

# DuPont Next Generation Refrigerant MAC Global Industry Solution

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*The miracles of science™*

## ***DuPont's Next Generation Refrigerant is a leading candidate to become the future MAC global industry solution***

- Environmentally sound (zero-ODP, very low GWP, low LCCP)
- Meets F-Gas requirements for MAC
- Very encouraging acute toxicity results, non-flammable
- Passed initial thermal stability, materials compatibility, lubricant miscibility and production vehicle tests
- OEM and Tier I testing in progress
- Targeted for all climates and all vehicles
- Potential for cost effective global transition across entire MAC value chain due to compatibility with conventional R134a MAC system technology

# ***Agenda***

- **Industry Regulatory Drivers**
- **MAC Refrigerant Development Challenges**
- **New Refrigerant Properties**
  - Environmental
  - Safety
  - Performance
  - LCCP
- **Next Steps**
- **Conclusions**

## ***Auto industry needs a new global MAC solution !***

- **EU 'F-gas' final regulation has been published**
  - Phaseout of HFC-134a for mobile air conditioning 2011-2017
  - Next generation MAC refrigerant GWP < 150
  - Leak rate restrictions in MAC starting in 2008
  - Strict inspection and repair regulations for other
- **US California Air Resources Board Climate Change proposed regulation**
  - Phaseout of HFC-134a from heavy equipment starting in 2010
  - Phaseout of HFC-134a from cars starting in 2017
- **Industry has indicated they want a single global solution**

# *New MAC Refrigerant Development Challenges*

- **Performance**

- Thermal Stability
- Materials Compatibility
- Lubricant Miscibility
- Cooling Capacity in all climates and car models
- Energy Efficiency
- Compatible with conventional MAC system technology

- **Safety**

- Toxicity
- Flammability

- **Environmental**

- Zero-ODP
- GWP
- LCCP/COP (Cradle to Grave)

- **Viability**

- Meets EU F-Gas Directive
- Raw Material Availability / manufacturability
- Cost Effective Transition cost for the Entire Value Chain
- Global Industry Solution

## ***DuPont has proven and comprehensive new technology development process***

- **Identified multiple MAC candidates**
- **Priority put on Global Solution with best balance of properties**
  - Non-flammable
  - Non-toxic
  - Zero-ODP
  - Very low GWP
  - Total environmental footprint (direct + indirect)
  - Compatible with conventional MAC system technology
  - Cost effective transition for entire MAC value chain vs other technology alternatives (CO<sub>2</sub>)
- **Actively leveraging technology in other refrigerant applications**

## ***DuPont Leading Refrigerant Candidate: DP-1***

- **Two component non-flammable blend**
  - Unique, innovative approach
  - Major component: non-flammable, fluorine based new compound
  - Minor component: commercially available refrigerant
- **Very encouraging toxicity data**
- **Zero-ODP, Very low GWP**
- **Properties and performance similar to R134a**
- **Compatible with conventional mobile air conditioning technology**

# ***DP-1: Superior Environmental Properties***

- **Zero-ODP**
- **Very Low GWP: estimated at 40**
- **LCCP: Significant improvement versus enhanced R134a & enhanced CO<sub>2</sub>**



## ***DP-1: Excellent Toxicity Results to Date***

<b>Test</b>	<b>Type</b>	<b>Compound</b>	<b>R134a</b>
<b>Ames</b>	<b>Genetic - Mutagenic</b>	<b>Passed</b>	<b>Passed</b>
<b>Chrome AB</b>	<b>Genetic - Chromosomal</b>	<b>Passed</b>	<b>Passed</b>
<b>LC-50</b>	<b>4 hour inhalation to 50% lethality</b>	<b>&gt;760,000 ppm</b>	<b>&gt;359,300 ppm</b>
<b>Cardiac sensitization</b>	<b>No Effect Level</b>	<b>In progress</b>	<b>50,000 ppm</b>
<b>Cardiac sensitization</b>	<b>Threshold Level</b>	<b>In progress</b>	<b>75,000 ppm</b>
<b>28- Day</b>	<b>Subchronic Inhalation</b>	<b>Exposures complete, analysis in progress</b>	<b>90 Day No effect level 49,500 ppm</b>

DuPont Haskell Laboratory - - World Class toxicologists and toxicological testing capability; enables accelerated toxicity assessment.

## DP-1: Excellent Thermal Stability

	DP-1 Only	DP-1+ Dry PAG	DP-1 + PAG + 1000 ppm Water
Rating	0	0	0-1
Aluminum	No change	No change	No change
Copper	No change	No change	No change
Steel	No change	No change	Very faint tan-gray film
	DP-1 Only	DP-1 + Dry POE	DP-1+ POE + 1000 ppm Water
Rating	0	0	0-1
Aluminum	No change	No change	No change
Copper	No change	No change	No change
Steel	No change	Very faintly dulled, still clean and lustrous	Very faintly dulled but still clean and lustrous

Rating: 0 = no changes  
1 = light changes

- Individual components of DP-1 very stable.

- DP-1 stable with commercially available PAG & POE lubricants at 175°C \* for two weeks.

- No decomposition after 1440 hours in system test

\* ASHRAE 97-99 at standard industry test temperature

## DP-1: Excellent Plastics Compatibility

- Compatible with PAG at 100°C for two weeks

Refrigerant	Plastics	Rating*	24 h Post Weight Chg. %	Physical Change
DP-1	Polyester	1	3.6	0
	Nylon	0	-1.1	0
	Epoxy	0	0.7	0
	Polyethylene terephthalate	1	2.8	0 - 1
	Polyimide	0	0.6	0
Refrigerant	Plastics	Rating*	24 h Post Weight Chg. %	Physical Change
R134a	Polyester	1	4.5	0
	Nylon	0	-1.2	0
	Epoxy	0	0.0	0
	Polyethylene terephthalate	1	4.2	0 - 1
	Polyimide	0	0.4	0
<b>Rating</b>	0 = best weight gain < 1 and physical change = 0			
	1 = borderline weight gain 1-10 and/or physical change = 2			
	2 = incompatible weight gain > 10 and/or physical change = 2			

## DP-1: Excellent Elastomers Compatibility

- Compatible with PAG at 100°C for two weeks

Refrigerant	Elastomers	Rating*	24 h Post Linear Swell %	24 h Post Weight Gain %	24 h Post Delta Hardness
DP-1	Neoprene WRT	0	-4.4	-2.6	3
	HNBR	0	5.8	6.9	-5
	NBR	0	-5.7	-1.4	3
	EPDM	0	-3.5	-1.8	1.5
	Silicone	0	5.4	3.8	-10
	Butyl rubber	0	-2.3	-0.1	-1.5
Refrigerant	Elastomers	Rating*	24 h Post Linear Swell %	24 h Post Weight Gain %	24 h Post Delta Hardness
R134a	Neoprene WRT	0	-3.8	-2.4	2
	HNBR	0 -- 1	8.6	9.8	-11.5
	NBR	0	-1.4	1.3	-1.5
	EPDM	0	-3.3	-1.3	0
	Silicone	0 -- 1	1.7	2.3	-10.5
	Butyl rubber	0	-3.1	-1.1	-2

- \* 0 = < 10% weight gain and < 10% Linear swell and < 10% hardness change  
 1 = > 10% weight gain or > 10% Linear swell or >10% hardness change  
 2 = > 10% weight gain and > 10% Linear swell and > 10% hardness change

## ***DP-1: Improved Dielectric Properties***

- Important for system reliability in hybrid vehicles

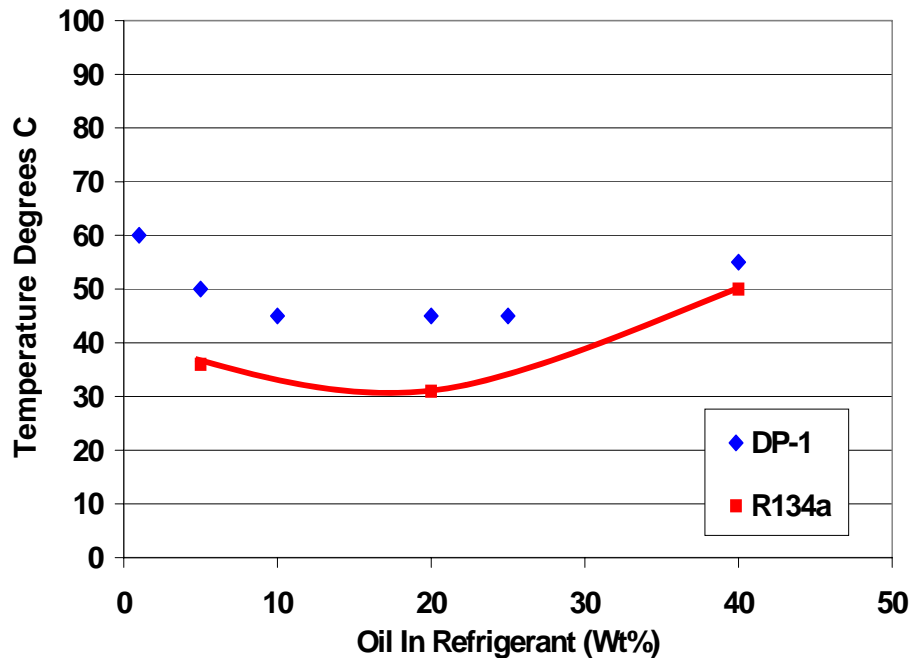
### Dielectric Constants

<b>T(C°)</b>	<b>R134a</b>	<b>DP-1</b>
-20	13.4	4.9
-15	12.9	4.7
-10	12.5	4.6
-5	12.1	4.5
0	11.7	4.3
5	11.3	4.2
10	10.9	4.1
15	10.6	4.0
20	10.2	3.9
25	9.9	3.8
30	9.5	3.7
35	9.2	3.6
40	8.9	3.4
45	8.5	3.3
50	8.2	3.2
55	7.9	3.1

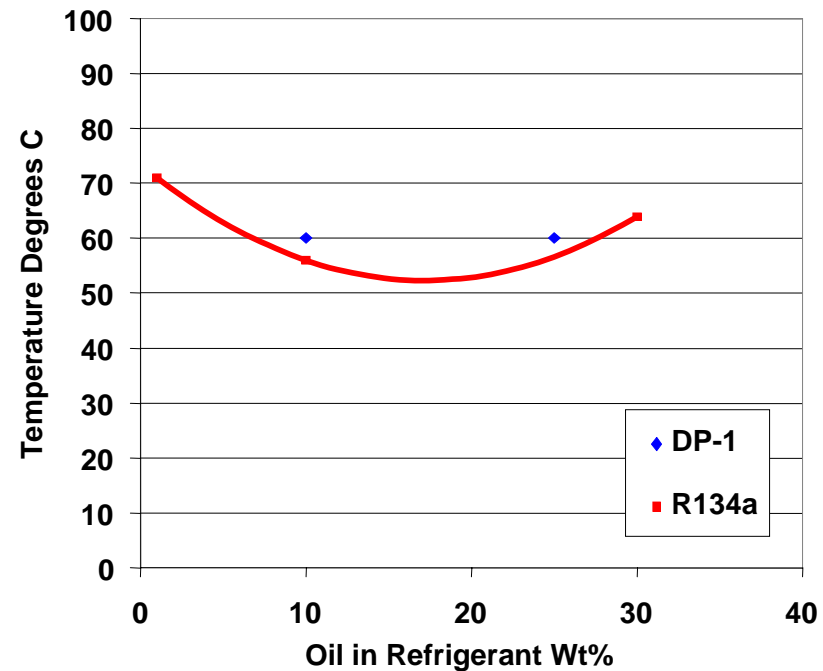
DuPont Proprietary model

# DP-1: Excellent Miscibility with PAG and POE Lubricants

Miscibility of 130 cst PAG with DP-1 and R134a



Miscibility of 46 cst PAG with DP-1 and R134a



POE 68 cst Lubricant Test: Completely miscible from - 40°C to 65 +°C

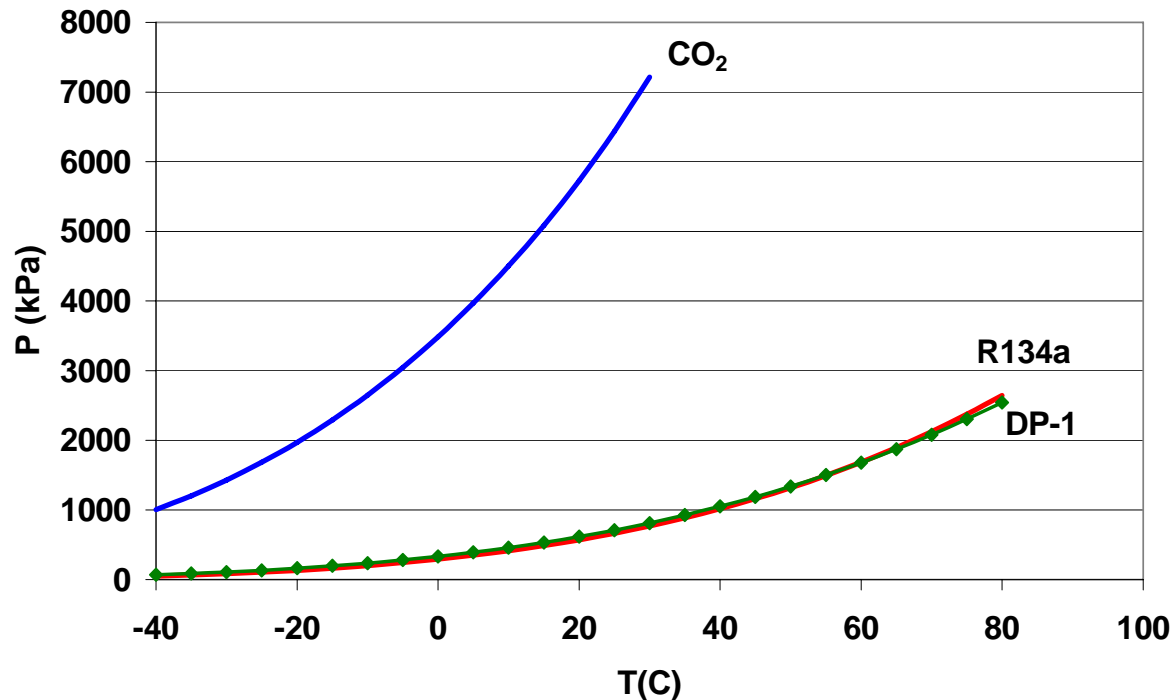
\*Ref: R134a-PAG miscibility lit. data, The Dow Chemical Co.

## ***DP-1: Exhibits Good Compatibility with Conventional Hoses***

- **Hose Permeation Test - SAE J2064**
  - **Tested Type C Barrier, Textile Reinforced Hose**
  - **Conditions: 80°C for 25 days**
  - **Permeation Rate:**
    - **R134a 1.07 kg/year meter<sup>2</sup>**
    - **DP-1 0.97 kg/year meter<sup>2</sup>**
  - **Maximum 5 kg/year meter<sup>2</sup> allowed for Type C hose per SAE J2064**

## DP-1: Thermodynamic Properties Similar to R134a

P-T Chart



- P-T profile very similar to R134a - significantly lower pressure than CO<sub>2</sub>
- Critical Point 105°C, versus R134a at 102°C and CO<sub>2</sub> at 31°C
- Charge Size based on liquid density ~4% higher than R134a
- Mass Flow Rate ~10% higher than R134a



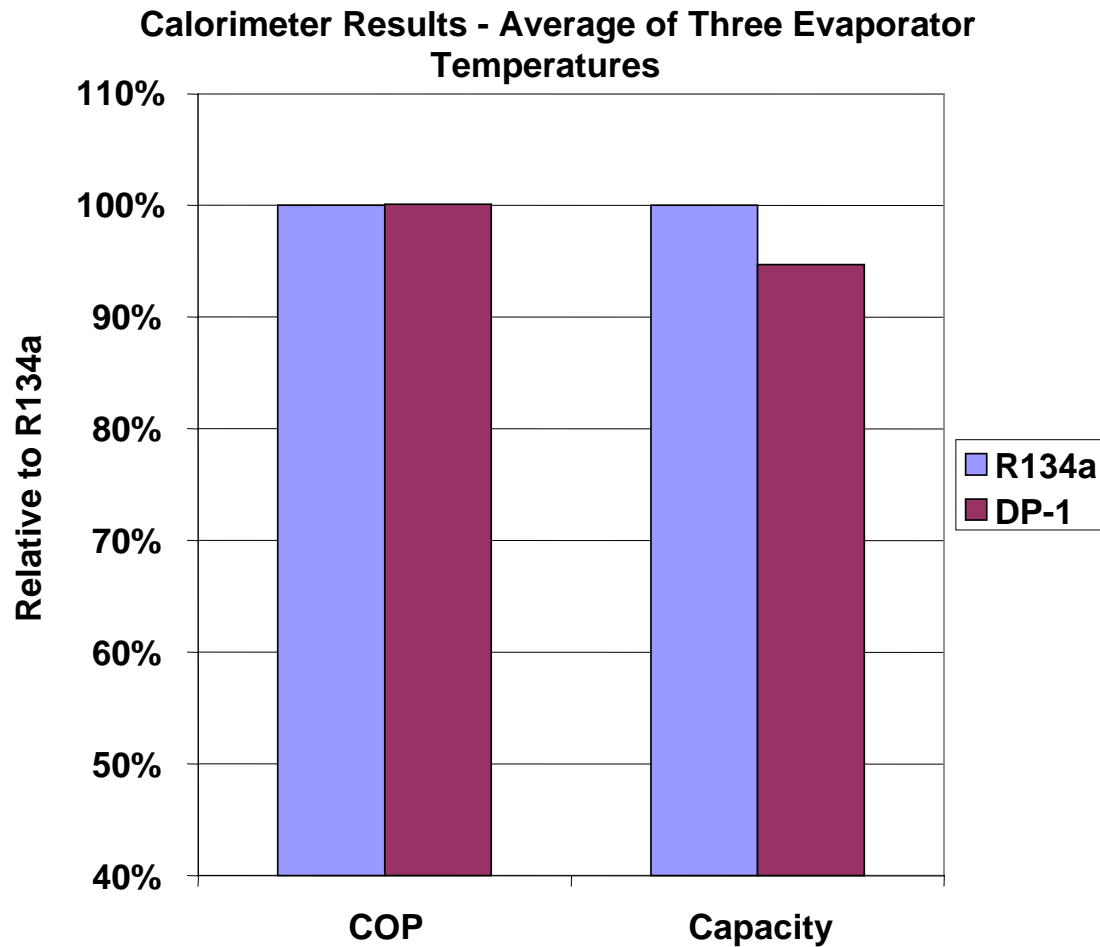
## **DP-1: Thermodynamic Cycle Performance Comparable to R134a**

- Cycle performance modeled at a/c conditions:
  - Condenser for Subcritical= 54°C
  - Evaporator = 5°C
  - Liquid line or Gas Cooler Temperature = 50°C
  - Suction Temperature = 15°C
  - Isentropic Efficiency = 100%

Candidate	Evap Press (kPa)	Cond Press (kPa)	Compr Disch T (C)	T Glide (C)	Capacity (kJ/m3)	COP	Cap Rel to 134a	COP Rel to 134a
R134a	350	1470	68	n/a	2250	4.38	100%	100%
DP-1	320	1380	64	4	2050	4.33	91%	99%
CO2	3970	13000	124	n/a	12100	2.09	537%	48%

Temperature glide is similar to R407C which has been used successfully in stationary air conditioning systems for 10+ yrs. DP-1 also performed well in third party direct substitution vehicle testing with no system changes and has potential for further optimization.

## ***DP-1: Calorimeter Tests confirm very good COP and Capacity***



- R134a electrically driven reciprocating compressor
- Tested at three evaporator temperatures (-25 °C, -20°C, -10°C)
- Calorimeter data consistent with thermodynamic calculations

## ***DP-1: Third Party Direct-Substitution Vehicle Test Results Very Encouraging***

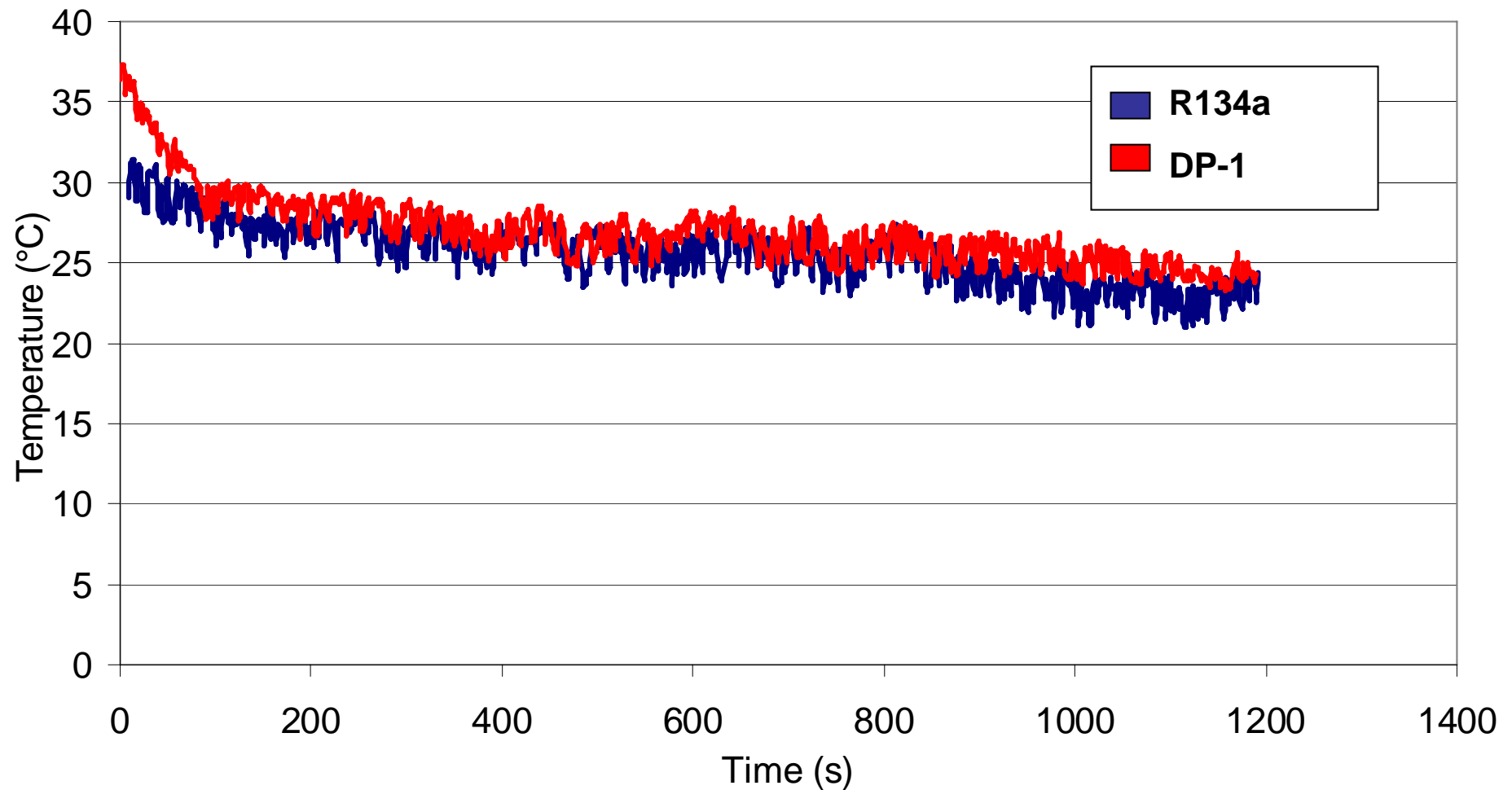
- **Globally recognized test facility and test protocol**
- **Tested 2006 Volkswagen Golf with TXV and no system modifications**
- **R134a was directly substituted with DP-1**
- **Tests conducted in environmental chamber with roll bench**
  - 35°C and 40°C ambient temperature, 50% humidity
- **Evaluated DP-1 versus R134a using NEDC European drive cycle**
- **Potential for further improvements with optimized TXV designed for DP-1 or EEV**



## *DP-1: Very Good Temperature Profile*

- Direct-substitution vehicle test by third party

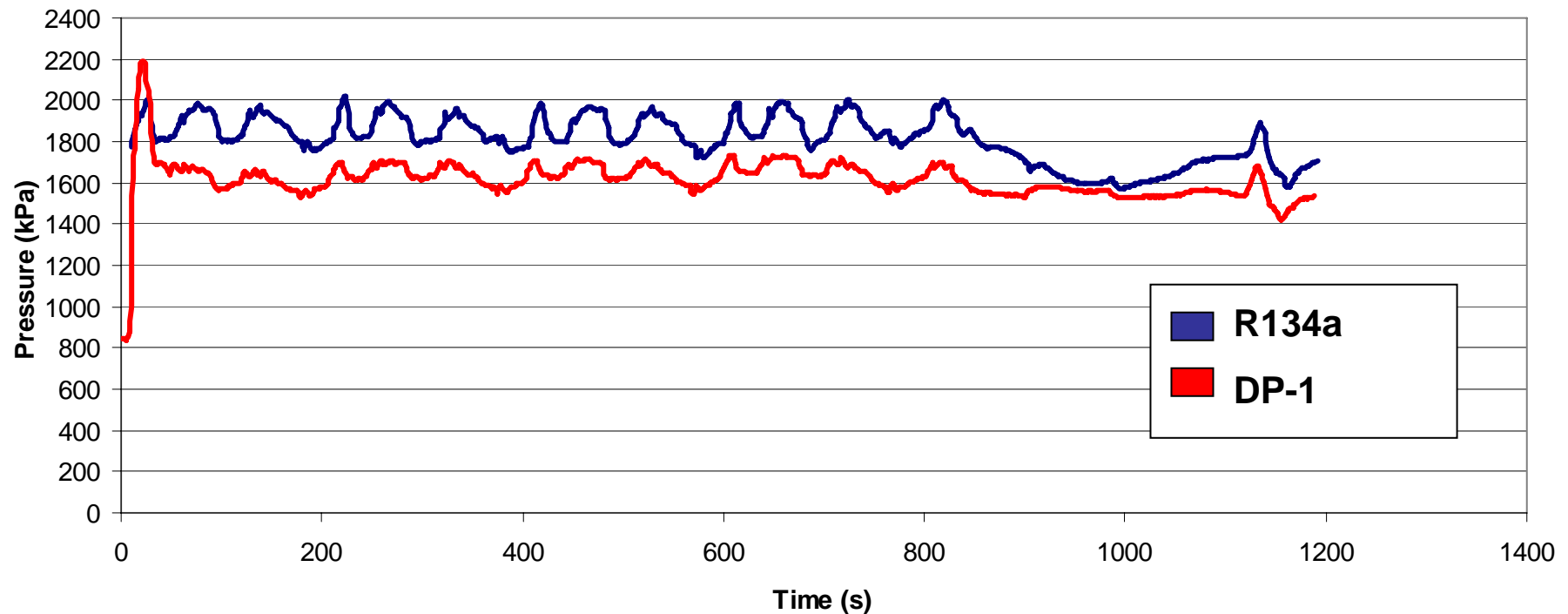
Interior Temperature in 35°C Ambient Test - NEDC Cycle



## DP-1: Low Discharge Pressure

- Direct-substitution vehicle test by third party

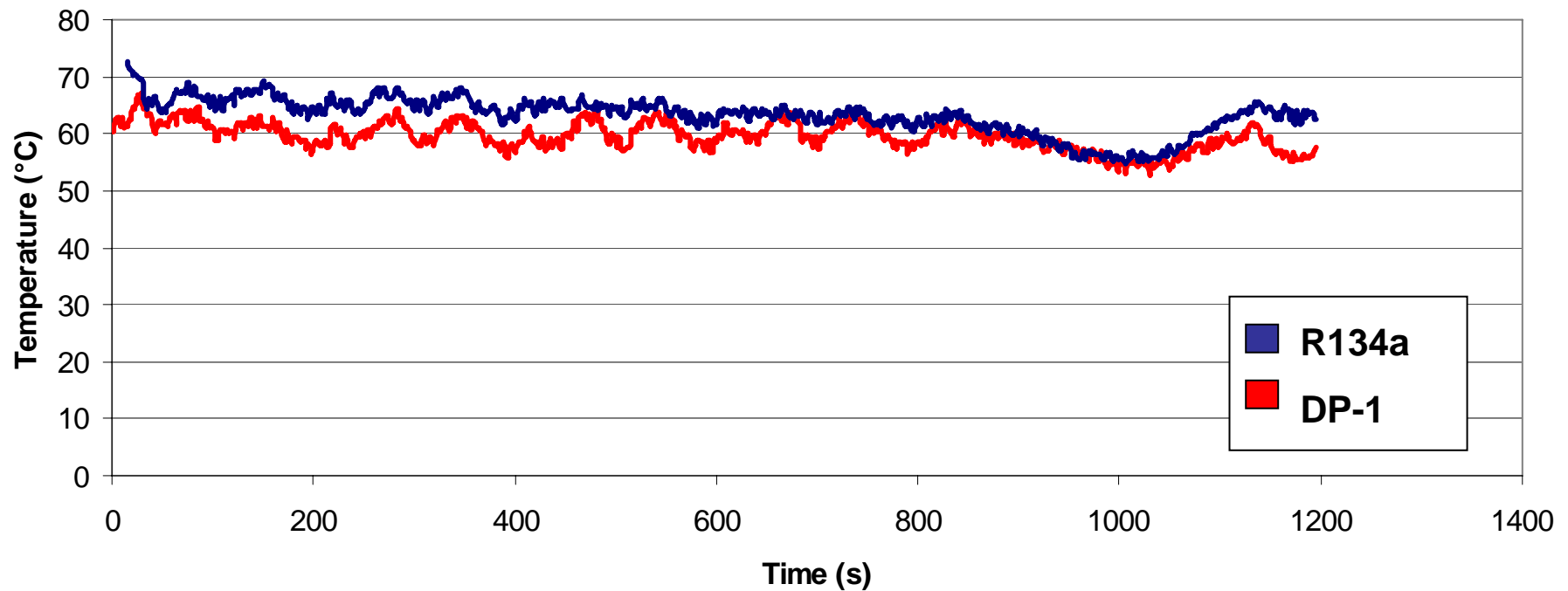
Discharge Pressure in 35°C Ambient Test - NEDC Cycle



# DP-1: Low Discharge Temperature

- Direct-substitution vehicle test by third party

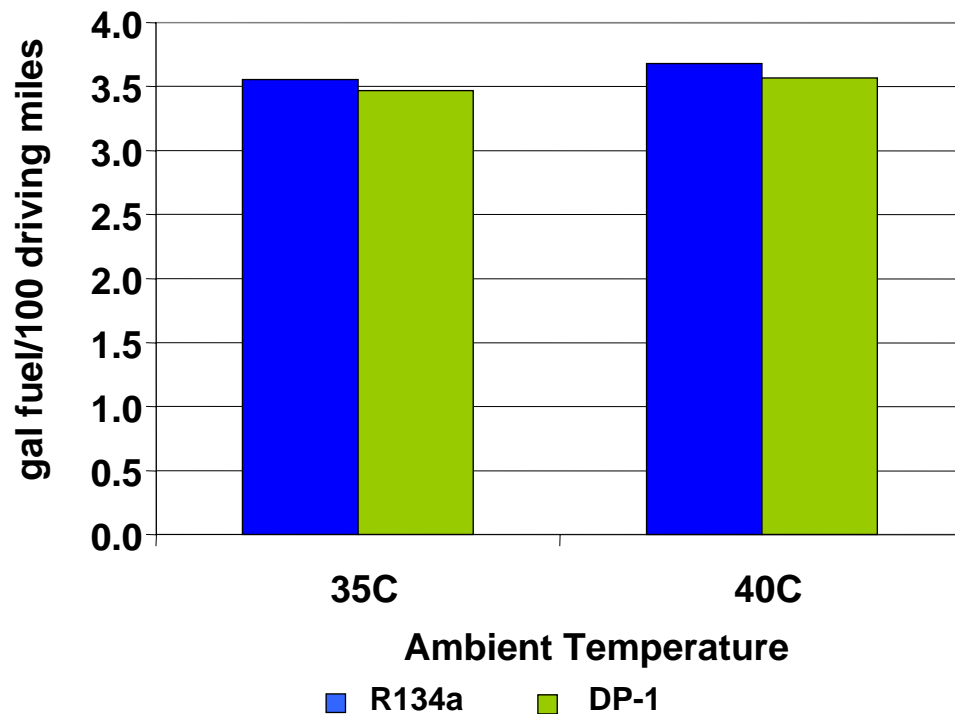
Discharge Temperature in 35°C Ambient Test - NEDC Cycle



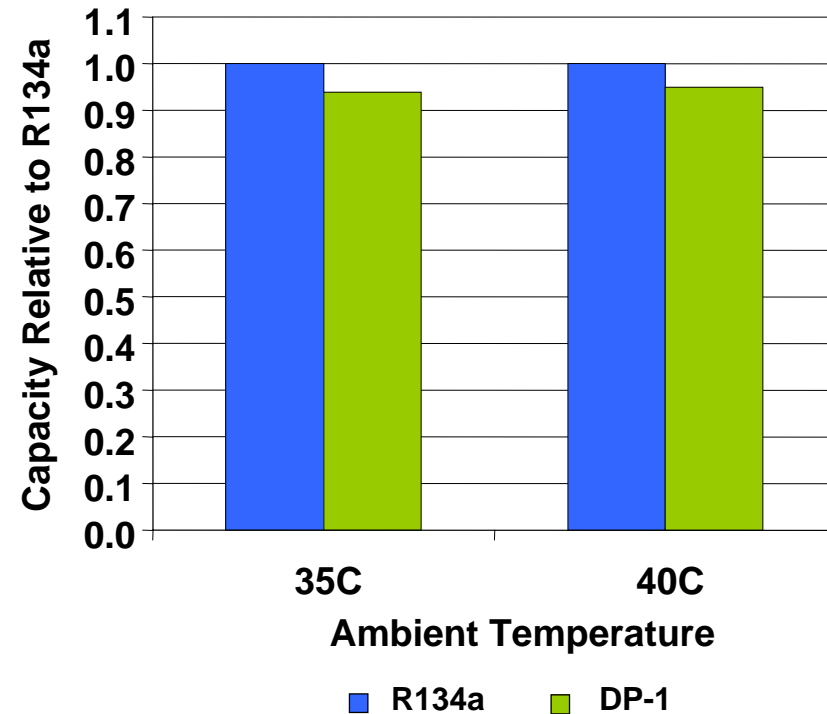
## ***DP-1: Comparable Fuel Consumption and Capacity***

- Direct-substitution vehicle test by third party

Fuel Consumption



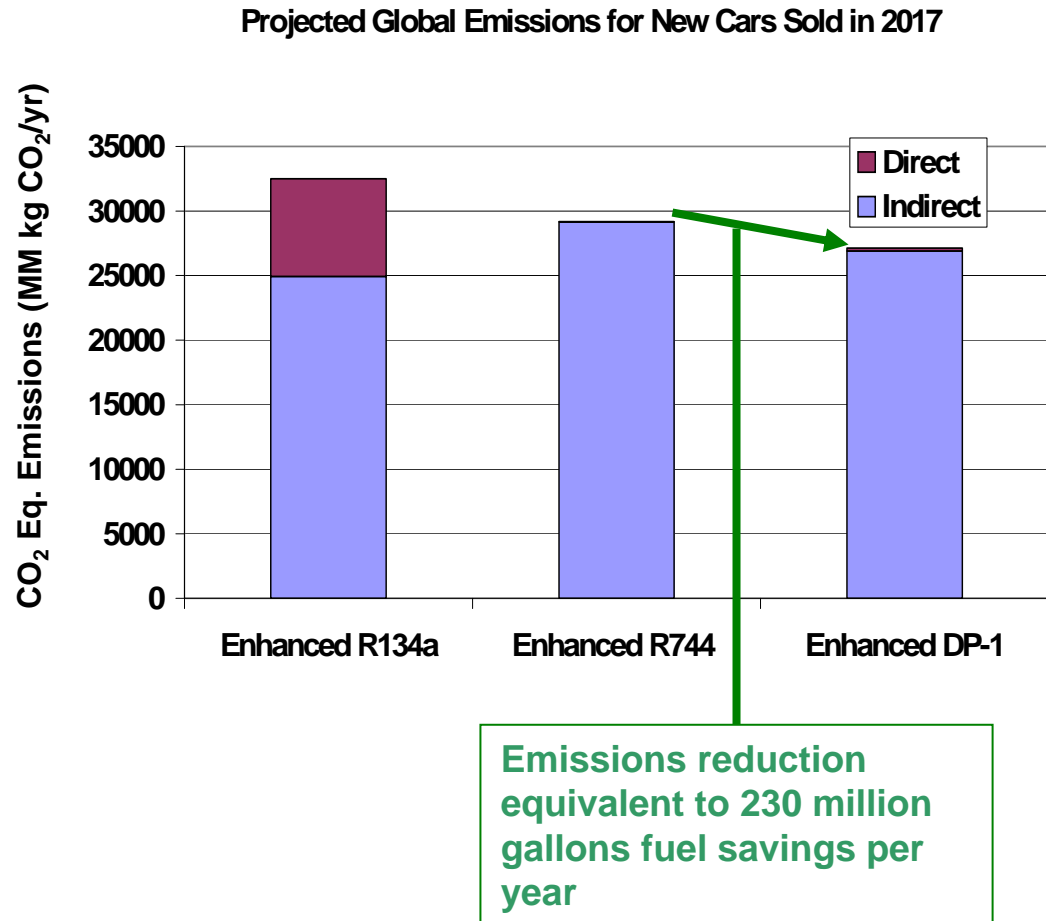
Cooling Capacity



**COP and capacity can be improved with optimization of TXV and/or heat exchangers**

## DP-1: Lower Projected Global LCCP than R134a and CO<sub>2</sub>

- Calculated combined global LCCP based on regional enhanced\* LCCPs to understand global impact of alternatives
- Used projected new car sales in different regions/countries\*\* and with different economic growth rates
- Warmer countries will have higher growth rates and more cars in future
- Hypothetical scenario that all new cars sold in 2017 have a given technology



\* Hill, W. R. et al, Industry Overview of the Environmental Performance of Non-CO<sub>2</sub> (R744) Alternatives, MAC Summit, 17February, 2006

\*\* Global Insights, May, 2006



# *DuPont is aggressively pursuing the next generation MAC global industry solution*

## Path Forward

### Internal

- Continue/accelerate toxicity testing
- Continue environmental testing
- Continue third party system/component testing and optimization
- Accelerate process technology development to support a future commercialization plan that meets F-Gas requirements.

### External

- Complete first phase of OEM/Tier-1 tests already in progress
- Broaden evaluations to additional OEMs and Tier 1 suppliers
- Communicate third party system/component testing and optimization results
- Provide periodic updates at [www.refrigerants.dupont.com](http://www.refrigerants.dupont.com)

## ***DP-1: DuPont's Leading Candidate to become the Next Generation global MAC industry solution.***

- Environmentally sound (Zero-ODP/Very low GWP/LCCP)
- Meets F-Gas requirements for MAC
- Encouraging toxicity
- Non-flammable
- Good materials compatibility/thermal stability
- Very encouraging third party production vehicle results; further improvement possible with optimization of TXV/heat exchanger
- Compatible with conventional MAC technology
- Targeted for all climates and all vehicles
- Cost effective transition for entire MAC value chain vs other technology alternatives (CO<sub>2</sub>)

# *Thank you!*

***DuPont Refrigerants***

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