3.43
<b>FEA (moles)</b>	<b>0.24</b>	<b>0.24</b>
Isocyanate	158	158
Foam Index	2.5	2.5
<b>Reaction Profile</b>		
Cream time(s)	15	14
Rise time(s)	110	110
Tack free time(s)	120	120
<b>Foam Initial Properties</b>		
Foam density(pcf)	2.1	2.2
<b>R-value (ft<sup>2</sup>.h.°F/Btu.in) @ 75°F</b>	<b>7.7</b>	<b>7.2</b>

# Aged R-value (FEA-1100 & HFC-245fa)

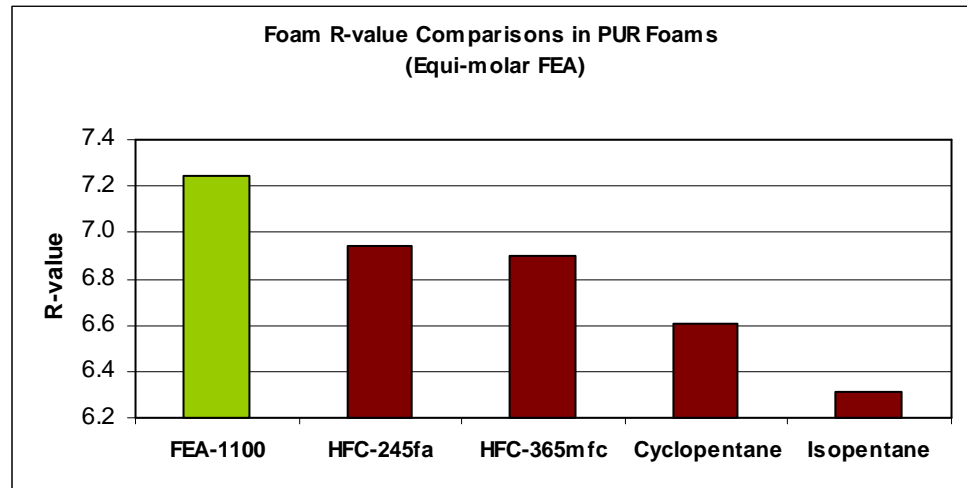
Superior insulation performance maintains with aging



# Generic Formulation - TDA-based Polyol

**FEA-1100 has the best insulation performance**

Ingredients	pbw
TDA-based polyol	100
Surfactant	2.13
Catalysts	2.00
<b>FEAs (moles)</b>	<b>0.18</b>
<b>Water (moles)</b>	<b>0.06</b>
Isocyanate	132
Foam index	1.2



FEAs	R-value (ft <sup>2</sup> .h.°F/Btu.in) @ 75°F	Density (pcf)
FEA-1100	7.2	2.1
HFC-245fa	6.9	2.2
HFC-365mfc	6.9	2.2
Cyclopentane	6.6	2.4
Isopentane	6.3	2.5

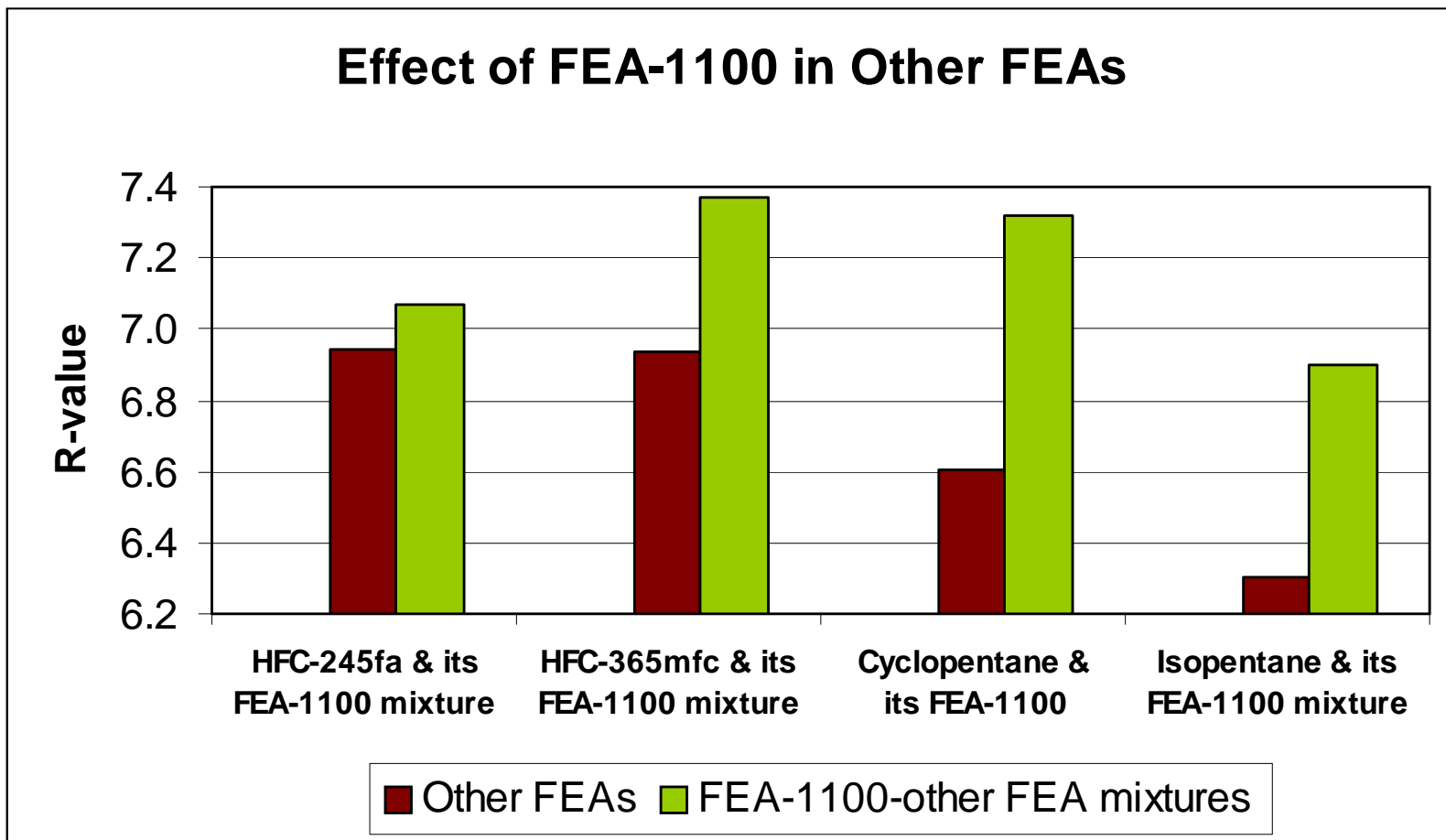
## FEA-1100 Mixture – Polyether polyol

- Adding FEA-1100 to other zero ODP FEAs
- Same foam formulation & equi-molar FEAs
- FEA-1100 improves performance

FEAs	R-value (ft <sup>2</sup> .h.°F/Btu.in) @ 75°F	Density (pcf)	Benefits
HFC-245fa	6.9	2.2	
FEA-1100/HFC-245fa mixture	7.1	2.4	Improved GWP, b.p & R-value
HFC-365mfc	6.9	2.2	
FEA-1100/HFC-365mfc mixture	7.4	2.2	Improved GWP, R-value & flammability
Cyclopentane	6.6	2.4	
FEA-1100/cyclopentane mixture	7.3	2.3	Improved R-value & flammability
Isopentane	6.3	2.5	
FEA-1100/isopentane mixture	6.9	2.4	Improved R-value & flammability

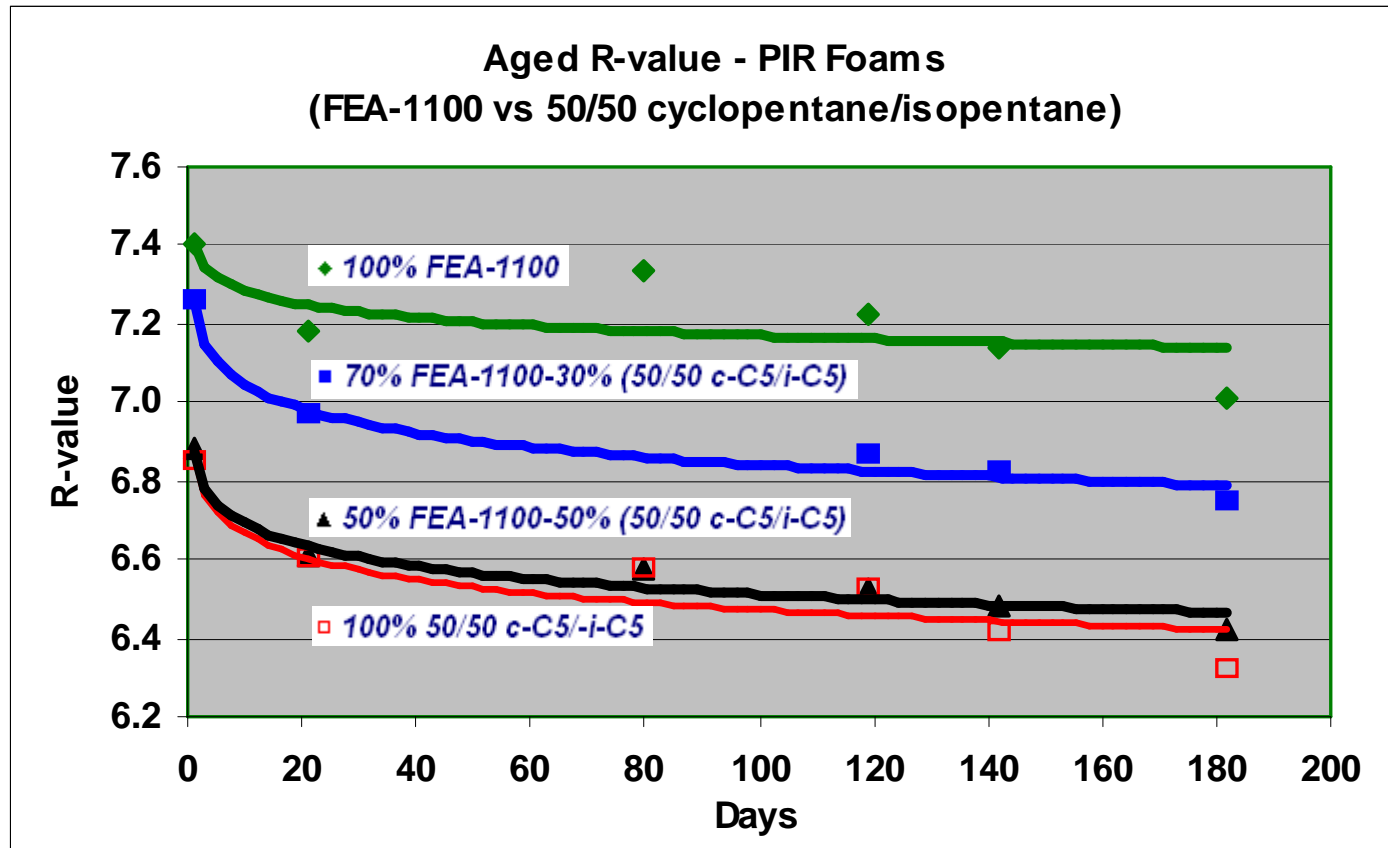
# Effect of FEA-1100 on R-values

Adding FEA-1100 improves R-values



# FEA-1100 Mixture – Polyester Polyol

- Blend FEA-1100 to 50/50 cyclopentane(c-C5)-isopentane(i-C5) mixture
- Same foam formulation & equi-molar FEAs
- FEA-1100 improves performance



# Material Compatibility - Metal

**FEA-1100 is compatible with commonly used metals**

Changes after 2 weeks at 100°C (212°F) in FEA-1100

Metal Coupons	Metal Coupon Weight	Metal Coupon Appearance	FEA Solution Appearance	FEA Solution Analysis
Stainless Steel	No weight change	No sign of corrosion	Clear	No fluoride detected **
Carbon Steel	No weight change	No sign of corrosion	Clear	No fluoride detected **
Copper	No weight change	No sign of corrosion	Clear	No fluoride detected **
Brass	No weight change	No sign of corrosion	Clear	No fluoride detected **
Aluminum	No weight change	No sign of corrosion	Clear	No fluoride detected **

\*\* Detection limit = 0.5 ppm

# Material Compatibility - Elastomers

**FEA-1100 is compatible with commonly used elastomers**

Changes after 2 weeks at room temperature in FEA-1100

Symbol	Material	Brand	% Weight Change	% Volume Change	% Hardness Change
NR	Natural Rubber	Natural Rubber	4.4%	1.9%	0.0%
CR	Polychloroprene	Neoprene® W	0.8%	0.1%	0.0%
NBR	Acrylonitrile Butadiene	BUNA N	15.3%	2.6%	-13.6%
CSM	Chlorosulfonated Polyethylene	Hypalon 40®	0.2%	0.8%	-1.3%
FFKM	Fluoroelastomer	Kalrez®	7.9%	-3.4%	-2.9%
T	Polysulfide	THIOKOL FA ®	0.3%	6.7%	-6.1%
IIR	Isobutylene Isoprene	Butyl Rubber	0.3%	13.1%	-13.3%
EPDM	Hydrocarbon (Ethylene-Propylene Terpolymer)	Nordel®	1.4%	5.5%	-7.1%

# Material Compatibility - Plastics

## FEA-1100 is compatible with commonly used plastics

Changes after 2 weeks at room temperature in FEA-1100

Symbol	Material	Brand	% Weight Change	% Volume Change	% Hardness Change
ABS	Acrylonitrile-butadiene-styrene	Cycolac®EX58	-0.1%	-0.6%	0.0%
HIPS	High Impact Polystyrene		0.3%	-0.4%	-2.9%
PEI	Poly(ethylene terephthalate)	Rynite®	0.0%	0.7%	-1.2%
PS	Polystyrene	Styron®	-0.4%	0.9%	0.0%
PVC	Polyvinyl Chloride	Bakelite®	0.0%	0.0%	0.0%
CPVC	Chlorinated Polyvinyl Chloride		0.0%	-0.3%	0.0%
PTFE	Fluorocarbon(PTFE)	Teflon®	1.1%	0.3%	-17.2%
ETFE	Fluorocarbon(ETFE)	Tefzel®	0.7%	0.0%	12.9%
	Ionomer	Surlyn®	0.3%	0.0%	1.9%
POM	Acetal	Delrin®	0.1%	-1.2%	-1.3%
PC	Polycarbonate	Tuffak®	0.0%	-0.6%	0.0%
PEEK	Polyetheretherketone	Victrex®	0.0%	0.2%	0.0%
	Polyarylate	Arylon®	0.2%	-0.2%	-4.4%
LCP	Polyester	Xydar®	0.0%	-0.4%	-1.5%
	Nylon 6/6	Zytel® 101	0.4%	-0.5%	3.1%
PEI	Polyetherimide	Ultem®	-0.1%	0.0%	0.0%
	Polyaryl sulfone	Radel®	-0.2%	0.3%	0.0%
PVDF	Poly(vinylidene fluoride)	Kynar®	0.1%	-0.3%	0.0%
PP	Polypropylene	Tenite®	0.3%	-0.5%	0.0%
	LCP	Zenite	-0.1%	-0.9%	0.0%
HDPE	High Density Polyethylene	Alathon®	0.0%	0.3%	3.3%
	Phenolic	Duzez®	0.0%	-0.1%	1.2%

# Summary

- **Environmentally sustainable**
  - **Zero ODP & low GWP**
- **Desired properties for broad applications**
  - **Nonflammable**
  - **Stable liquid (physically and chemically)**
  - **Low vapor thermal conductivity**
- **Superior foam insulation performance**
  - **Better R-values than HFCs and hydrocarbons**
  - **R-values maintain with aging**
  - **Improve performance as FEA mixtures**
- **Potential drop-in alternative with improved performance**