Refrigerants Technology

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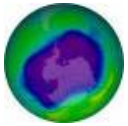
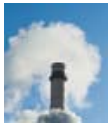
Agenda

- Introduction to Refrigerants
  - Refrigerants Technology Evolution
- HCFC-22 Replacements
  - Air Conditioning
  - Refrigeration
- Next Generation Low GWP Refrigerants
  - Auto AC applications: HFO-1234yf
  - Low GWP refrigerants for Stationary applications
- Final Comments

Honeywell Regulatory Requirements Driving Change



Montreal Protocol /
Ozone Depletion Concerns



Kyoto Protocol /
Global Warming Concerns

CFC Phase-out

HCFC Phase-out

EU F-Gas Regulation

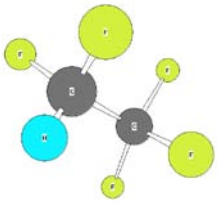
CFCs → **HCFCs** → **HFCs** → **HFOs**

CFCs	HCFCs	HFCs	HFOs
✗ Ozone	✗ Ozone	✓ Ozone	✓ Ozone
✗ Global warming	✗ Global warming	✗ Global warming	✓ Global warming

Simple Chemistry › Enhanced Chemistry › New Molecule Development › Advanced Molecules Development + Complex Chemistry

R12 → **R134a** → **R1234yf**

HFC Refrigerants



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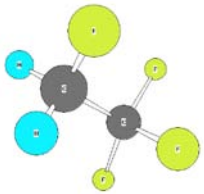
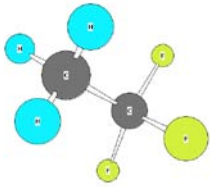
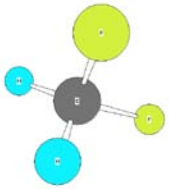


134a



143a



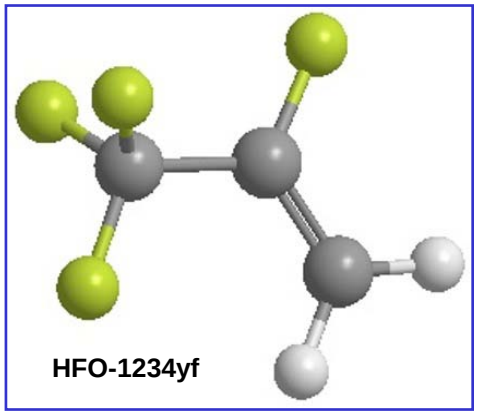
32

- The major HFC refrigerants (by volume):
  - R-410A: 50/50 mixture of 32 and 125 which is industry choice to replace R-22 in residential and light commercial a/c.
  - R-134a: Used in mobile a/c, large chillers, & small refrigeration applications.
  - R-404A: 44/52/4 mixture of 125, 143a, and 134a &
  - R-507: 50/50 mixture of 125 & 143a. Both are used in commercial (supermarket) and industrial refrigeration.

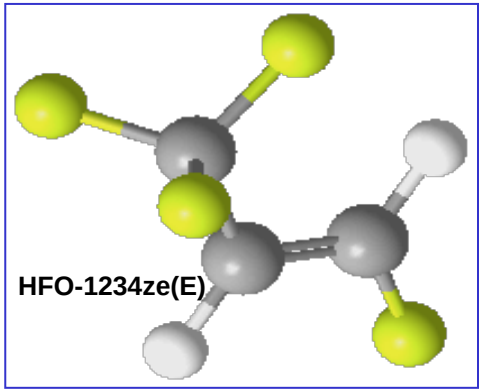
Honeywell Low Global Warming Molecules

New Hydro-Fluoro-Olefins have been developed:

- Solstice™**1234yf (R-1234yf)** has been identified as replacement for R134a by the automotive industry.
  - It has an atmospheric life of only 11 days (12 years for HFC-134a) and an extremely low GWP~0 (1430 for R-134a).
  - R-1234yf is mildly flammable, ASHRAE Safety Classification A2L
  - Can also be used in refrigerant blends



- Solstice™ **1234ze(E)**, is currently replacing R-134a for one-component foam applications and looks promising for centrifugal chillers.
  - This molecule has a very short atmospheric lifetime with a GWP=1
  - R-1234ze is nonflammable at room temp but ASHRAE A2L
  - Can also be used refrigerant blends



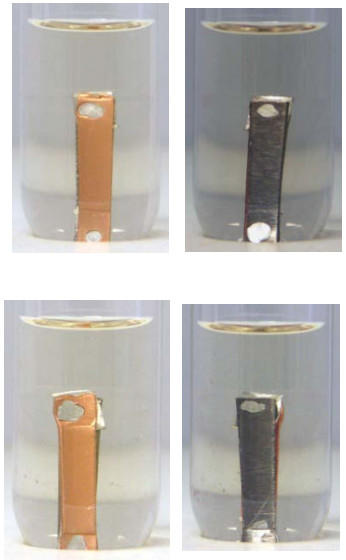
- Solstice™ 1233zd(E) is also being commercialized
  - Intended refrigerant application is low pressure centrifugal chillers.
  - It has a GWP of 1 and is non-flammable , likely AHSRAE A1

Refrigerant Stability

Thermal Stability:

- Sealed tube tests using 1234ze and 1234yf with lower viscosity POE oils ISO-10 and ISO-7.
- Test Conditions: 2-week duration; 2 temperatures (175°C and 200°C); 2 moisture levels (<50 ppm and 1000 ppm).
- Both 1234yf and 1234ze show **excellent** stability: Clear color and very low TAN numbers.

1234ze 2-week Tests
1000 ppm Moisture @ 200°C



1234yf 2-week Tests
1000 ppm Moisture @ 200°C

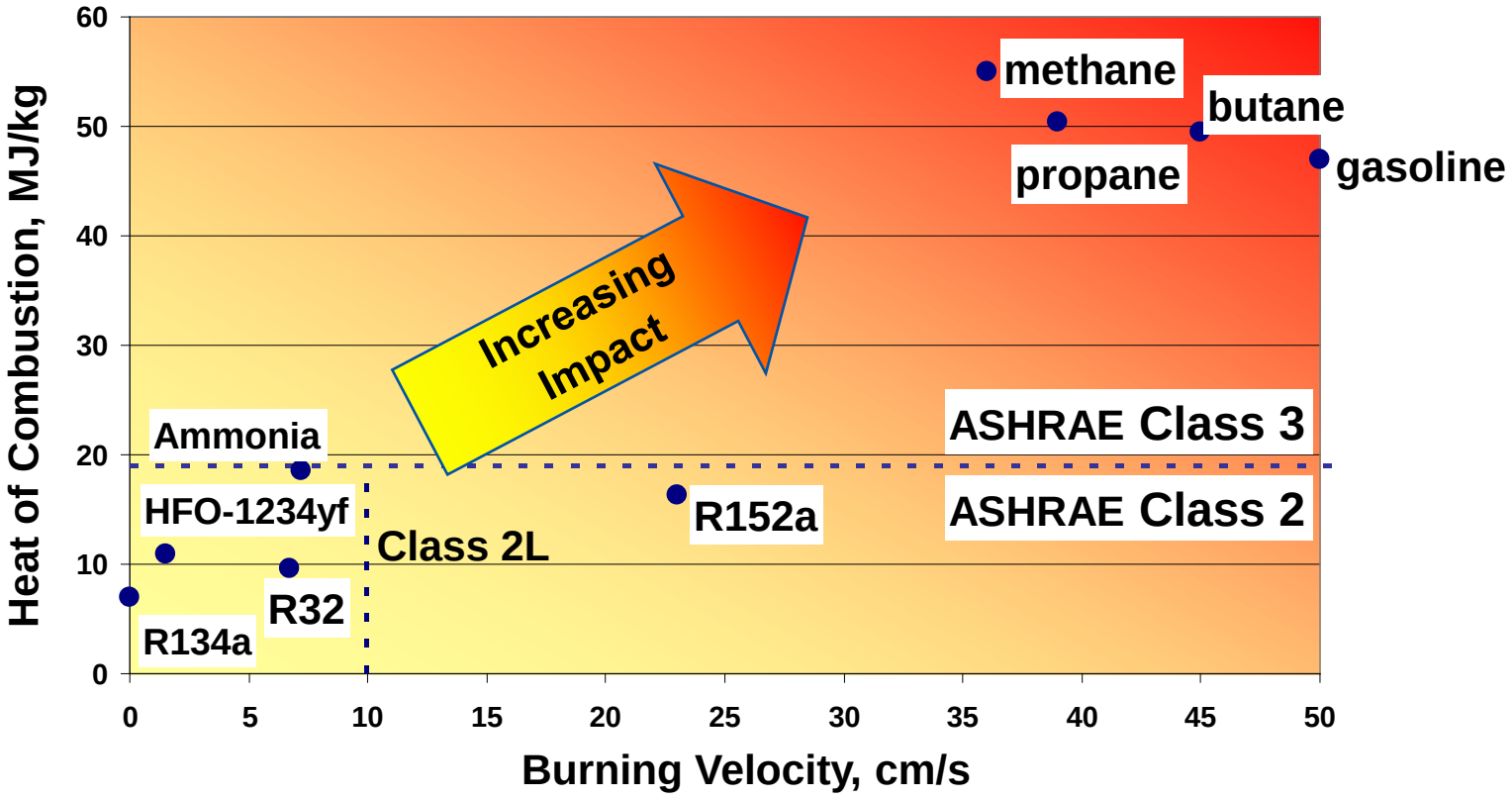
Refrigerants: Flammable Gas Definitions

- **ASHRAE Standard 34** (for a single component refrigerant)
  - ASTM E681-01: 12 liter flask, spark ignition, 1 atmosphere, air RH (50% at 23°C) 60°C
    - **Class 1**: no flame propagation
    - **Class 2**: < 19,000 kJ/kg and > LFL 0.10 kg/m^3
      - Safety Group 2 is subdivided into 2 and 2L
      - 2L refrigerants have a **Burning Velocity** less than 10 cm/sec (less flammable)
    - **Class 3**: ≥ 19,000 kJ/kg or ≤ LFL 0.10 kg/m^3
- **Japan Definition**
  - Flammable if the LEL < 10 vol.%
  - Flammable if the difference UEL-LEL > 20 vol.%
  - Measurement temperature and apparatus not clearly defined.
- **ISO 817 (Standard is published but not yet approved)**
  - Flammability classification is essentially the same as ASHRAE Standard 34 (test temperature is 60^{o}C)

Damage Potential

Flammability is evaluated by ‘Chance of Flame occurring’ and ‘Effect of Flame occurring’

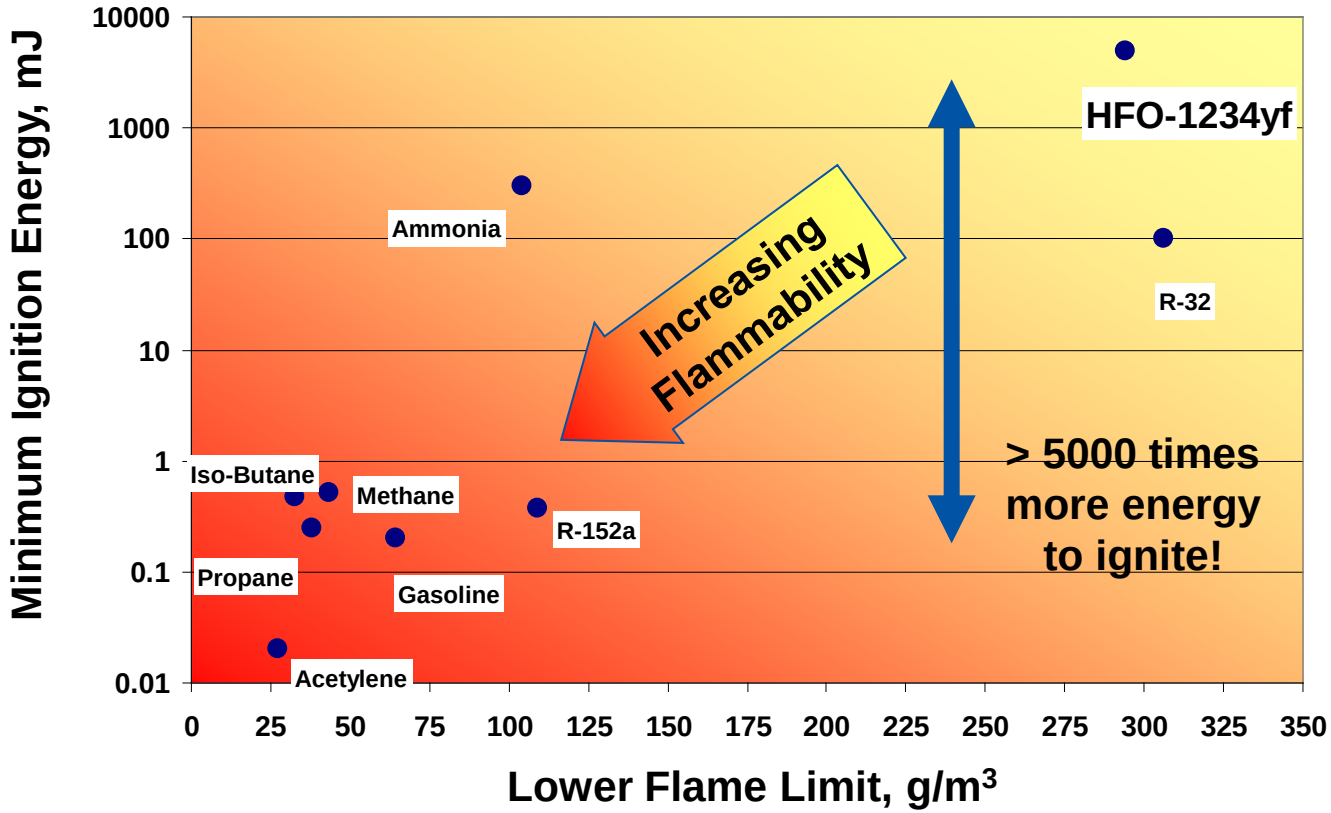
- Effect of Flame occurring -> Burning Velocity, Heat of Combustion



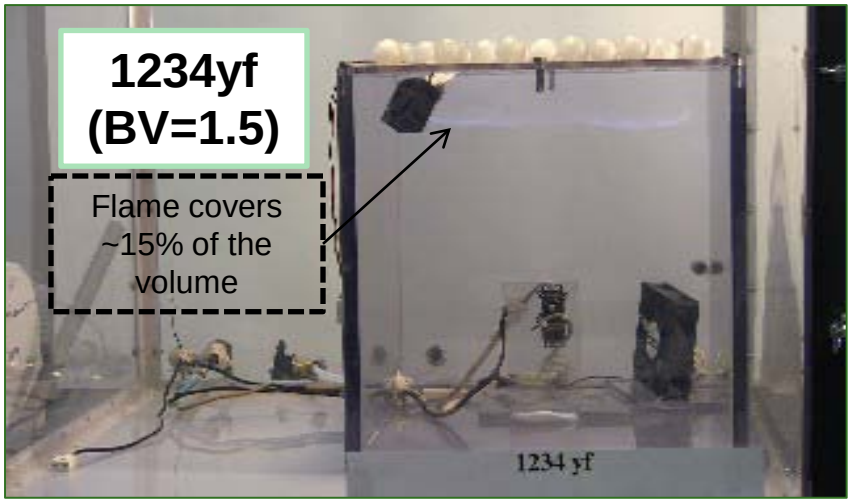
Probability of Ignition

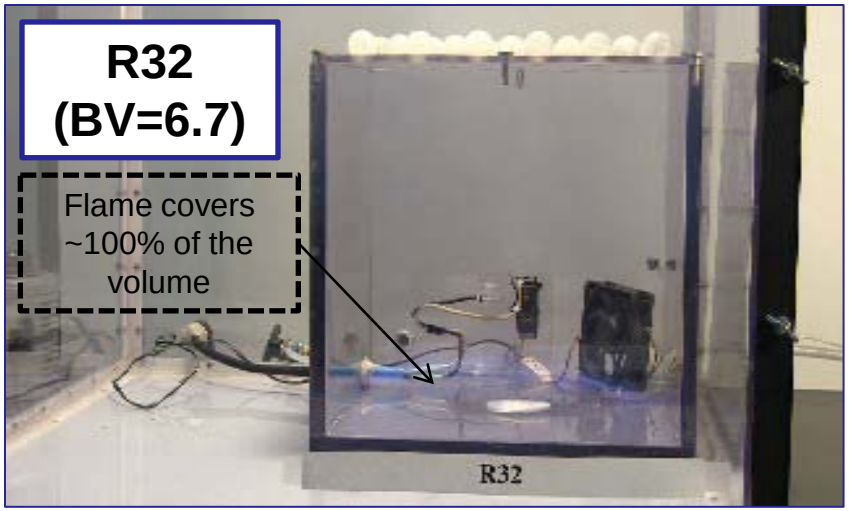
Flammability is evaluated by 'Chance of Flame occurring' and 'Effect of Flame occurring'

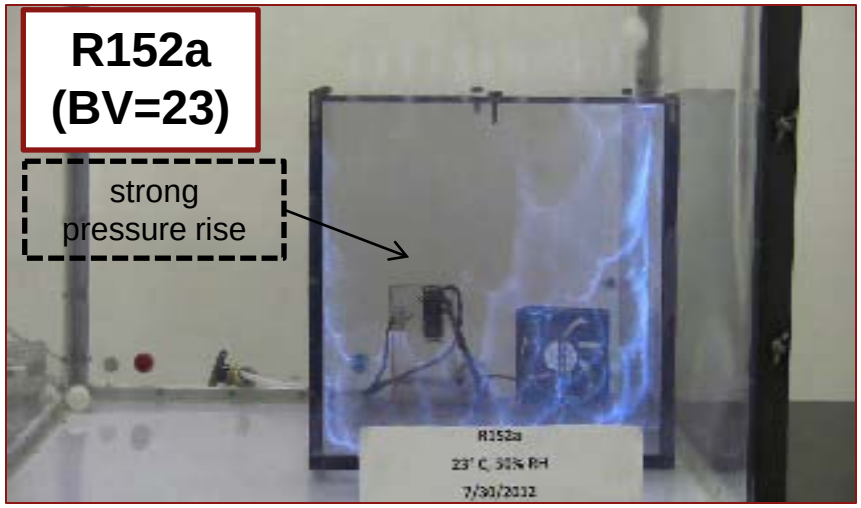
- Chance of Flame occurring -> Lower Flame Limit, Minimum Ignition Energy

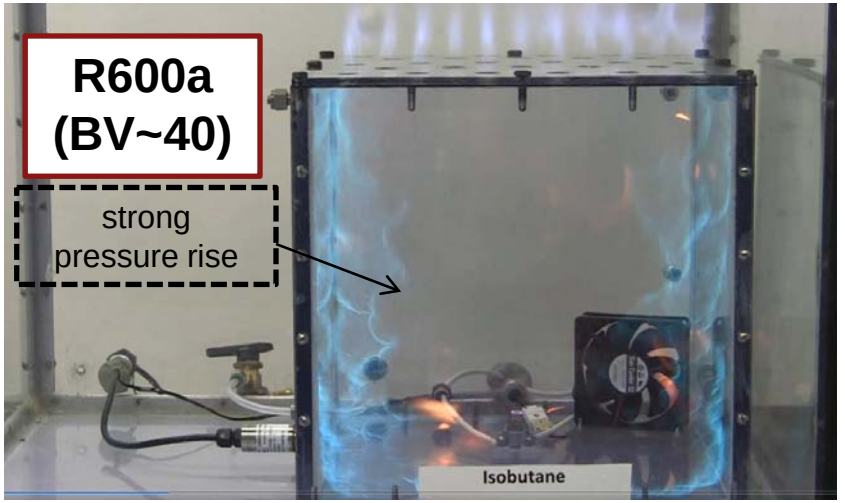


Ignition/Deflagration of 2L Refrigerants







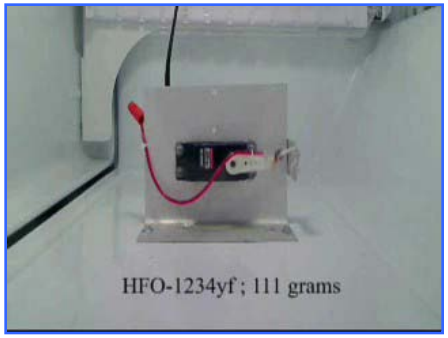


Practical Application - Refrigerator Test

Total Refrigerator Volume	
ft3	m3
25	0.70792

For an Homogeneus distribution, 1234yf is not in the flammable range.

Refrigerant	Vapor Density (23°C, 1 Atm)	Leaked Refrig. (80% of Charge)	Volume Occupied by Refrig.	C-vol	LFL - UFL
	kg/m3	kg	m3	%	%
HFO-1234yf	4.801	0.111	0.02312	3.3%	6.2% - 12.3%
R152a	2.779	0.089	0.03202	4.5%	3.9% - 16.9%
Isobutane	2.458	0.055	0.02237	3.2%	1.8% - 8.4%



1234yf
(A2L)

R-152a
(A2)

Isobutane
(A3)

Air Conditioning

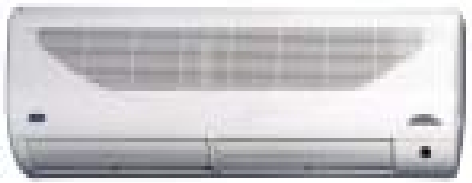
Honeywell Air Conditioning Equipment Segments

Residential

Unitary AC

Heat Pump

Window Unit



Ductless Split (mini-split)

Regional use	US	US	US, AS, LA	EU, AS, LA, MX
Refrigerant	410A	410A	22 > 410A	22, 410A, 407C

Commercial

Packaged Rooftop

PTAC

Chillers

Regional us	Global	Global	Global
Refrigerant	22, 410A	22 > 410A	123, 134a, 22, 407C, 410A

Primary Replacements for HCFC-22 in A/C

Product	Primary Application	Lubricant	Segregation Potential	Retrofit?
R-410A	Unitary A/C	POE	Very Low	NO
R-407C	Unitary A/C	POE	High	YES
R-134a	Chillers	POE	None	NO

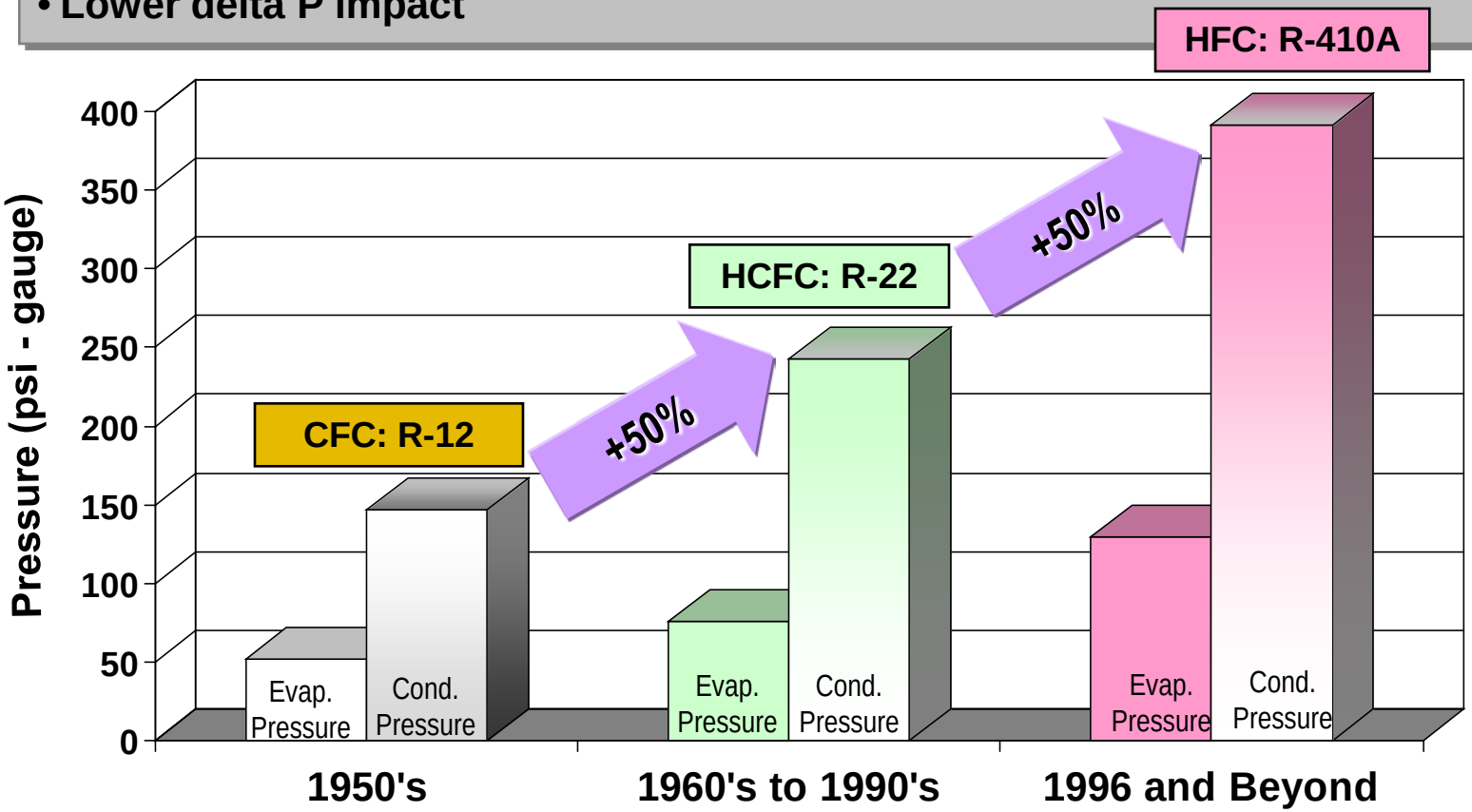
There were few good candidates to replace R-22 in A/C

System/Refrigerant Interaction

Efficiency Effect (%)	R-134a	R-407C	R-410A
Thermodynamics	+2	-4	-7
Compressor	-3	-1	+5
Heat Exchangers	-6	-2	+5
Lines	-2	0	+2
Total (Net)	-9	-7	+5

Why R-410A?

- Higher system efficiency despite lower thermodynamic efficiency
- More compact equipment
- Better heat transfer
- Lower delta P impact



Evaporation Pressure at 45° F & Condensing Pressure at 115° F

Retrofitting HVAC Systems

Refrigerant Options

R-407C (HFC)

- Best capacity and efficiency match to R-22
- The most efficient R-22 retrofit option in the marketplace
- A change to POE lubricant is recommended. If existing MO is used, the addition of some POE to the system is required for proper oil return
- Requires a minimum of 20% POE for close-coupled A/C systems
- No TXV change required
- Lowest GWP (1774) among R-22 replacements
- Lower discharge temperatures than R-22

R-422D (HFC)

- No oil change* or TXV change** in most installations
- Satisfies customers looking for a "drop-in" option
- Slightly less capacity and efficiency but lower discharge temperatures
- Can be used with AB, MO, POE lubricants* when short connecting lines are used
- Lower discharge temperatures than R-22

* System designs vary and the addition of POE may be required to assure proper oil return

** The mass flow of R-422D is higher than that of R-22 and an evaluation of the expansion device is recommended

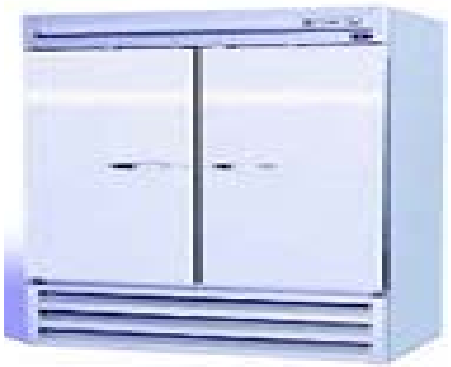
Refrigeration

Honeywell Refrigeration Equipment Segments

R-134a

Convenience Store Coolers (MT)

R-134a



Restaurant Refrigerators (MT)

R-404A
R-507
R-134A

Iced Cream Dispensing (LT)

R-404A
R-134A

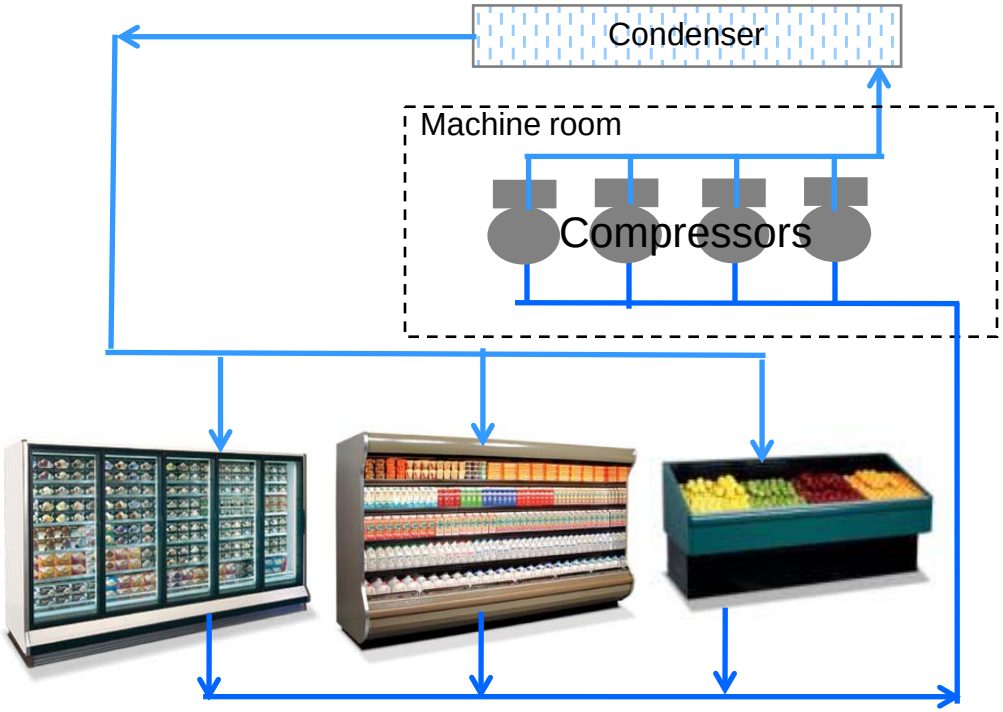
Transport Food Refrigeration

R-404A
R-507

Supermarket/Deli Cases (MT)

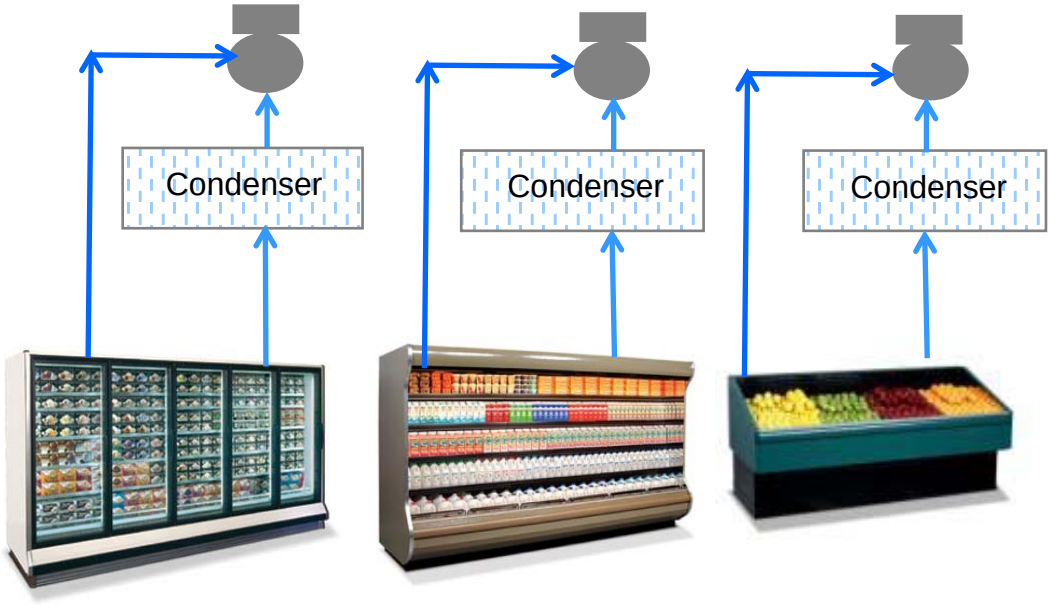
Supermarket Freezer Cases (LT)

Centralized DX System



Features	Pros	Cons	Current	Future
- Compressor rack in machine room far from cases - Long connecting lines	-Convenient installation in most buildings – in common practice -Very familar to store owners and contractors	- Larger refrigerant charge - Higher leak rates	R22 R404A R407A R407F	N40

Distributed DX System

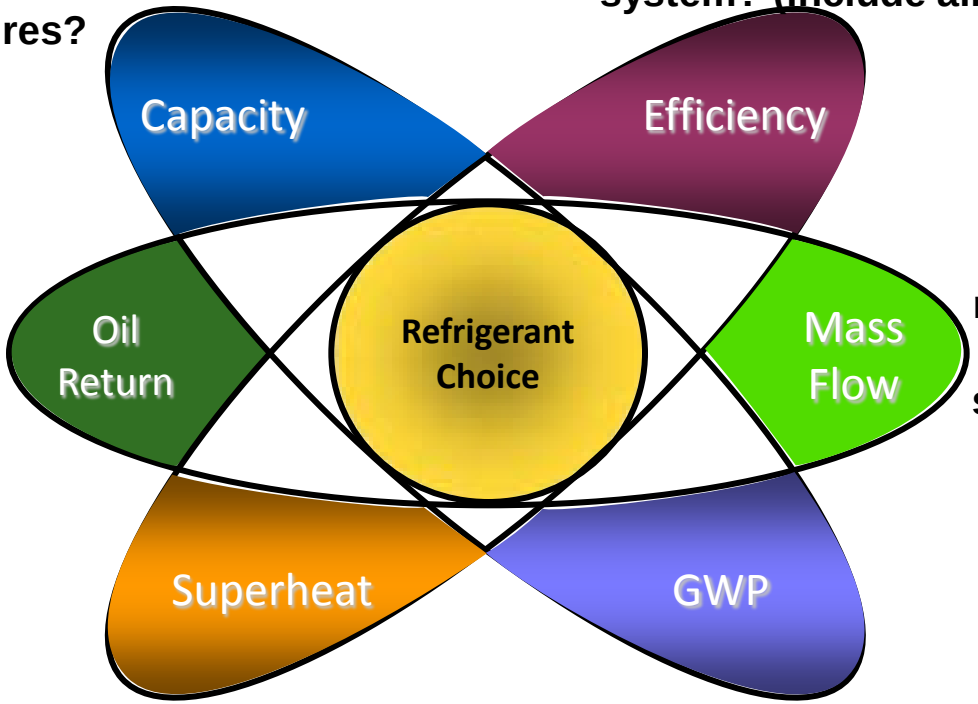


Features	Pros	Cons	Current	Future
- Condenser in rooftop and compressor at store level closer to cases - Short connecting lines	- Lower refrigerant charge (about 1/2 of centralized systems) - Lower leak rates since condensing units are factory assembled - potentially more efficient than centralized – better match of suction groups, shorter lines	- Not always feasible in some buidings	R22 R404A R407F	N40

Selection Criteria for Supermarket Refrigeration

Is there enough capacity to keep the food at required temperatures?

How much does the refrigerant add to the total and peak power consumption of the system? (include all powered systems)



Is refrigerant miscible with oil so that oil returns and protects the compressor?

Higher mass flow means more refrigerant moving through the system. Different mass flow requires changes to TXV valves.

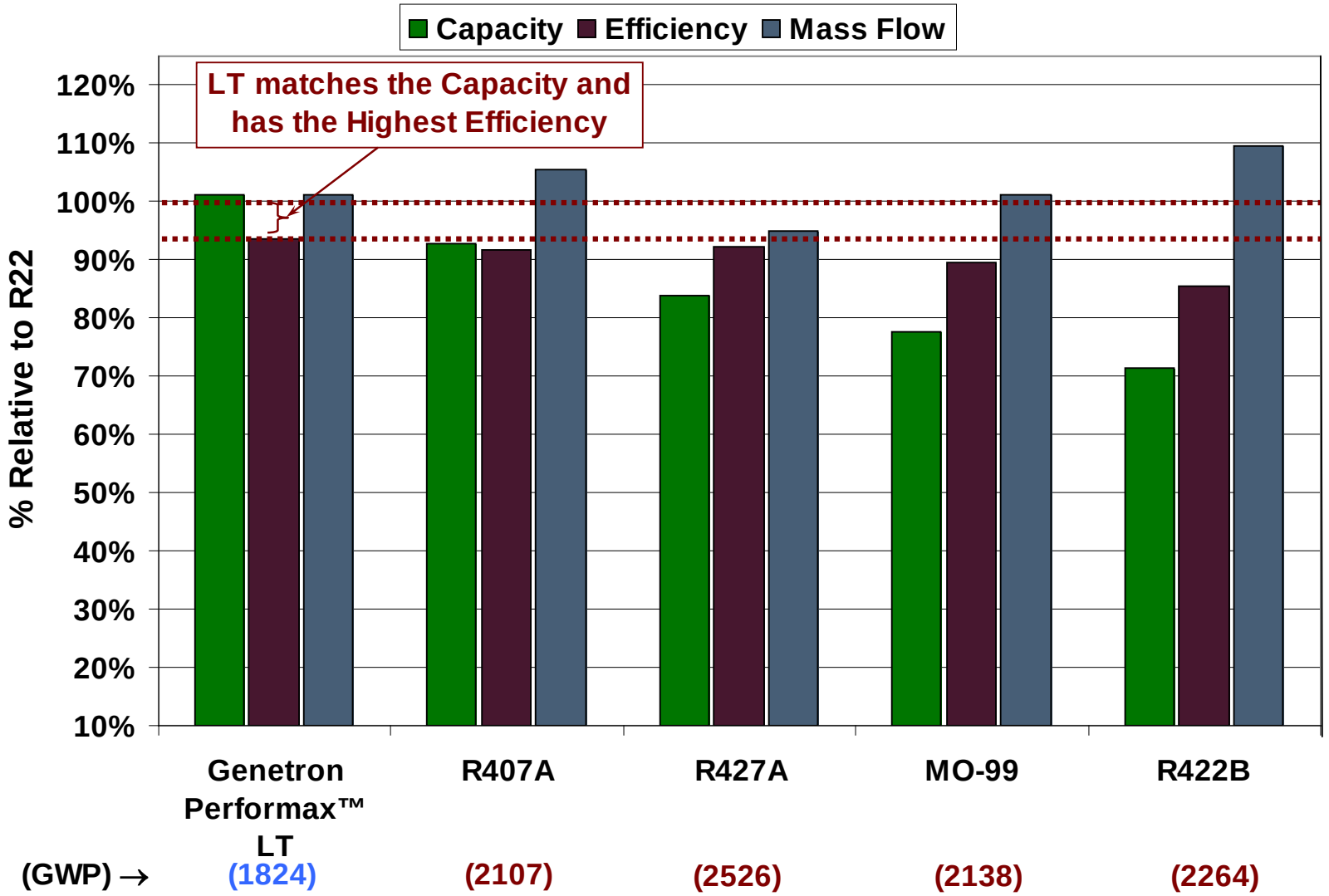
Need to protect compressors and ensure full use of refrigerating capacity.

Lower is better. (possible future GWP tax)

Key Selection Criteria for New Installations and Retrofits

Honeywell

Performance Comparison



CONDITIONS: -25°F Suction Temp., 15°F Entering Compressor, 10°F Superheat, 105°F condensing, 10°F subcooling

Genetron Performax™ LT Outperforms Alternatives

R22 Options - Summary

	Project & Ongoing Costs	Importance Factor	22	407F	407A	422B	427A	MO99	Why Does This Matter?
PROJECT	No TXV changes or adjustments	●	●	●	◑	◑	◑	◑	TXV changes and adjustments add significant cost
	No oil change/Oil Return	◑	●	◑	◑	◑	◑	◔	One oil change required for 407F. Mineral oil not fully miscible with refrigerants like MO99
OPERATIONAL	Maintain System Performance (Capacity)	●	●	●	◑	○	◔	○	Key system performance item. Better capacity keeps food fresh and reduces system run time
	Minimize Electrical Costs (efficiency)	●	●	●	●	◑	●	◑	KWH cost of operating the system
	Minimize GWP Based Taxes	●	●	●	◑	◔	◑	◑	At $10.00/MT CO2E, every 100 GWP pts = $0.45/lb. in Taxes
	Maintains Superheat	◑	●	●	◑	◔	◔	◔	Prevents floodback issues and protects compressors
		GWP Value	1810	1824	2107	2526	2138	2264	

No Change
No Adjustment

Best Capacity

○ Unfavorable/ Not important ◑ Neutral/ Neutral ● Favorable/ Important

Sorting Thru all Options

Commercial Options:
16 Refrigerants

407A, 407C, G.P. LT 421A, 422A, 422B 422C, 422D, 417A 427A, 424A, 428A, 507A, 404A, 434A R438

Better than 95% Capacity

Commercial Options:
5 Refrigerants

407F 407A 428A 404A 507A

No TXV Change GWP < 2000 Efficiency (95% + relative to R-22)

Commercial Solution:
1 Refrigerant

R407F Performax™

The capacity, mass flow, efficiency, GWP, superheat & oil return solution

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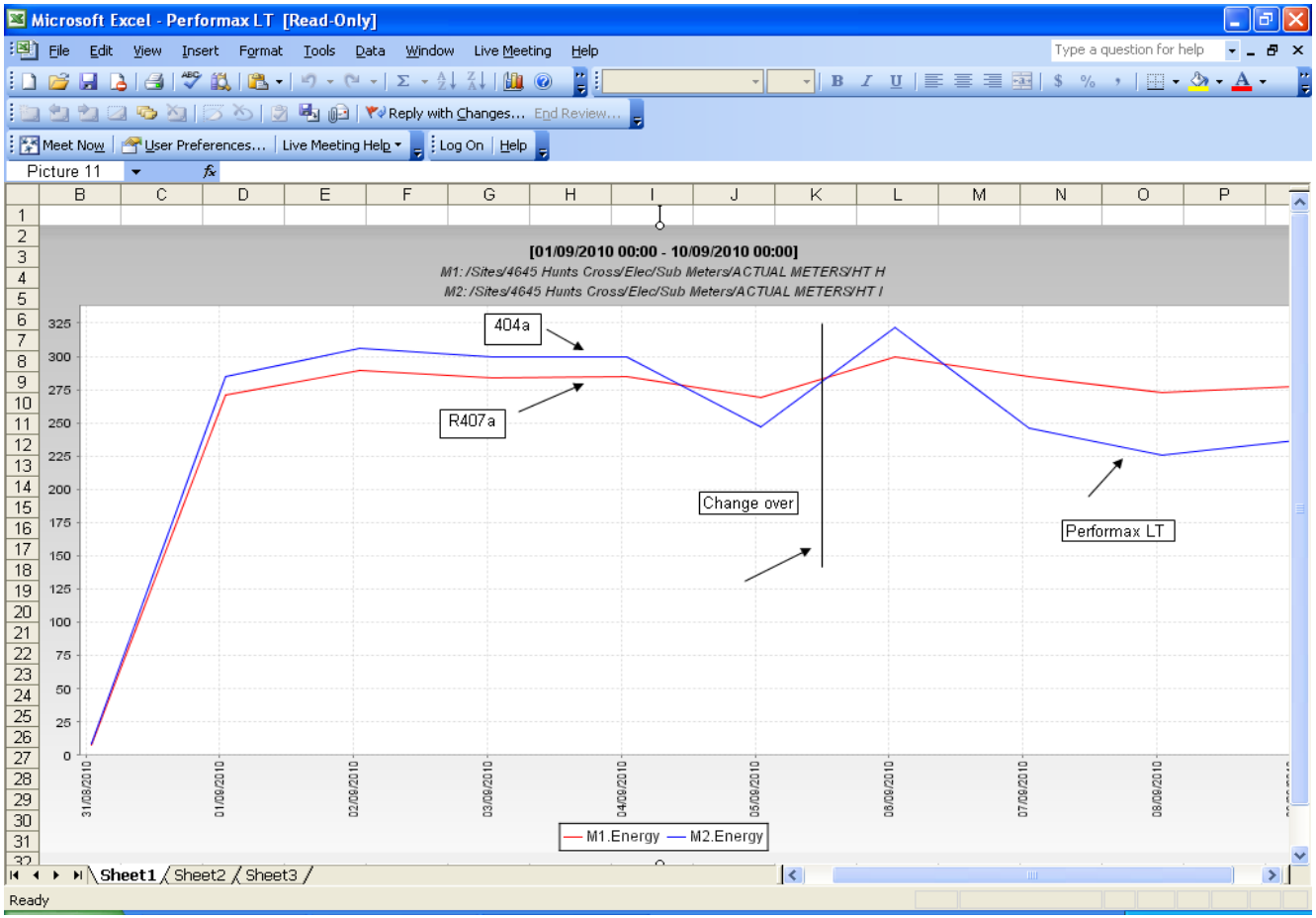
ASDA Hunts Crossing Case Study



- Case study by ASDA, Copeland, local utility, Honeywell, refrigeration contractor and consultants
- Identical MT systems
- The R404A system had a 7% over consumption vs. the R407A system
- After retrofit to Performax LT, system is using 13% less power than the R407A system and around 20% less than the R404A performance
- **Why? The extra capacity of Performax LT allowed for more compressor down time vs. 407A**

Performax consumed 13% less energy than 407A

Next Generation
Low GWP Refrigerants

Honeywell

Solstice™ 1234yf for MAC Applications

The Product

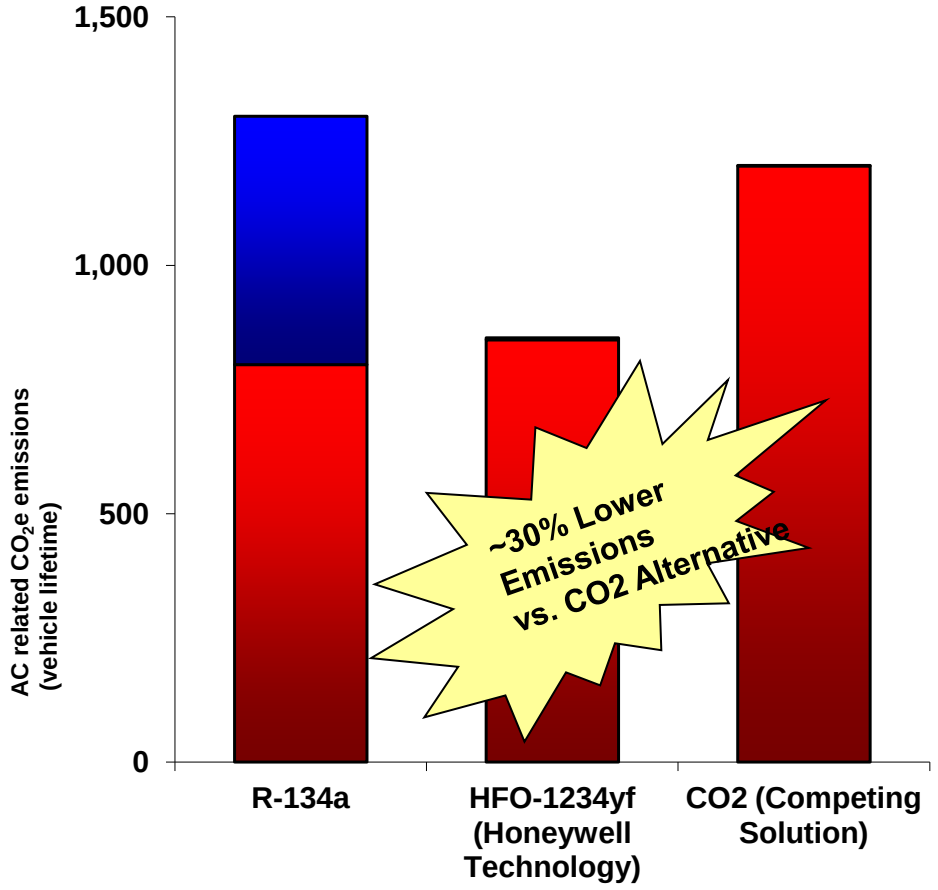
- Global Warming Potential of <1
  >99% Reduction in Greenhouse Gases
- Performance Similar to R-134a
- Effective Cooling in All Climates
- Developed Specifically for MAC Systems
- Familiar Serviceability
- Reliable Technology

The Properties

- GWP of <1 is Significantly Below the MAC Directive
- High Performance with Lower Fuel Consumption and CO_2 Emissions
- Near Drop-in Solution, Minimal Re-design Required
- Global Solution
- Easy Implementation for Aftermarket
- Cost-Effective

A Global Solution to Benefit the Environment and Industry

Superior Environmental Performance



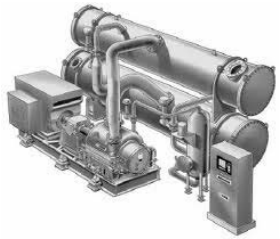
Drivers

- **Europe:** Regulates Use of Refrigerant with GWP Below 150 for New Vehicle Types
- **US:** Trade-off with CAFE Tailpipe Emission for LGWP Refrigerant Replacement
- **Asia:** Conversion for Vehicles Exported to EU and U.S.
- **Demand:** Global Annual Light Vehicle Builds Expected to Grow from 67M to 94M by 2019

Superior Environmental Performance

Honeywell's Solstice™ Low GWP Refrigerants

Solstice™ HFO's			
Current Product	**Non Flammable**	**Mildly Flammable (ASHRAE A2L)**	**Examples of Possible Applications**
HFC-134a GWP=1300		Solstice yf GWP=0	Auto A/C, Vending, Refrigerators
		Solstice ze GWP=1	Chillers, CO_2 Cascades Refrigerators
R-123 GWP= 79	Solstice zd GWP = 1		Centrifugal Chillers



Note: All GWP values use the latest assessment from the ICCP, "AR5"

Solstice™ HFO's for Low and Medium Pressure Applications

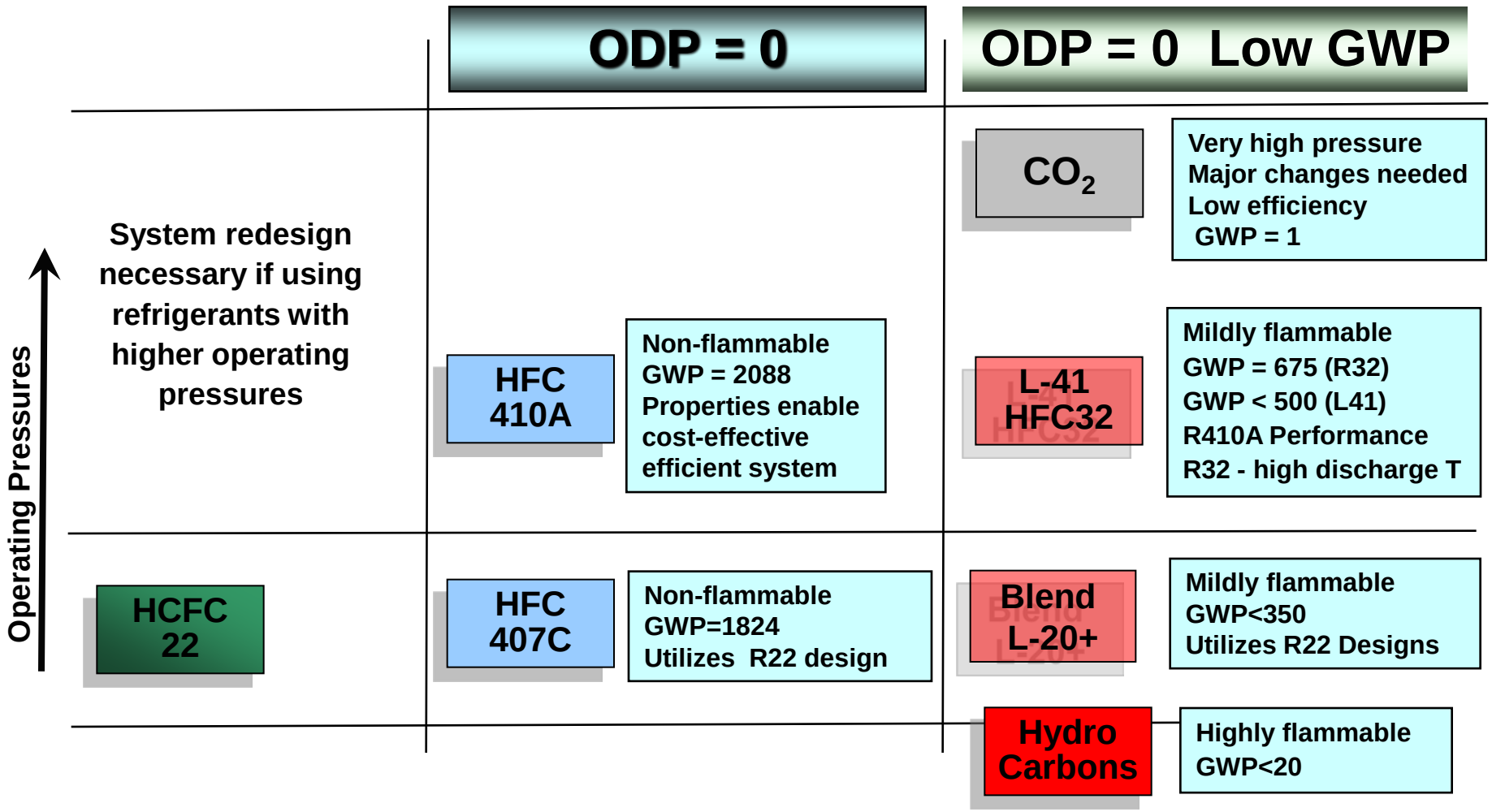
Honeywell's Solstice™ Low GWP Refrigerant Blends

Solstice™ HFO Blends			
Current Product	*Solstice™ N Series* Reduced GWP Option Non Flammable (ASHRAE A1)	*Solstice™ L Series* Lowest GWP Option Mildly Flammable (ASHRAE A2L)	Examples of Possible Applications
HFC-134a GWP=1300	N-13 - GWP=547		Chillers, Med-temp Refrigeration
HCFC-22 GWP=1760	N-20 - GWP=891	L-20 - GWP=295	Stationary A/C, Refrigeration
R-404A GWP=3943	N-40 - GWP=1273	L-40 - GWP=285	Low-Temp Refrigeration
R-410A GWP=1924		L-41 – GWP=461 GWP=572	Stationary A/C Applications

Note: All GWP values use the latest assessment from the ICCP, "AR5"

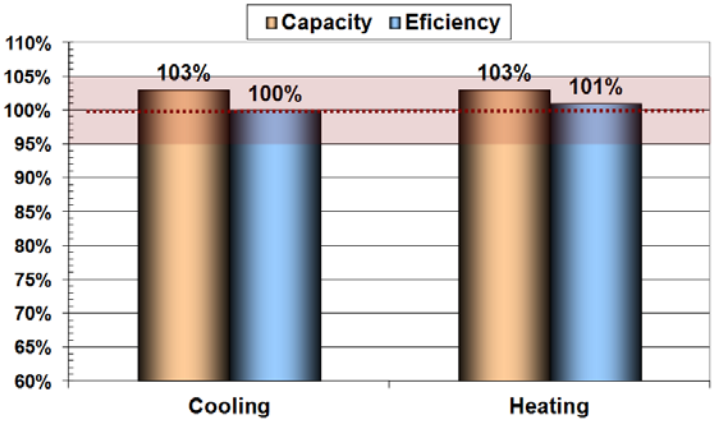
Solstice™ HFO Blends for Medium & High Pressure Applications

Evolution of Replacements in Air Conditioning



R410A and R22 Replacements in AC Systems

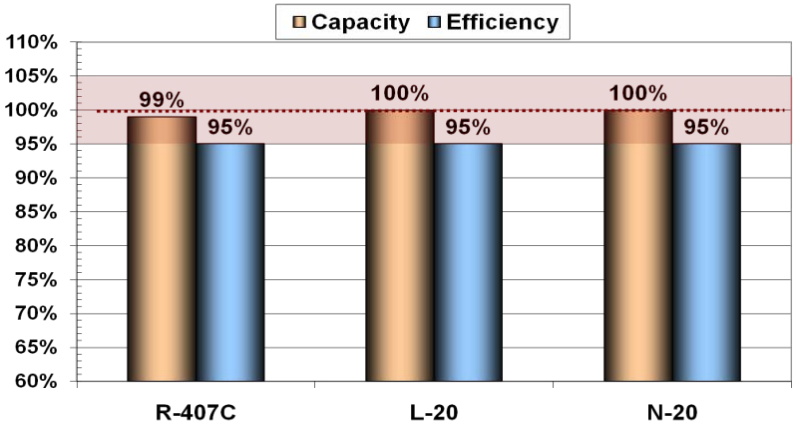
L-41
HFC-410A Replacement



*Used 11% larger displacement compressor

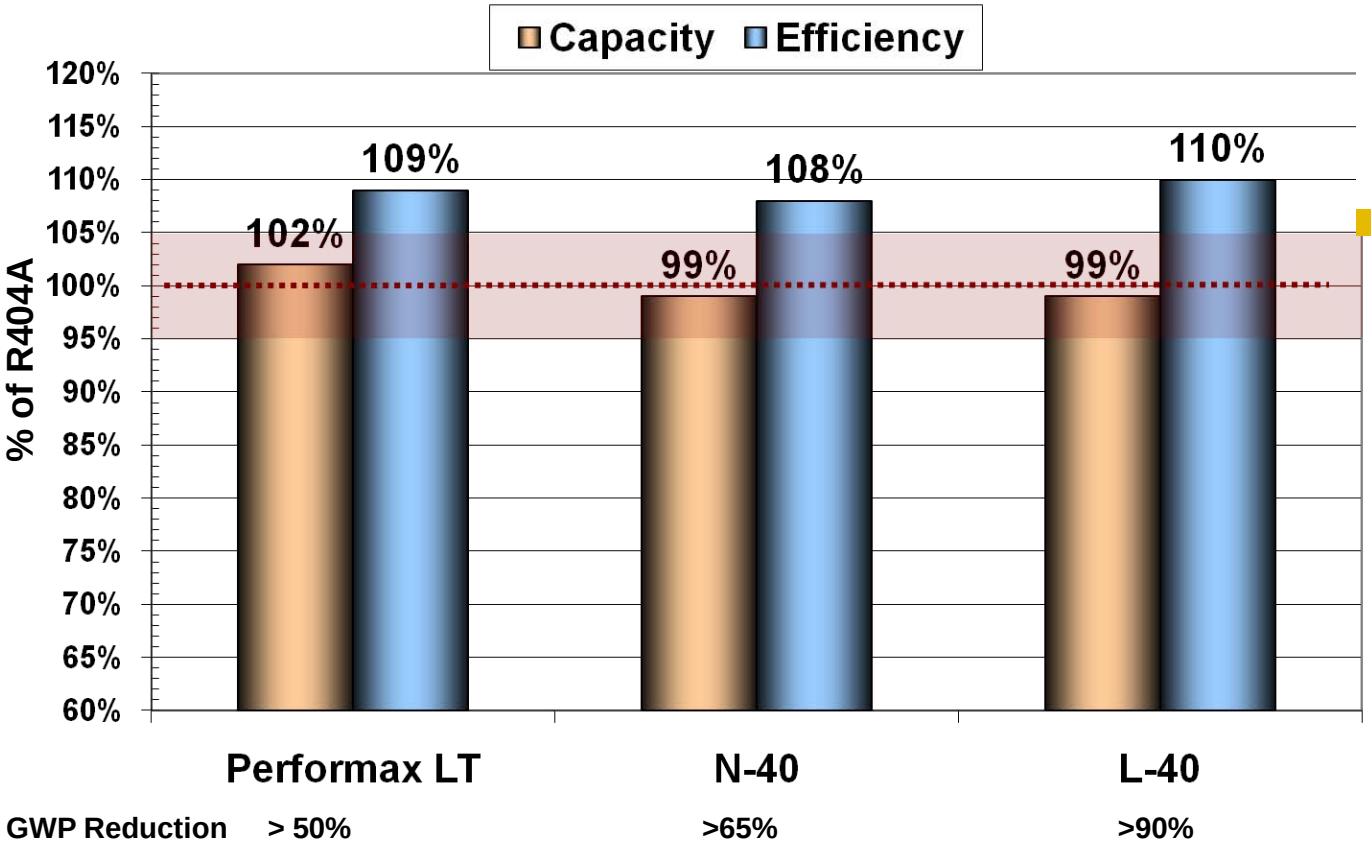
- After recovering capacity, **L-41** offers excellent performance and a significant GWP reduction.
- It enables compact high efficiency systems in many regions.
- No problems with high discharge temperatures.

L-20
HCFC-22 Replacement



- **L-20** replaces R-22 in AC systems without significant design changes.
- With a **GWP of 295**, it reduces significantly environmental impact.
- It performs well at high ambient temperatures.

Refrigeration Applications



Supermarket/Deli Cases (MT)

Supermarket Freezer Cases (LT)

	Performax LT	N-40	L-40
GWP Reduction	> 50%	>65%	>90%

All options offer significantly improved efficiency & GWP reduction compared to R-404A

Honeywell

Solstice™ Low GWP Replacements for Chillers

Solstice™ ze

- Equal (or better) efficiency compared to R-134a
- 99.7% reduction in GWP

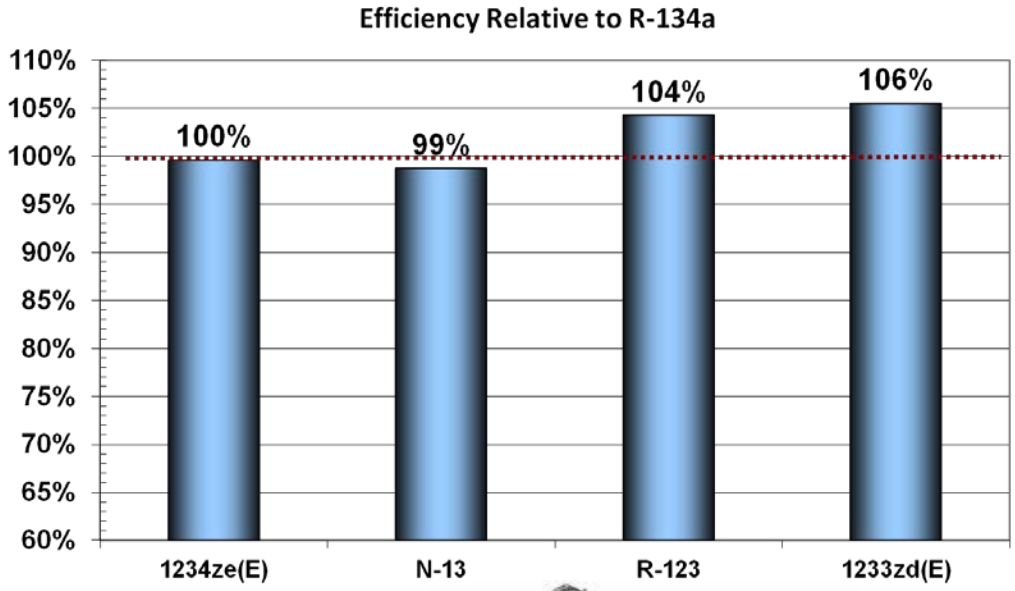
Solstice™N-13

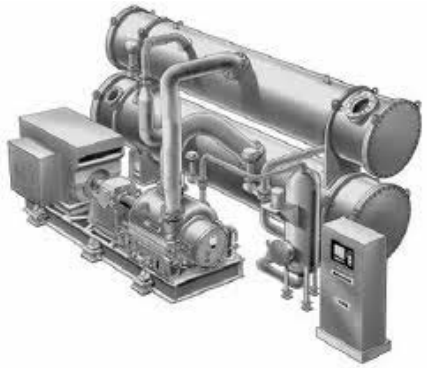
- Comparable efficiency to R-134a and is non flammable. Potential for retrofit.
- ~60% reduction in GWP

Solstice™ zd

- Higher efficiency than R-123 – the current efficiency leader.
- 94% reduction in GWP

Performance of Solstice ze, zd, N-13

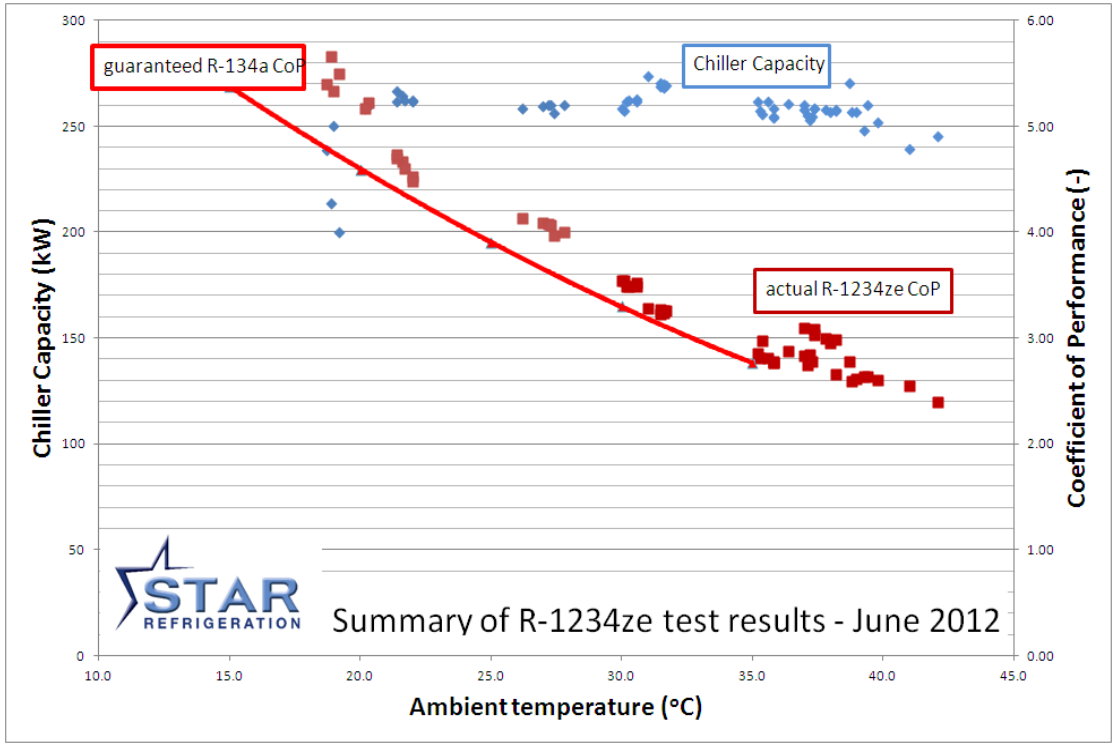




HFOs Offer Large GWP Reductions & High Efficiency

Star Chiller with Solstice™ ze

- Star Chiller Installed at Honeywell's Research Center



Solstice™ ze Shows 7 to 12% Higher COP than R-134a

Commercial Status of Solstice™ Products

Solstice™ yf

- In commercial use by auto industry now
- Sample quantities available today for stationary applications

Solstice™ ze

- Commercially available today
- Announced world scale plant for 2013

Solstice™ zd

- Commercial plant on stream 2nd quarter 2014
- Sampling for chiller, foam and solvent applications

Solstice™ Blends

- Contains Solstice ze and/or yf blended with other products
- Recently announced availability of Solstice ™ L-41
- Currently sampling to OEM's, compressor mfgrs, and AREP

Working with Industry to Commercialize Solstice™

Final Comments

- Reduced and Low GWP replacements have been identified for all major refrigerant applications.
- GWP reductions of 50 to 99% are possible
  - Solstice™1234yf for Mobile Air Conditioning
  - HFO blends for Commercial Refrigeration and Stationary A/C
  - Performax™ LT to replace R-22 and R-404A in new and existing equipment
  - Solstice™ 1234ze(E) and Solstice™ 1233zd(E) for Medium and low pressure chillers, respectively
- Some of the lowest GWP options are mildly Flammable but much safer the HC's