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Is a Refrigerant Change Coming to Heavy Duty Vehicles?

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What Drives a Refrigerant Change?

- **Motivation**
  - Government Regulations
  - Government Incentives
  - Economics
  - Availability

How it Started

- **In 2006, the European Union Directive 2006/40/EC called for the phase out of R-134a in Automobile Air Conditioning**
- **Beginning in 2011, all new models introduced in the EU must contain a low GWP (Global Warming Potential) Refrigerant**
- **January 1, 2017, All new vehicles must use a low GWP Refrigerant**

Approved Low GWP Refrigerant Options

Refrigerant	GWP (Global Warming Potential)	SNAP Listing Date
HFC-152a	124	June 12, 2008
R-744 (CO^2)	1	June 6, 2012
HFO-1234yf	<4	March 29, 2011

- **Note: All Options have use conditions placed on them for occupant safety**

Current State

- **Final Rule 20 - Protection of Stratospheric Ozone: Change of Listing Status for Certain Substitutes under the Significant New Alternatives Policy Program**
  - HFC 134a is not approved for use starting Model Year 2021 for Automobiles and Light trucks
    - Narrowed use limits apply for export to countries without servicing infrastructure through model year (MY) 2025

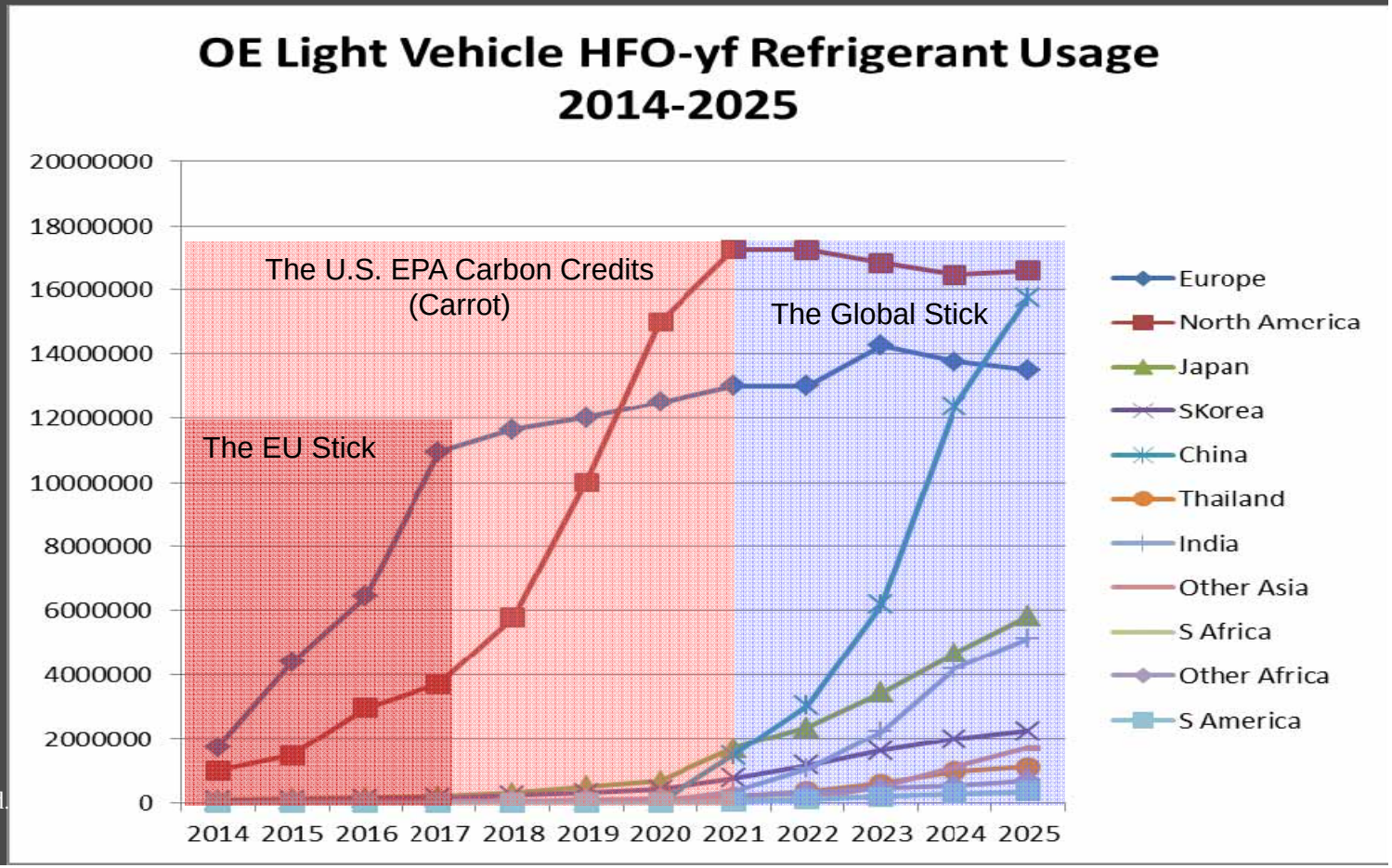
Current State

- **Final Rule 21 - Protection of Stratospheric Ozone: Significant New Alternatives Policy Program New and Changed Listings**
  - "EPA is also listing as acceptable, subject to use conditions, HFO-1234yf newly manufactured medium-duty passenger vehicles (MDPVs), heavy-duty (HD) pickup trucks, and complete HD vans."
  - Effective January 3, 2017

Governmental Motivation

- **The Carrot (Incentives such as carbon credits in the United States)**
- **The Stick (Legislation of Phaseout of High GWP Refrigerants in the European Union and the United States)**
- **Neither Currently Exist for Heavy Duty or Off Highway Vehicles**

The Carrot and the Stick in Real World Terms



Adoption of R-1234yf

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Currently Using R-1234yf

BMW
BMW i3 (electric)
BMW X1
BMW i-2 i-Reihe
BMW X3
BMW i8
Chrysler
Chrysler 200
Chrysler 300
Chrysler Pacifica
Dodge Durango
Dodge Ram 1500
Dodge Challenger
Dodge Charger
Dodge Dart
Jeep Cherokee KL
Jeep Grand Cherokee
Jeep Renegade
Jeep Wrangler
Citroën
Citroën C3 Picasso
Citroën C-Quatre
Citroën C4 Cactus
Citroën DS5
Citroën C4 Picasso
Citroën Elysee
Daimler Reported, but not confirmed

Ferrari
LaFerrari
Ferrari F12
Ferrari F150
Fiat
Fiat 500
Fiat 500L
Fiat 500X
Fisker Automotive
Fisker Karma
Ford
Ford Escape
Ford F-150
Ford Fusion
Ford Mustang
Ford Nugget
Ford Tourneo Custom
Ford Transit
Ford Transit Custom
General Motors
Buick V300
Cadillac ATS
Cadillac CT6
Cadillac SRX
Cadillac XTS
Chevrolet Malibu
Chevrolet Spark EV
Chevrolet Tracker
Chevrolet Trax
Opel Astra
Opel Karl
Opel Mokka
Opel Vivaro Combi
Pontiac Sunfire

Honda
Honda Civic
Honda Fit EV
Honda Jazz
Honda Pilot
Honda Ridgeline
Hyundai
Hyundai i10
Hyundai i20
Hyundai i30 GDH
Hyundai i40
Hyundai Genesis
Hyundai Santa Fe
Hyundai Tucson
Infinity Q50
Jaguar Land Rover
Jaguar F Type
Jaguar XE
Jaguar XF
Jaguar XJ
Range Rover
Range Rover Discovery
Range Rover Discovery Sport
Range Rover Sport
Range Rover Evoque
Kia
Kia Cadenza
Kia Carens (z)/Rondo
Kia Cee`d Kia Optima
Kia Picanto
Kia Sorento
Kia Soul
Kia Sportage

Lexus
Lexus GS 250 Lexus NX300H
Lexus GS 450 H Lexus RC F
Lexus LS
Lotus
Lotus Exige S
Lotus Elise LMaruti-
Suzuki
Suzuki Maruti
Suzuki Celerio
Maserati
Maserati Ghibli
Maserati Quattroporte GTS
Mazda
Mazda 2 Mazda CX3
Mazda CX5
Mia
MIA (electric)
Mitsubishi
Mitsubishi Mirage
Mitsubishi Spacestar
Nissan
Nissan e-NV200
Nissan Note
Nissan Qashqai
Nissan Pulsar
Nissan X-Trail
Pagani Automobili
Pagani Huayra
Peugeot
Peugeot 301
Peugeot 308

Renault
Renault Espace
Renault Kadjar
Renault Talisman
Renault Twingo
Renault ZOE
Subaru
Subaru BRZ Outback
Subaru Forester Subaru
Subaru Impreza
Subaru Legacy
Subaru Z
Suzuki
Suzuki SX4
Suzuki SX4 S Cross
Suzuki Grand Vitara
Suzuki Vitara
Tesla
Tesla Model S
Toyota
Toyota Prius plus)
Toyota Tacoma
Toyota Z (GT86
Volkswagen
Volkswagen Tiguan
Volvo
Volvo S80
Volvo V70
Volvo XC90

What Would Drive a Refrigerant Change in Heavy Duty Vehicles?

- **Motivation**
  - Government Regulations
  - Government Incentives
  - Economics
  - Availability

U.S. EPA Adopted Federal Phase 2 GHG Regulations

- Second phase of federal heavy–duty GHG standards for vehicle manufacturers.
  - Final rulemaking published Oct. 2016
  - Establishes technology forcing standards for engines and vehicles
  - Combination Tractors
  - Trailers (not regulated in Phase 1)
  - Vocational Vehicles
  - HD Pick-ups and Vans
  - Phase in model year 2021 to 2027 (from 2018 for trailers)

U.S. EPA Adopted Federal Phase 2 GHG Regulations

- Federal Phase 2 Standards include a air conditioning refrigerant leakage standard that set a maximum cap for refrigerant leak rate.
- Federal Phase 2 Standards do not include any requirement or credit incentive for the use of low-Global Warming Potential (GWP) refrigerants.

Other Government Actions

- **The European Union studied the issue some years ago but no plans were ever finalized.**
- **California Air Resources Board is actively developing their own GHG regulations to coincide with the Federal Phase 2 Regulations.**
  - A credit incentive for using a low GWP refrigerant maybe a part of their regulations.
  - Board consideration of California Phase 2 proposal Oct. 2017

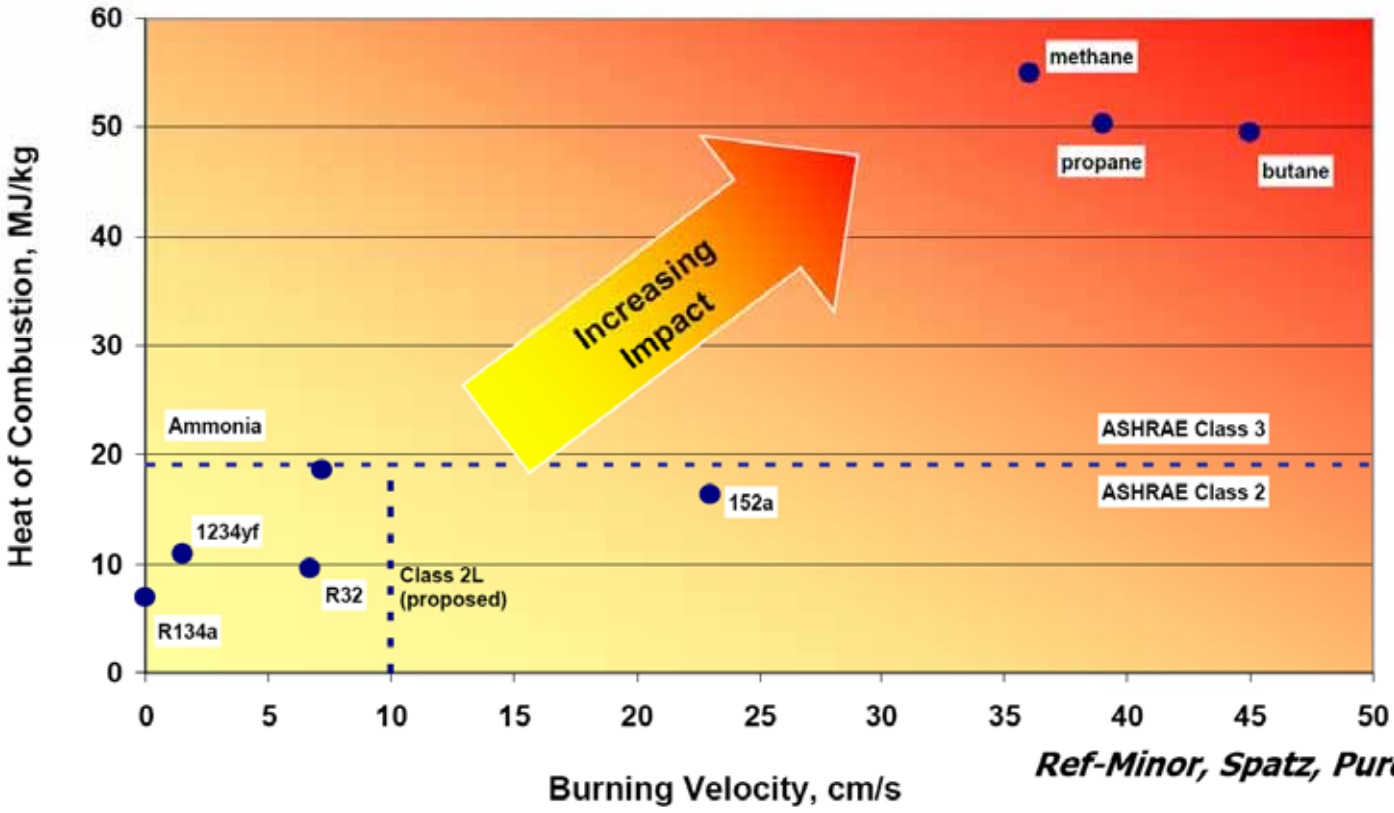
Assessing Risk

- **In order to use any of the Low GWP Refrigerants require proof of safe application of the refrigerant to the vehicles occupants.**
- **In the case of R-152a and R-1234yf, the concern is flammability.**

R-1234yf Burning Velocity

Even if ignited, HFO-1234yf burns weakly, would have limited effect

Flammability is evaluated by 'Chance of Flame' and 'Effect of Flame"
- Chance of Flame occurring -> Lower Flame Limit, Minimum Ignition Energy



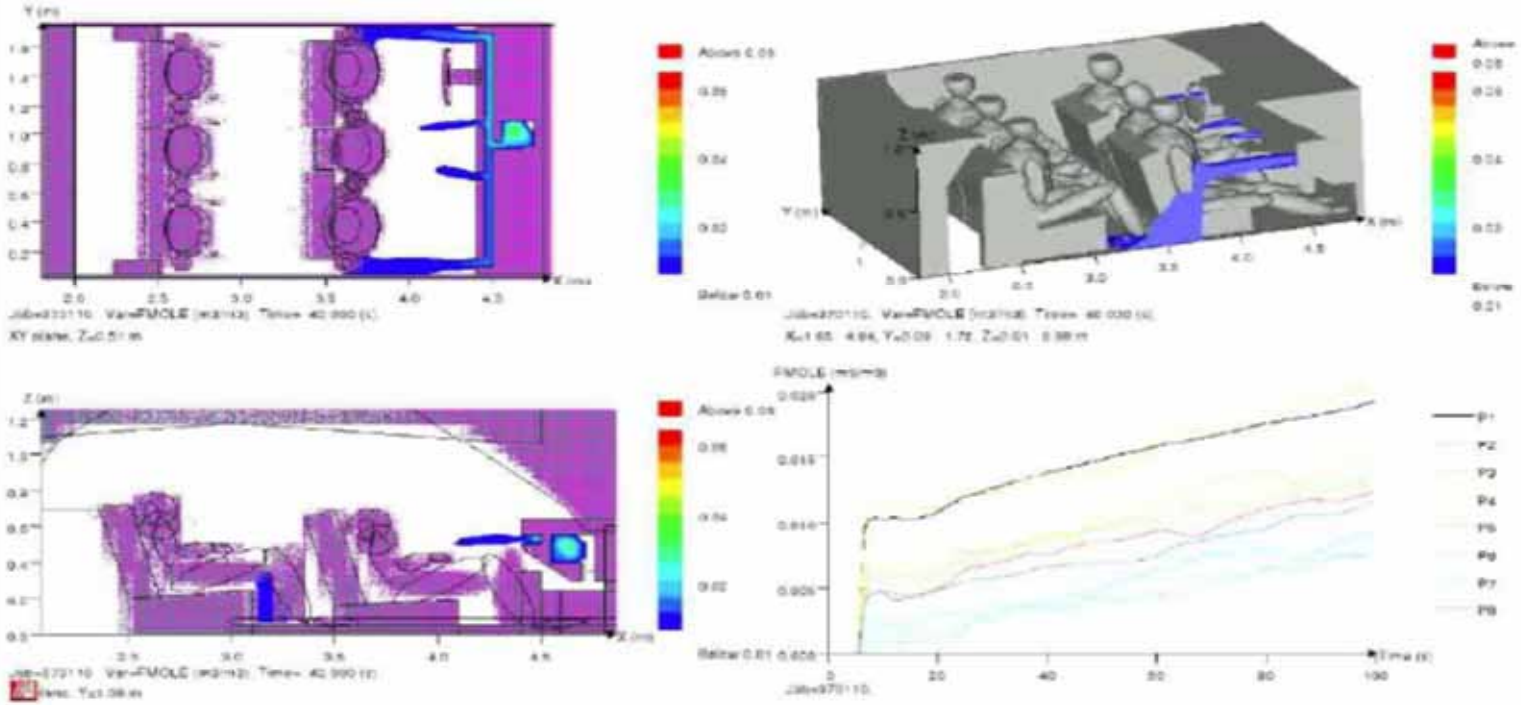
Ref-Minor, Spatz, Purdue 2008

R-1234yf Risk Assessment for Autos

DUPONT The miracles of science

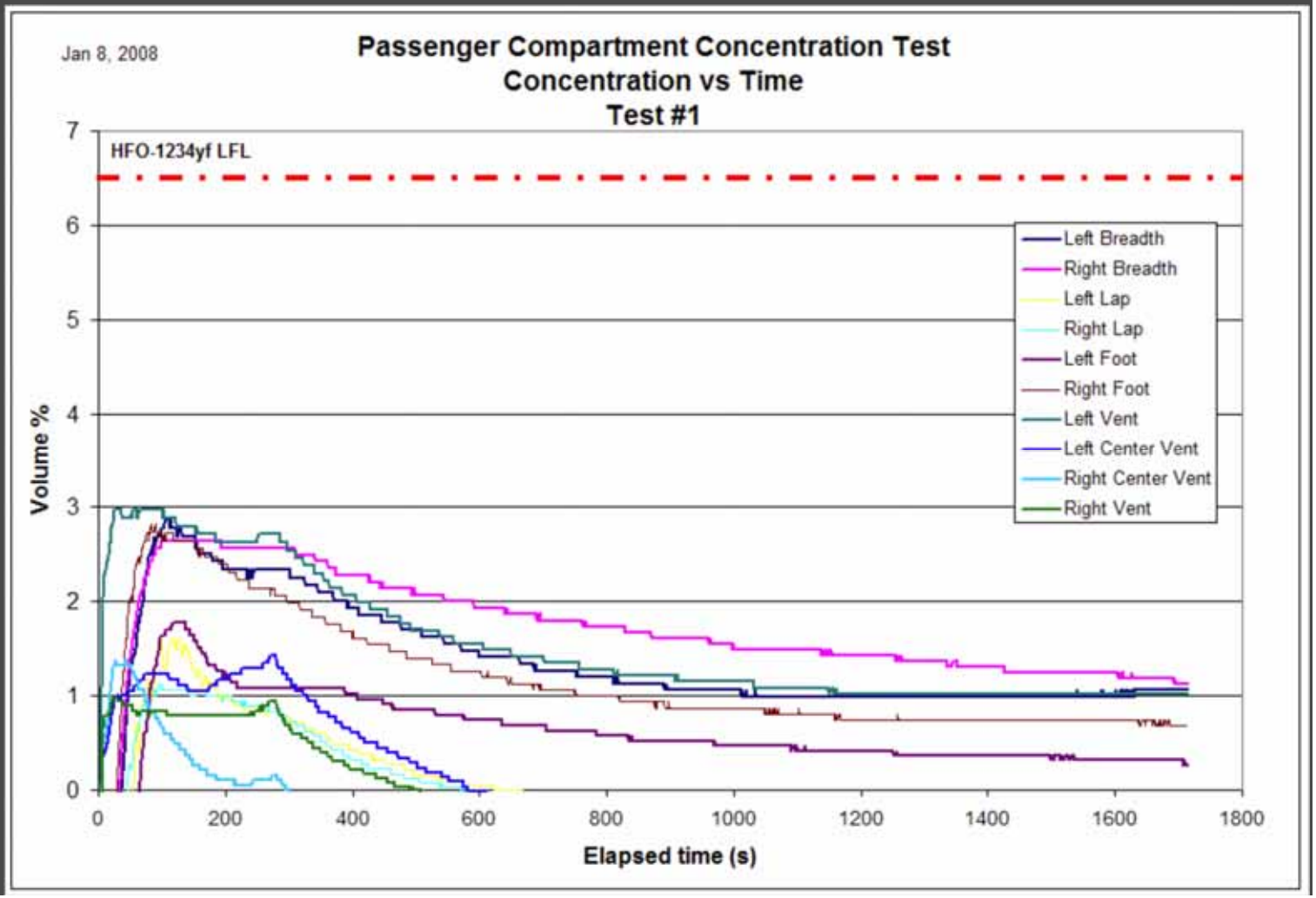
0.5 mm, 100% Recirc – 40 seconds

Honeywell



Chemours

R-1234yf Risk Assessment for Autos



Risk Assessment

- **Before R-1234yf can be approved for use in Heavy Duty Vehicles similar studies would need to be carried out.**
- **The diversity of vehicles, vehicle applications, cab sizes, and refrigerant charge levels make risk studies very complex and lengthy.**
- **Chemours has started work on medium & heavy duty trucks but is lacking a willing partner to move forward.**

Economics

- **Cost of the Refrigerant**
- **Cost Impact on the A/C Systems**

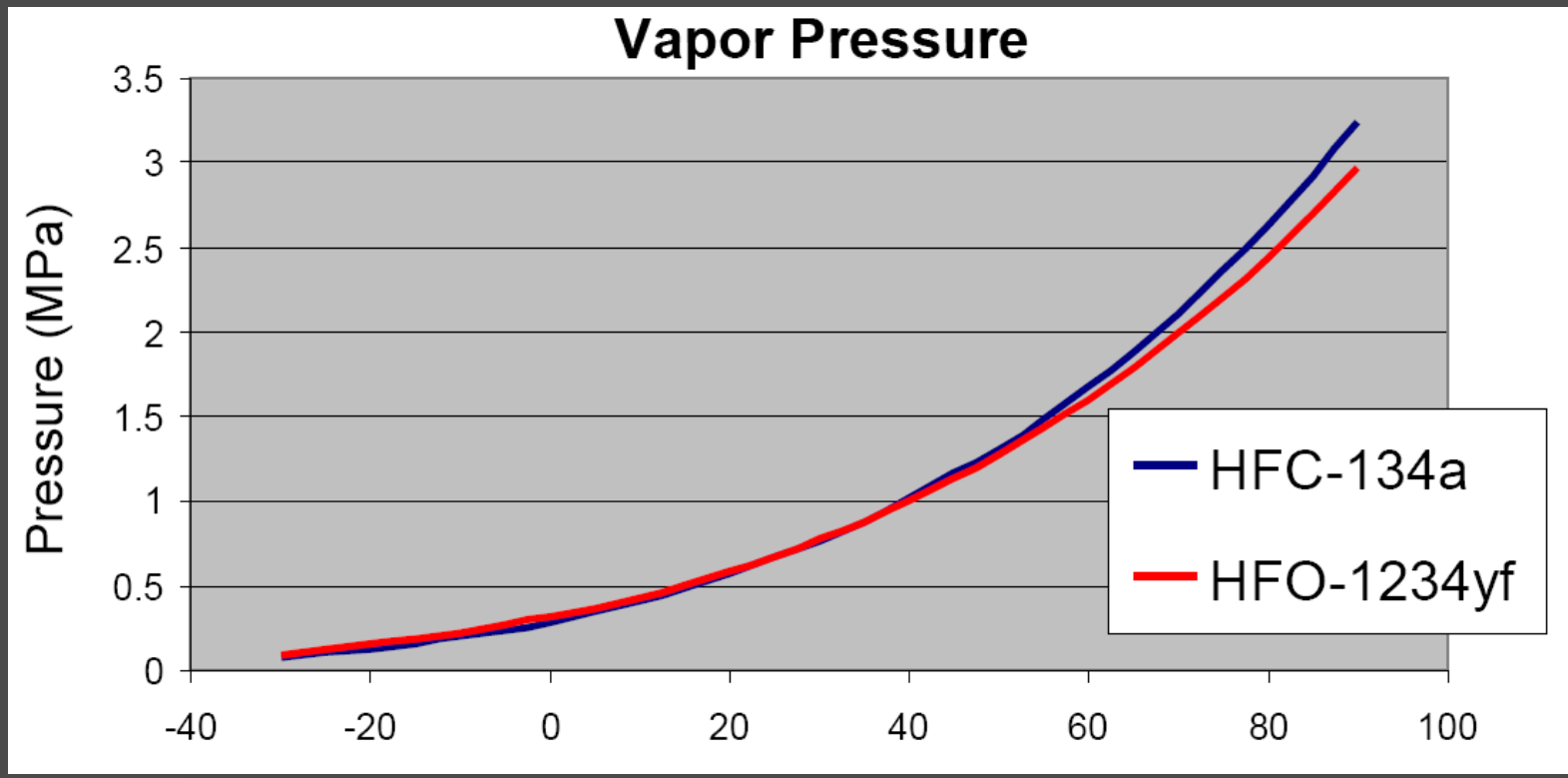
Refrigerant Cost Comparison

Refrigerant	Part Number	Retail Price	Cost per Pound	Cost of 3.5 lb Charge
R-134a	R134A-30	$199.99	$6.67	$23.35
R-1234yf	1234y-10	$999.99	$100.00	$350.00

O'Reilly Auto Parts

At AAPEX 2016, the best verbal price for R-1234yf was $40 per pound. Which is still over **ten times** the cost of R-134a.

R-134a versus R-1234yf Properties



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Expected System Performance Difference
5 to 8% less for R-1234yf

R-1234yf Fahrenheit Pressure/ Temperature Chart

EVAPORATOR PSIG	°F		CONDENSER PSIG	°F		CONDENSER PSIG	°F
9	0		77	72		200	132
11	4		80	74		206	134
14	8		83	76		212	136
16	12		86	78		218	138
19	16		89	80		223	140
19	17		92	82		229	142
20	18		96	84		236	144
23	22		99	86		242	146
24	23		102	88		248	148
25	24		106	90		255	150
28	28		110	92		261	152
31	32		113	94		268	154
33	34		117	96		275	156
35	36		121	98		282	158
37	38		125	100		289	160
38	40		129	102		296	162
40	42		133	104		304	164
42	44		137	106		311	166
44	46		142	108		319	168
47	48		146	110		326	170
49	50		148	111		334	172
51	52		150	112		342	174
53	54		155	114		351	176
56	56		160	116		359	178
58	58		164	118		368	180
61	60		169	120		376	182
63	62		174	122		385	184
66	64		179	124		394	186
68	66		184	126		403	188
71	68		190	128		413	190
74	70		195	130			

Data courtesy of DuPont and generated using REFPROP, Std Ref Program, NIST

RD-5-13074-OP Rev–

R-134a Pressure/ Temperature Fahrenheit Chart

EVAPORATOR PSIG	°F		CONDENSER PSIG	°F
16	16		125	101
18	19		130	103
20	22		135	105
22	25		140	107
24	27		145	110
26	30		150	112
28	32		160	116
30	34		170	120
32	36		180	124
34	39		190	127
36	41		200	131
38	44		210	134
40	48		220	137
42	47		230	141
44	49		240	144
46	50		250	147
48	52		260	150
50	54		270	152
55	58		280	155
60	62		290	158
65	66		300	160
70	69		310	163
75	73		320	165
80	76		330	168
85	79		340	170
90	82		350	172
95	85		360	175
100	88		370	177
105	91		380	179
110	93		390	181
115	96		400	183
120	98		410	185

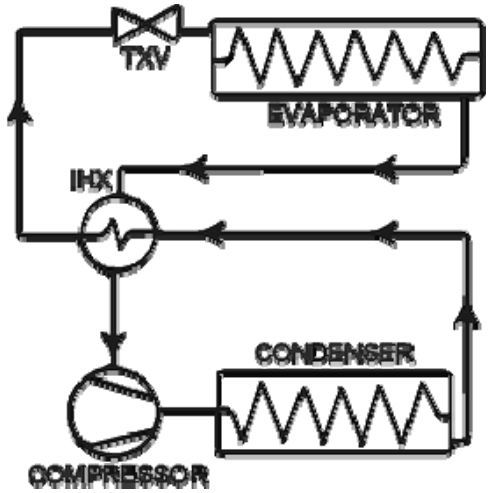
Torque Settings

#6 O-Ring Fitting:	11-13 ft-lb
#8 O-Ring Fitting:	15-20 ft-lb
#10 O-Ring Fitting:	21-27 ft-lb
#12 O-Ring Fitting:	28-30 ft-lb
#14 O-Ring Fitting:	30-35 ft-lb
Pressure switch on Schrader port (7/16-20):	85-90 in-lb
Pressure switch on M10 port:	60-65 in-lb
Schrader port valve insert:	3-5 in-lb

RD-5-13053-OP Rev–

Addition of an Internal Heat Exchanger

- **Improves System Performance around 7%**
- **With the Addition of IHX into Existing System will Make Up the Performance Difference of R-1234yf.**



Refrigerant Availability

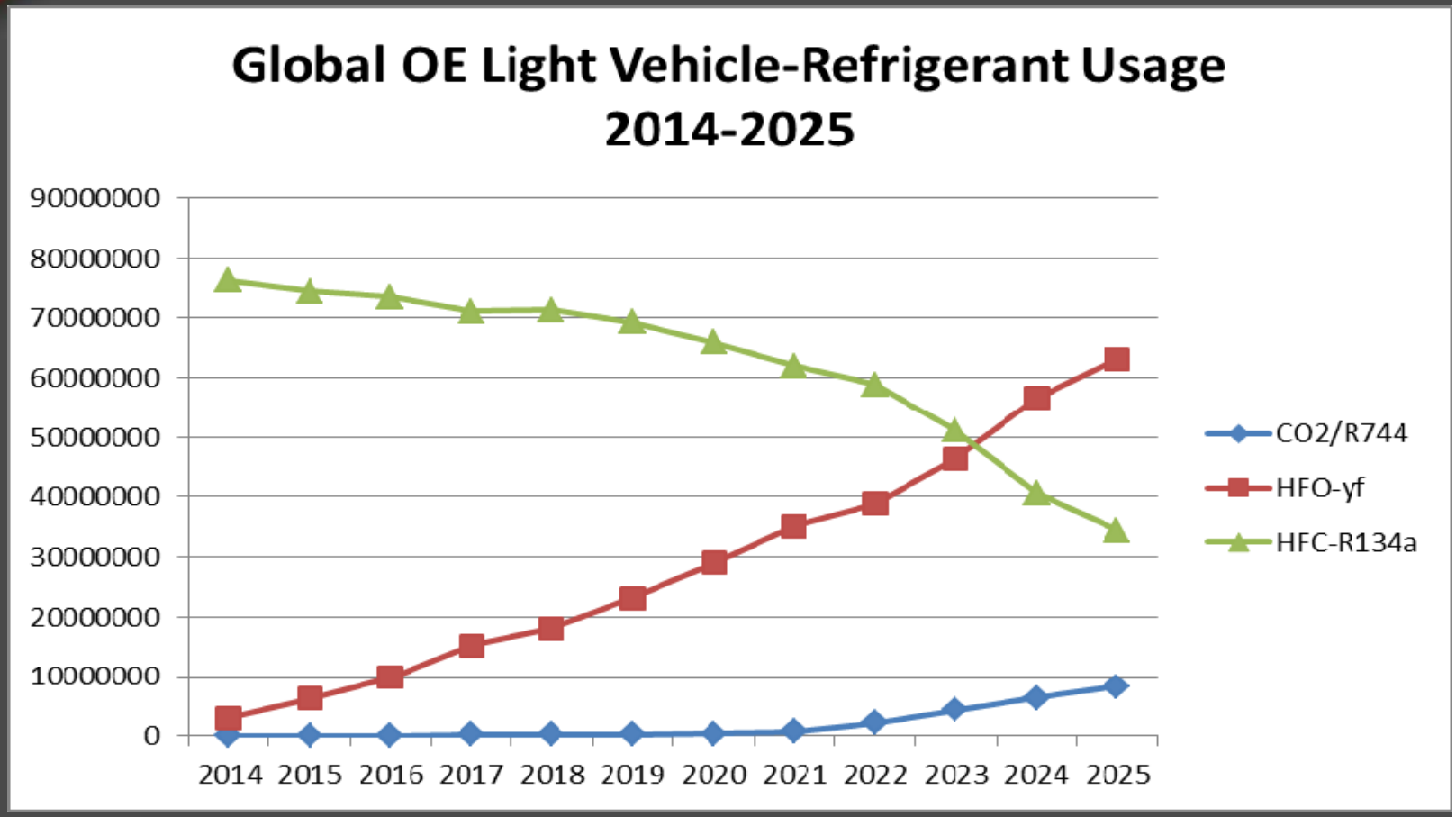
- **Long Term Driver for Refrigerant Change may come down to Availability.**
- **The European Union F-Gas Regulation (EC 842/2006) has a HFC Cap and Phase Down Plan for All HFCs.**
- **The United States has a Similar Proposed Plan.**

The EU HFC Phasedown Schedule

Year	Original phase down schedule
2015	100%
2016	94%
2017	83%
2018	56%
2019	56%
2020	56%
2021	40%
2022	40%
2023	40%
2024	28%
2025	28%
2026	28%
2027	21%
2028	21%
2029	21%
2030	19%

Courtesy of Dan Foss

Projected Refrigerant Usage



Conclusions

- **A Mandatory Change Away From R-134a in Heavy Duty Vehicles Highly Unlikely Before 2023.**
  - Refrigerant Availability and Cost Along with Risk Assessments and Infrastructure Change Seem to Support That Timeframe.
  - The Necessary Risk Assessments will provide Plenty of Lead-time Before Any Change. Estimated at 2 - 4 years.
  - Without Government Incentives, Voluntary Change Very Remote unless the Economics Change (refrigerant cost & availability)

Final Thoughts

- **Current Standards are focused on Autos and will need to be reviewed for Heavy Duty Vehicles**

SAE J2844	New refrigerant purity and container requirements for MAC systems
SAE J2099	Recycled Refrigerant Purity Standards
SAE J2297	Ultraviolet leak detection dye standard
SAE J2670	Stability and compatibility criteria for additives and flushing materials
SAE J2762	Method for removal of refrigerant from MAC system to quantify charge amount
SAE J2064	MAC hose and assemblies
SAE J2843	R/R/R equipment for flammable refrigerants in MAC systems
SAE J2851	R-1234yf Refrigerant Recovery equipment for MAC systems
SAE J2845	Technician training for safe service and containment of refrigerants used in MAC systems
SAE J2888	R-1234yf service hose, fittings and couplers for mobile refrigerant systems service equipment
SAE J2911	Certification requirements for MAC system components, service equipment and service technicians to meet SAE J standards
SAE J1628	Technician procedures for refrigerant leak detection in service of MAC systems
SAE J2913	Refrigerant electronic leak detectors minimum performance criteria
SAE J2912	Refrigerant identification equipment for use with MAC systems
SAE J2927	R-1234yf refrigerant identifier installed in R/R/R equipment for use with MAC systems

Sources of Information

- **Special Thanks to the following individuals that provided information for this presentation.**
  - Mary E Koban – Chemours
  - Chenise Farquharson – U.S. EPA
  - David Smith-Tilley – IHS Markit
  - Ron Henselmans – Auto.AC.Reporter
  - Michael Harris - MACPartners

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