Refrigerants Update

Rajan Rajendran

Emerson Climate Technologies, Inc.

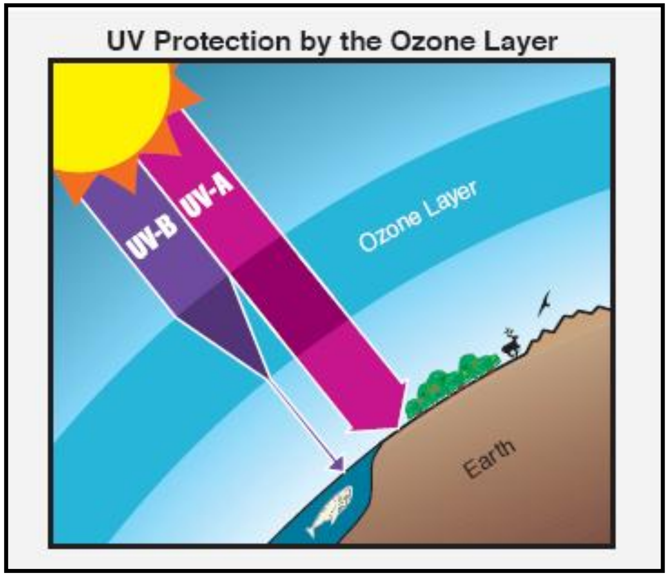
September 19, 2011

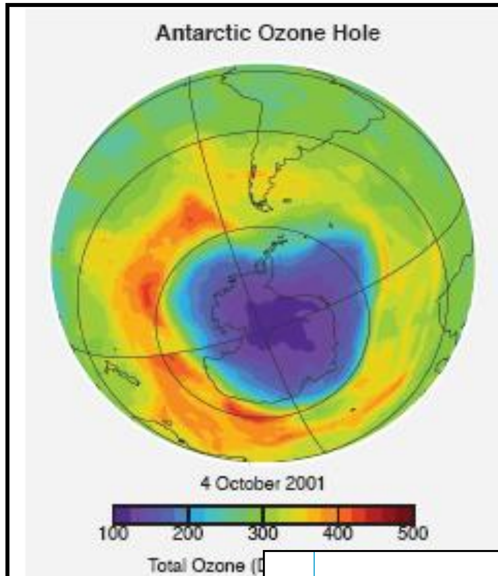
Environmental Drivers Affecting Industry

- Ozone Depletion Effect
  - Protective Ozone Layer Damaged By Chlorine & Bromine Gases
  - Montreal Protocol In September 16, 1987
    - Bans CFCs
    - HCFC R22 Elimination

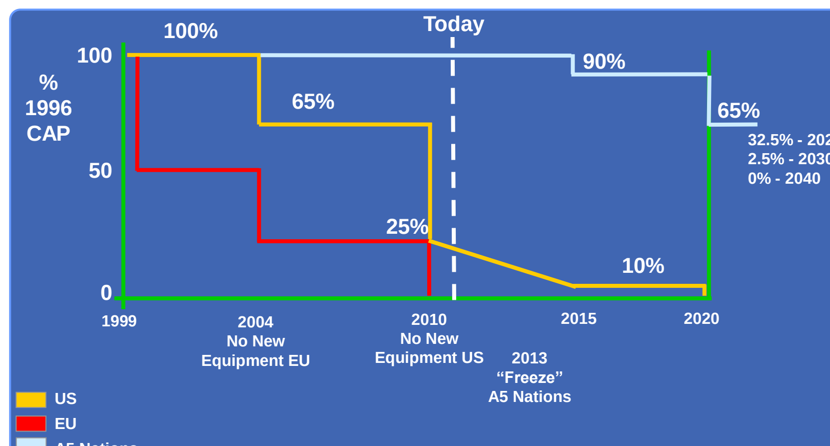
- Climate Change Effect
  - “Greenhouse Gases” Contribute To Global Warming Is Theory
  - Kyoto Protocol (1997) Aims To Curb All Greenhouse Gases
  - Most Refrigerants In Use Today Are Classified As Greenhouse Gases

Ozone Depletion & Montreal Protocol





Montreal Protocol Agreement For Reducing ODP Refrigerants: R-22 Phase-Out Timeline



* **All Reference Material Sourced From:**

UNEP Ozone Layer Q&A

TWENTY QUESTIONS AND ANSWERS ABOUT THE OZONE LAYER

URL: http://www.epa.gov/Ozone/science/unepSciQandA.pdf

AHRI Sponsored Research - Alternative Refrigerant Evaluation Program (AREP)

TABLE 1
R-22 ALTERNATIVE REFRIGERANTS EVALUATION PROGRAM
LIST OF PARTICIPATING COMPANIES

NORTH AMERICAN	
Bristol Compressors	National Research Council of Canada
Carrier Corporation	Rheem Manufacturing Company
Copeland Corporation	SnyderGeneral Corporation
Dunham-Bush, Inc.	Tecumseh Products Company
Hussmann Corporation	Thermo King Corporation
Inter-City Products Corporation	The Trane Company
Lennox Industries, Inc.	Tyler Refrigeration Company
Matsushita Compressor Corporation of America	Wolverine Tube, Inc.
	York International Corporation
EUROPEAN	
Aspera Whirlpool Italia Srl	Officine Mario Dorin
Bitzer Kühlmaschinenbau GmbH	Stal Refrigeration AB
Bock GmbH & Co. Kältemaschinen	Sulzer Brothers, Ltd.
Grasso Products BV	Unidad Hermética, S.A.
Necchi Compressori Srl	Zanussi Elettrmeccanica SpA
JAPANESE	
Daikin Industries, Ltd.	Mitsubishi Electric Corporation
Hitachi, Ltd.	Mitsubishi Heavy Industries, Ltd.
Kobe Steel, Ltd.	Sanden Corporation
Matsushita Electric Industrial Company, Ltd.	Sanyo Electric Company, Ltd.
Matsushita Refrigeration Company	Sharp Corporation
Mayekawa Manufacturing Company, Ltd.	Toshiba Corporation

TABLE 2
ALTERNATIVE REFRIGERANTS FOR TESTING AND EVALUATION IN AREP

Refrigerant or Refrigerant Blend	Percent Composition (by weight)	Baseline Reference
R-134a	100	R-22
R-290 (propane)	100	R-22
R-717 (ammonia)	100	R-22
R-32/125	60/40	R-22
R-32/134a	20/80	R-22
R-32/134a	25/75	R-22
R-32/134a	30/70	R-22
R-32/134a	40/60	R-22
R-32/227ea	35/65	R-22
R-125/143a	45/55	R-22
R-32/125/134a	10/70/20	R-22
R-32/125/134a	24/16/60	R-22
R-32/125/134a	30/10/60	R-22
R-32/125/290/134a	20/55/5/20	R-22
R-125/143a	45/55	R-502
R-32/125/134a	20/40/40	R-502
R-32/125/143a	10/45/45	R-502
R-125/143a/134a	44/52/4	R-502

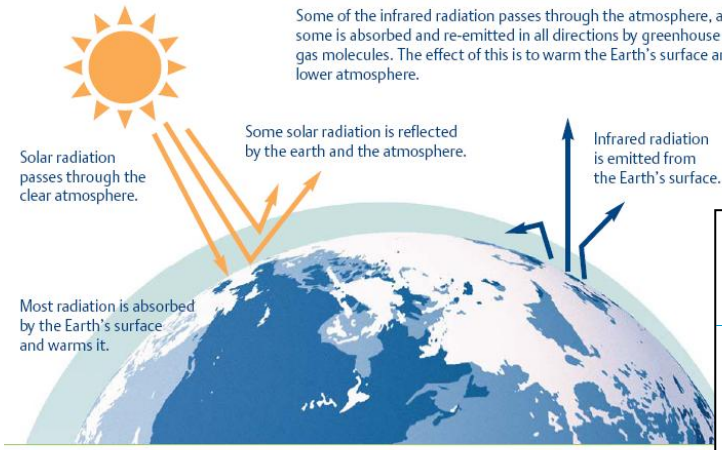
Notes:
- *Refrigerants are not listed in any particular ranking order.*
- *Compositions are nominal, and do not include deviations of charged or circulating compositions from nominal.*

- **AREP Results Led To Selection Of R134a, R404A, R407C & R410A In Various Applications**
- **Higher Pressure Refrigerants Like R410A Performed Better In Actual Systems; Adoption In Efficiency Regulated AC Applications Grew In US/Europe**

Alternative Refrigerants Evaluation Program (AREP)
Compressor Calorimeter And System Drop In Tests With R-22 Alternatives
By David S Godwin, Air-Conditioning & Refrigeration Institute (now AHRI)
18 March 1994

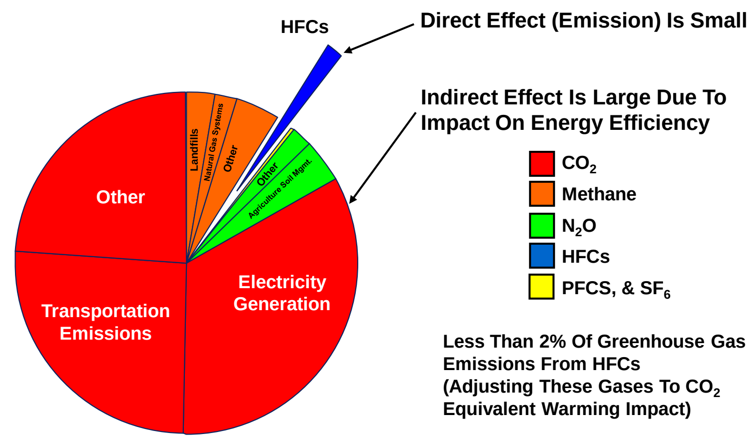
Global Warming & Impact Of HFCs

Greenhouse Effect & Global Warming Concerns



What Is The Effect Of HFCs On Global Warming?

CO_2 Equivalent

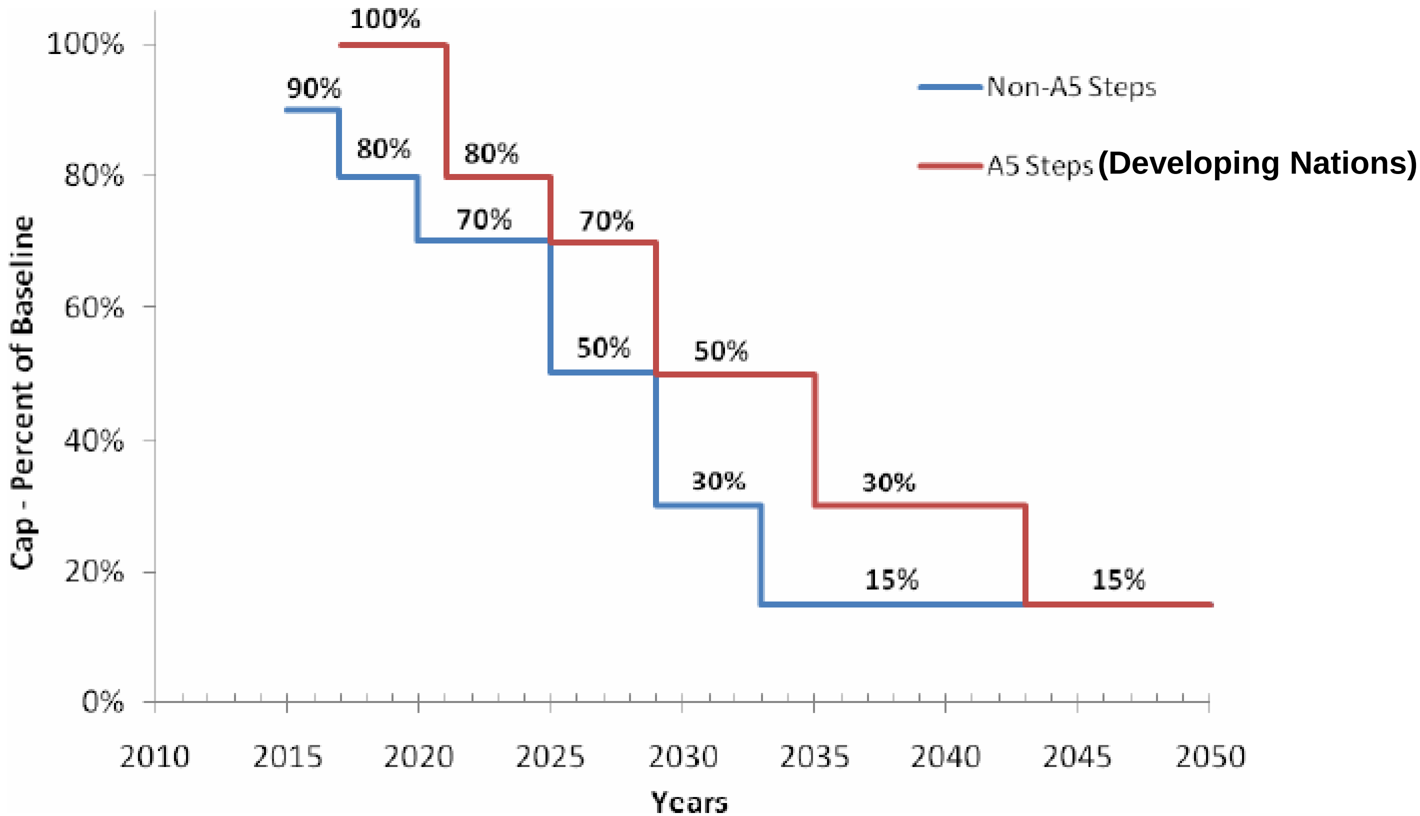


Source: Environmental Protection Agency, U.S. Greenhouse Gas Emissions & Sinks: 1990-2002

10% Of Global Carbon Emissions (And Energy Use) Due To Refrigeration, A/C And Heat Pumps

High GWP HFCs Coming Under Pressure To Be "Phased-Down" Or "Eliminated"

North American Proposal For Consumption Phase-Down Of HFCs' GWP



Efforts To Make NAP Part Of Montreal Protocol Continue – Over 91 Countries Signed On So Far

Global Warming Potential (GWP) & Values For Some Refrigerants (IPCC-AR4 Report)

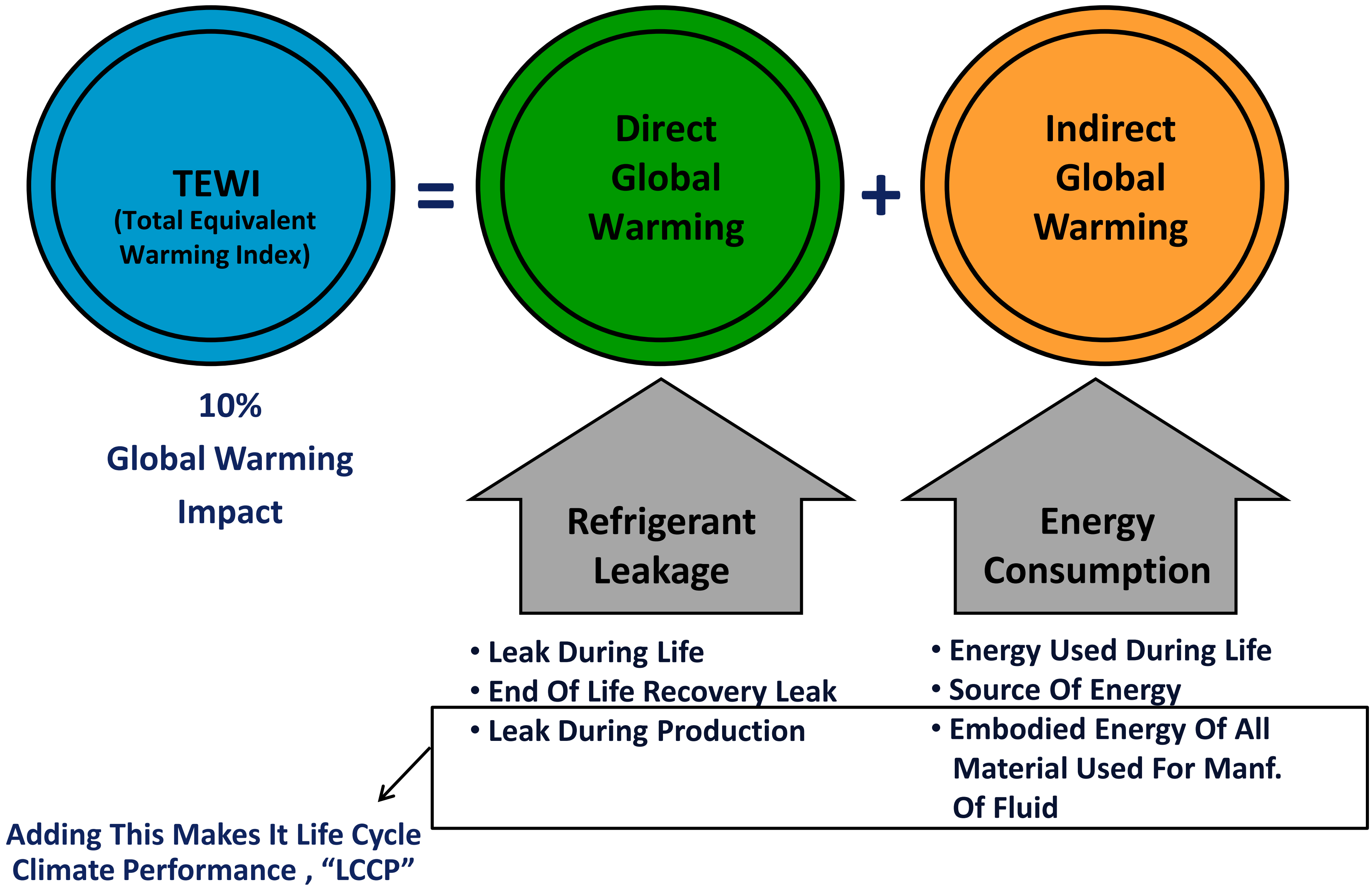
- **Measure Of How Much Given Mass Of Greenhouse Gas Is Estimated To Contribute To Global Warming**
- **Relative Scale, Compares Gas To Same Mass Of Carbon Dioxide (Whose GWP By Convention Is 1)**
- **GWP Is Calculated Over A Specific Time Interval, Typically 100 Years**
- **Intergovernmental Panel On Climate Change (IPCC), A UN Body Issues Reports That, Among Other Things, Updates The GWP Values For Various Global Warming Gases**
  - **Latest Report Is Assessment Report 4 (AR4), 2007**

Selected Refrigerant GWPs			
HFCs	SAR 1995	**TAR 2000 Used by F-Gas**	AR4 2007
HFC-32	650	550	675
HFC-134a	1300	1300	1430
R-407A	1770	1990	2107
R-407C	1526	1653	1774
R-404A	3260	3784	3922
R-410A	1725	1975	2088
R-507	3300	3850	3985
R-422D	2232	2623	2729
R-427A	1828	2013	2138
For comparison not covered by F-Gas or Kyoto			
HCFC-22	1500	1700	1810

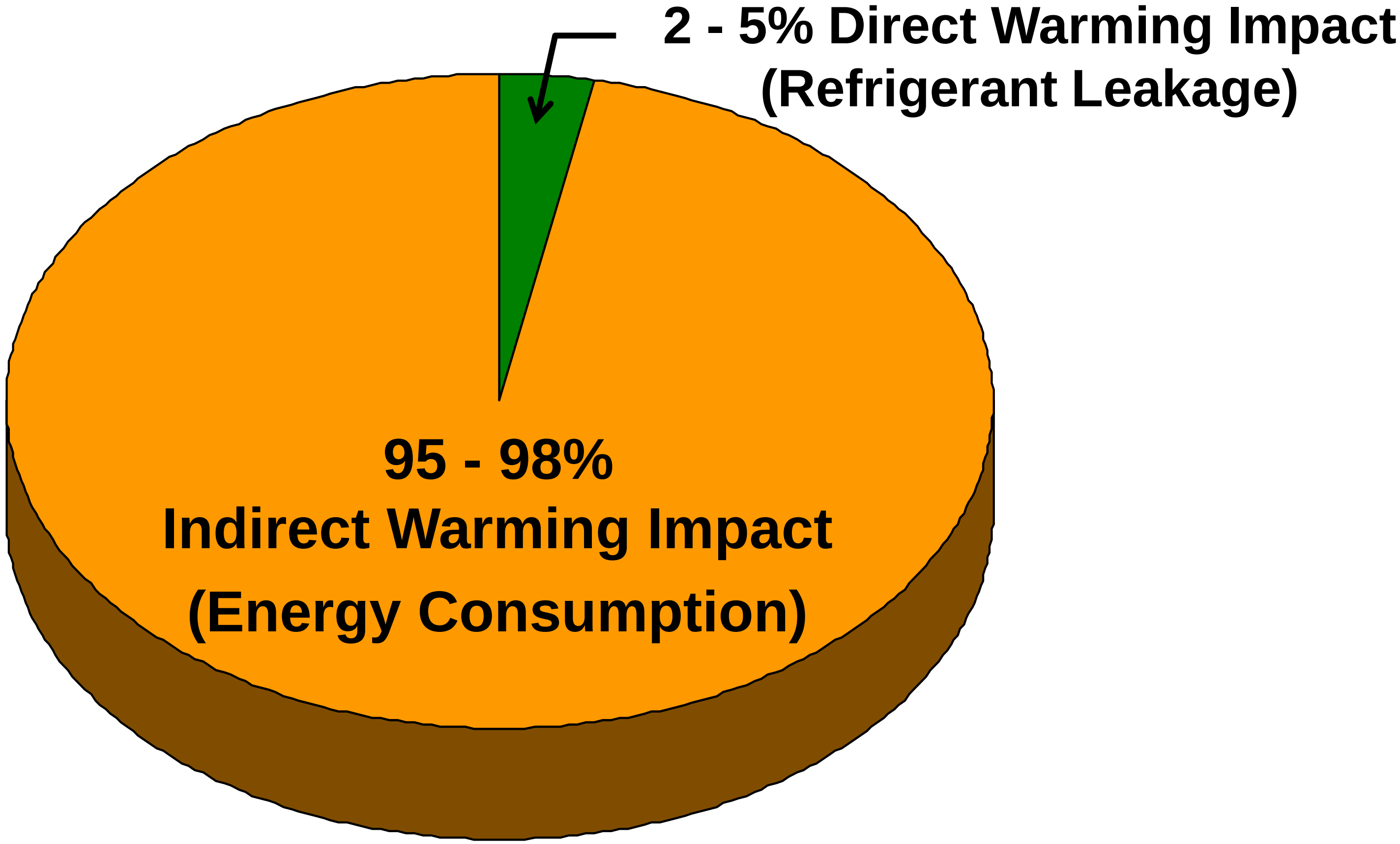
GWP – Is Important But Not The Only Measure Of Environmental Impact!

Reference: http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter2.pdf

Refrigerants Should Be Measured On Life Cycle Performance – TEWI Or LCCP



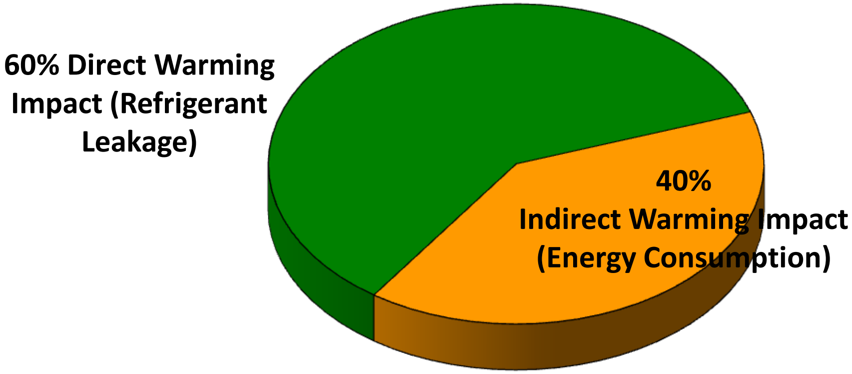
Life Cycle Performance: Typical Low Charge Systems
(AC, Heat Pump, Reach-In, Walk-In, Transport Applications)



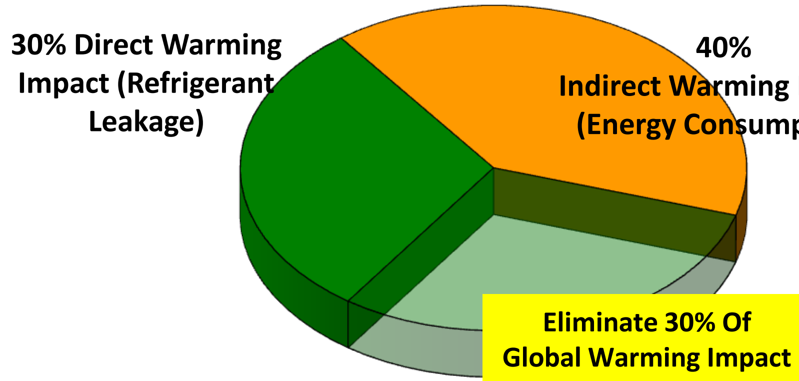
For Hermetic Systems, Global Warming Is An Efficiency Issue*
(Therefore, Future Refrigerants Must Be Equal Or Higher Efficiency)

*** Simple Analysis To Show Relative Impact Only; Not Based On Field Data**

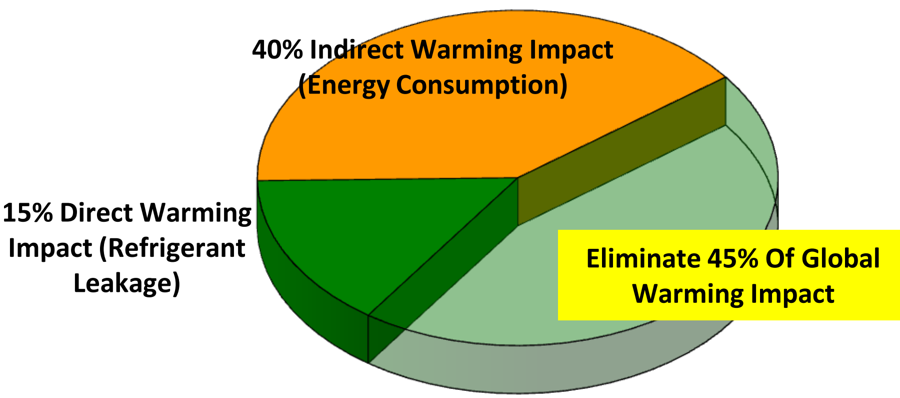
Life Cycle Performance: Typical Large Refrigeration Systems



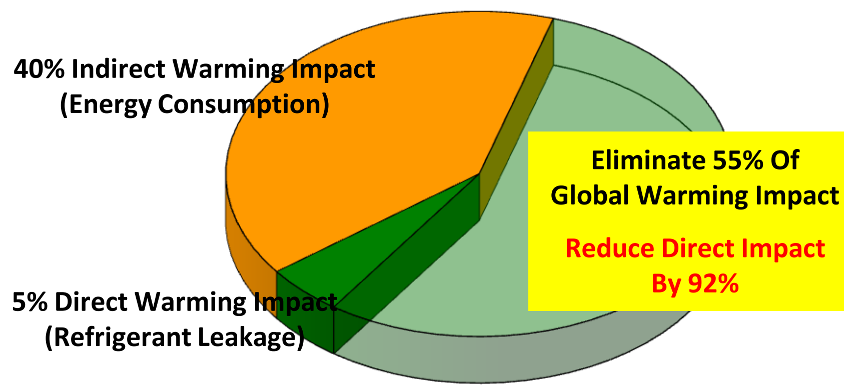
Example Analysis For A 3000 lb, R404A System With 20% Annual Leak, Medium & Low Temperature*



1. Reduce Refrigerant Leak To 10% Per Year*



2. Reduce Refrigerant Leak To 10% Per Year & Reduce Refrigerant GWP By 50%*



3. Reduce Refrigerant Leak To 10% Per Year, Refrigerant GWP By 50%, And Reduce Charge By 65%*

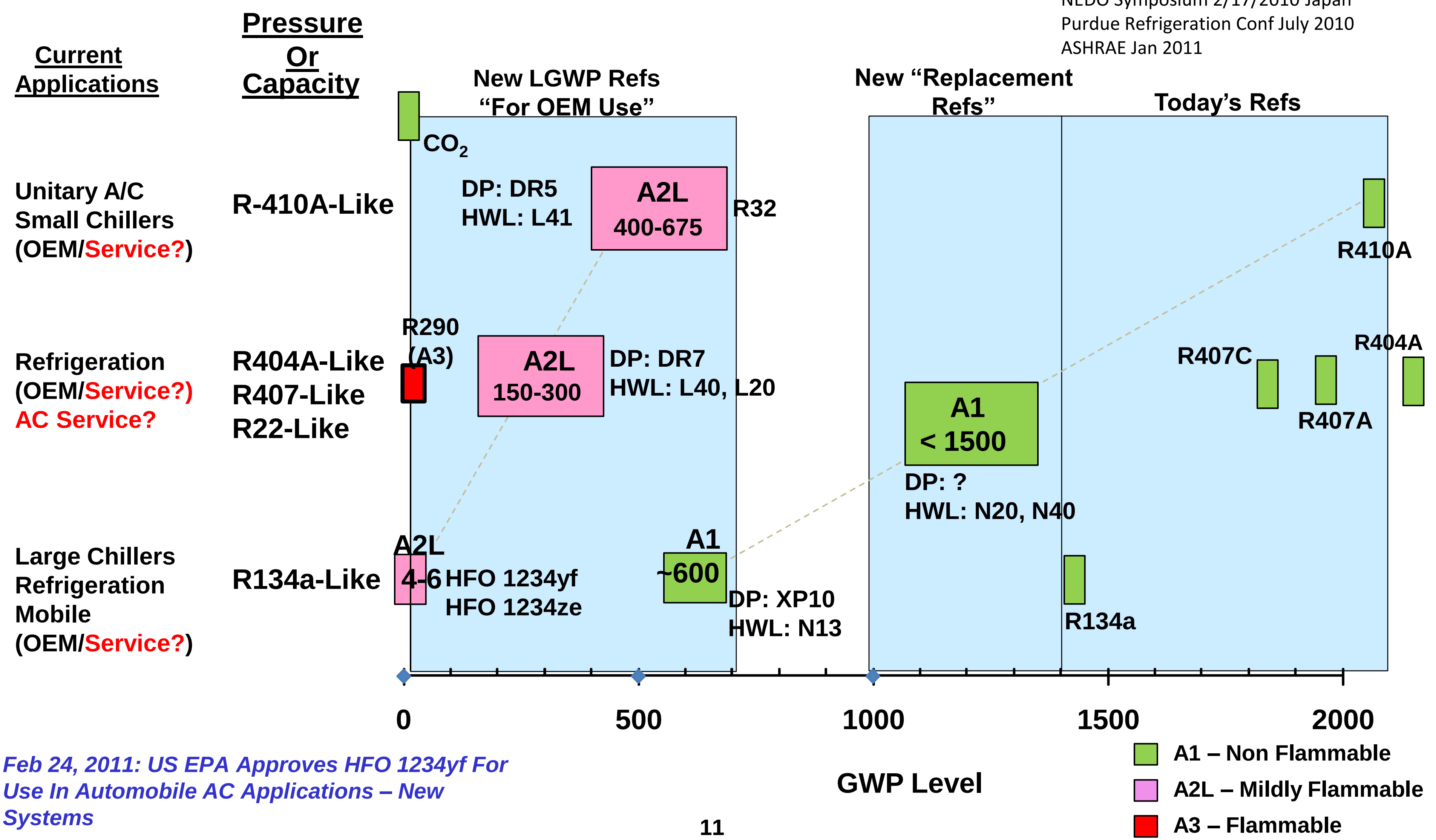
For Large Systems, Global Warming Becomes An Efficiency Issue If Charge/Leaks Are Reduced
(Therefore, Future Refrigerants Must Be Equal Or Higher Efficiency)

* Simple Analysis To Show Relative Impact Only; Not Based On Field Data

Whatever The Regulation, Low GWP Refrigerants Will Be Needed In Future…

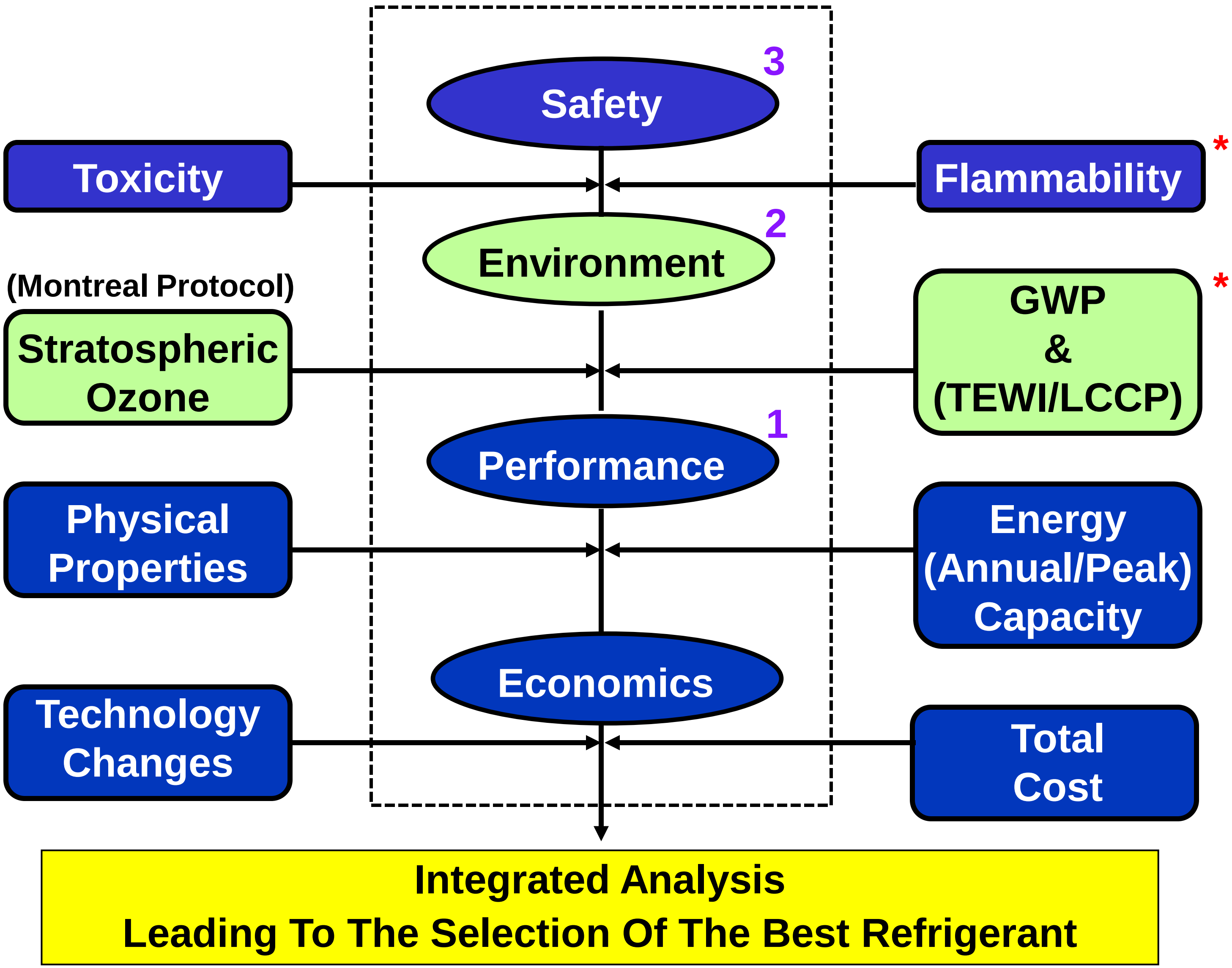
Emerging Low GWP Candidates

Source : Papers by DuPont, Honeywell, Daikin, Panasonic, Mitsubishi Electric
NEDO Symposium 2/17/2010 Japan
Purdue Refrigeration Conf July 2010
ASHRAE Jan 2011



Feb 24, 2011: US EPA Approves HFO 1234yf For Use In Automobile AC Applications – New Systems

Holistic Approach To Refrigerant Selection



* Key Hurdles

Search For Lower GWP Refrigerants – Performance Evaluation Steps

- **Five Basic Steps In Performance Evaluation:**
  1. **Compare Saturation Pressure – Temperature (P-T) Data**
  2. **Perform Simple Thermodynamic Analysis**
  3. **Perform Analysis (Performance/TEWI) Including System Effects**
     1. **Pressure Drop**
     2. **Heat Transfer**
     3. **Discharge Temperature Effects (Additional Cooling)**
     4. **High Condensing, Low Condensing Temperatures**
     5. **Annual & Peak Power Consumption**
  4. **Perform "Drop-In" System Tests/TEWI Analysis**
  5. **Perform "Soft-Optimized" System Tests/TEWI Analysis**
  6. **Continue To Optimize & Improve System Performance**

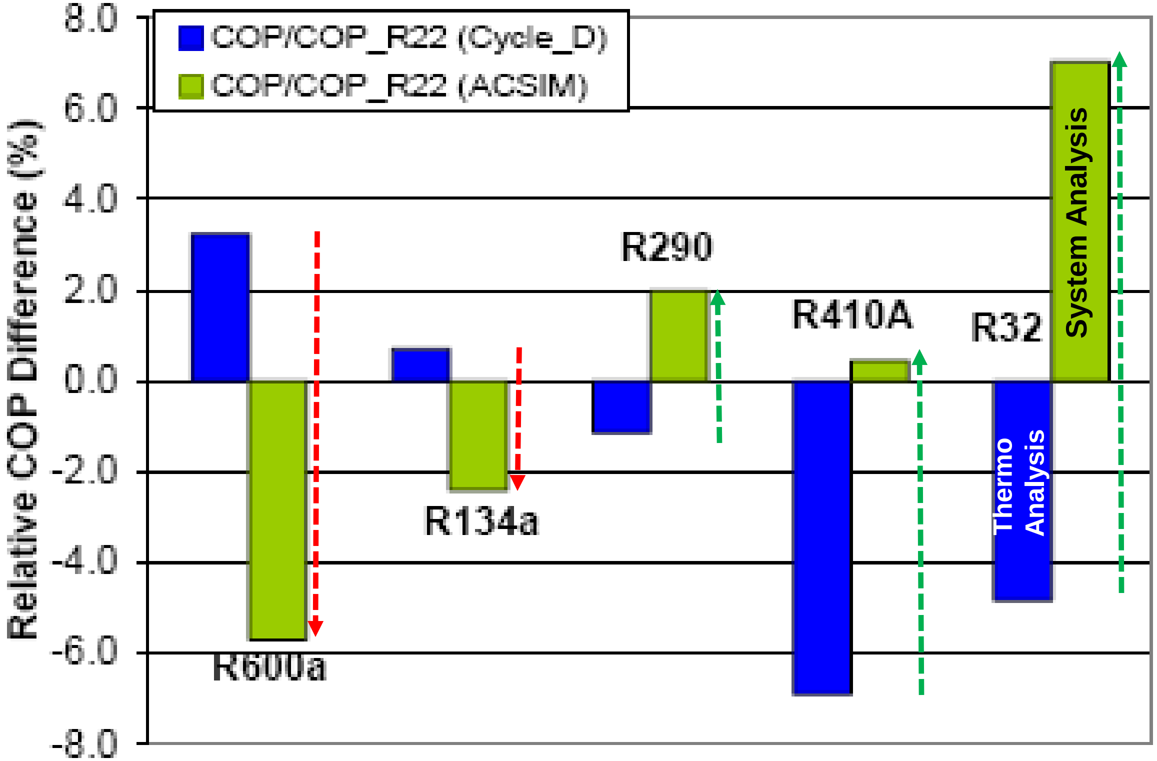
Decision After Step 2 Without Step 3 Could Be Erroneous…!

Difference Between Simple Thermodynamic Analysis & System Analysis

7th IIR Gustav Lorentzen Conference on Natural Working Fluids, Trondheim, Norway, May 28-31, 2006

COMPARABLE PERFORMANCE EVALUATION OF HC AND HFC REFRIGERANTS IN AN OPTIMIZED SYSTEM

PIOTR A. DOMANSKI[(a)], DAVID YASHAR[(b)]



Baseline R22, AC System

Pressure Drop & Heat Transfer Properties Affect Refrigerant Side Performance In System

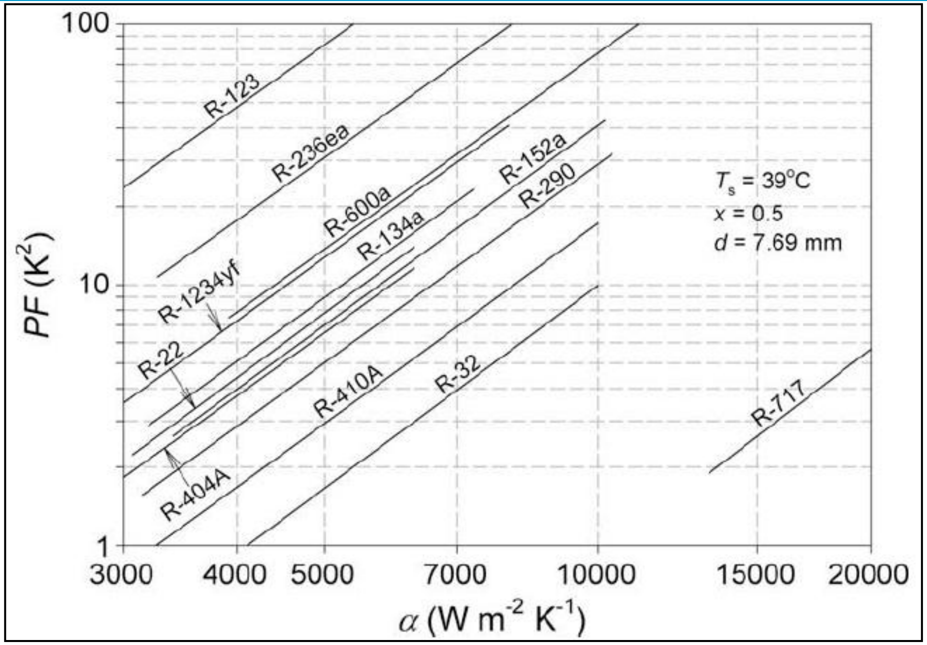
System Effects Can Have Significant Effect On Performance Of Refrigerant

Esample: System Effects In Refrigerants Analysis

In-tube condensation performance of refrigerants considering penalization terms (exergy losses) for heat transfer and pressure drop

Alberto Cavallini [a], J. Steven Brown [b,*], Davide Del Col [a], Claudio Zilio [a]

International Journal of Heat and Mass Transfer 53 (2010) 2885–2896



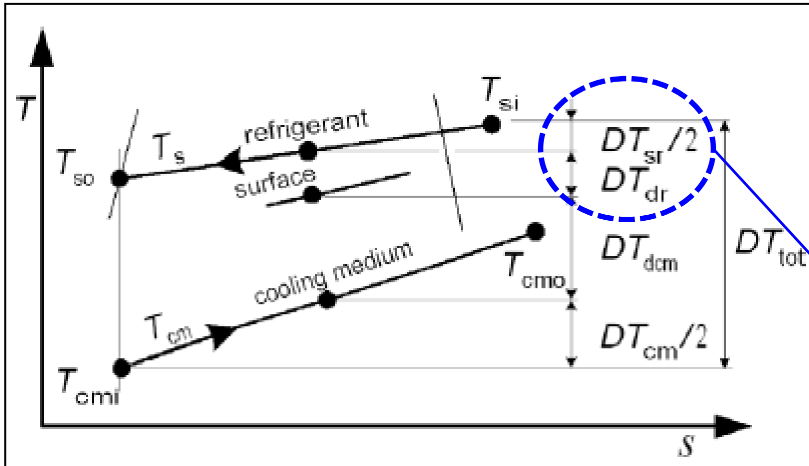


Fig. 4. Idealized temperature profiles in a counter-flow condenser.

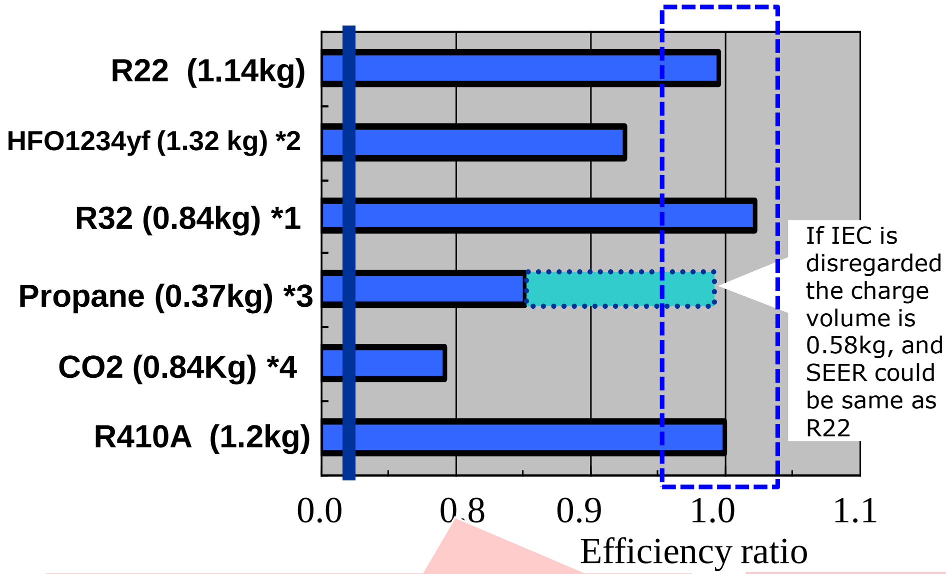
- **Cavallini et al Propose A "Penalty Factor" (PF) For Analytical Consideration Of System Effects**
- **PF = Pressure Drop Impact + Heat Transfer Impact**
- **Lower PF Is Better For System Performance**
- **PF Leads To "Two Temperature Penalty" (TTP) Term For Refrigerant Side**
- **TTP = Pr Drop Temperature Effect + Heat Transfer Temperature Effect**

Condenser Example, TTP For:
R32 = 1.37K; R410A = 1.83K; R134a = 3.19K

Annual & Peak Power Comparison Also Important (AC System Example)

•SEER Comparison (cooling mode)

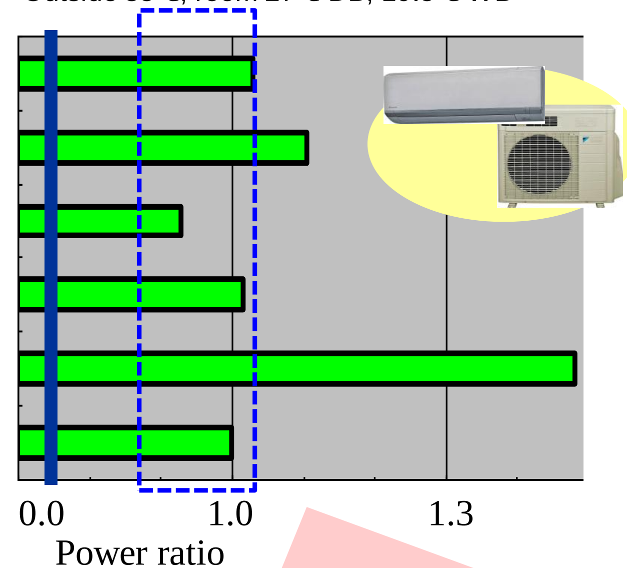
HPs （Reversible） - 3.5kW-Room AC in Europe



•Peak power comparison

(R410 ratio) under cooling condition

Outside 35℃, room 27℃ DB, 19.5℃ WB



Consideration:
In terms of SEER, CO_2 is the worst, and the rest of candidates are equivalent to R410A.

Consideration:
A big difference exists in the peak power under cooling condition. HFO and CO_2 will cause peak power supply problems in large cities.

(Precondition for Calculation) Note: HX= Heat Exchanger

*1 Taking low pressure loss into consideration, narrower heat exchanger was used to reduce charge volume.

*2 To improve efficiency, HX size was increased : Indoor HX x 1,1 + Path x 2, Outdoor HX x 1.2, and connecting pipe increased from 3/8=> 5/8

*3 To meet IEC requirements, charge volume was reduced: Indoor HX x 0.8, Outdoor HX x 0.5, narrower piping was used.

*4 To Improve efficiency: Outdoor unit HX was increased x 1.1

R32 + HFOs Blends Perform Well Compared To Today's HFCs - Refrigeration

HFO Blends for Stationary Applications

Honeywell

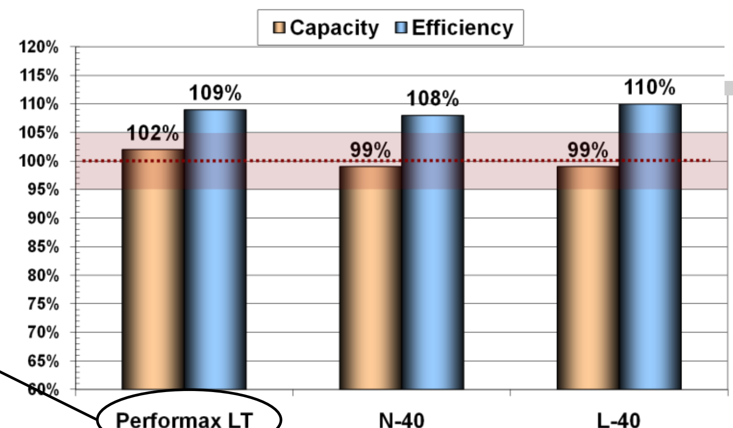



	N Series (A1)	L Series (A2L)
Current Product	Reduced GWP Option (Non-flammable)	Lowest GWP Option (Mildly Flammable)
R-404A **GWP=3922**	N-40 **GWP~1300 (retrofit)** N-20 **GWP~1000 (new equip)**	L-40 **GWP~200-300**
HCFC-22 **GWP=1810**	N-20 **GWP ~1000**	L-20+ **GWP <350**
HFC-134a **GWP=1430**	N-13 **GWP ~600**	L-YF **GWP = 4** L-ZE **GWP = 6**
R-410A **GWP=2088**		L-41 **GWP <500**

Refrigeration

R-22 Replacements in Refrigeration: Options with Lower GWP than R-404A

Honeywell



> 50% GWP Reduction From R-404A | >65% | >90%

Supermarket/Deli Cases (MT)

Supermarket Freezer Cases (LT)

R407-Series Of HFCs Would Be Similar (RR Note)

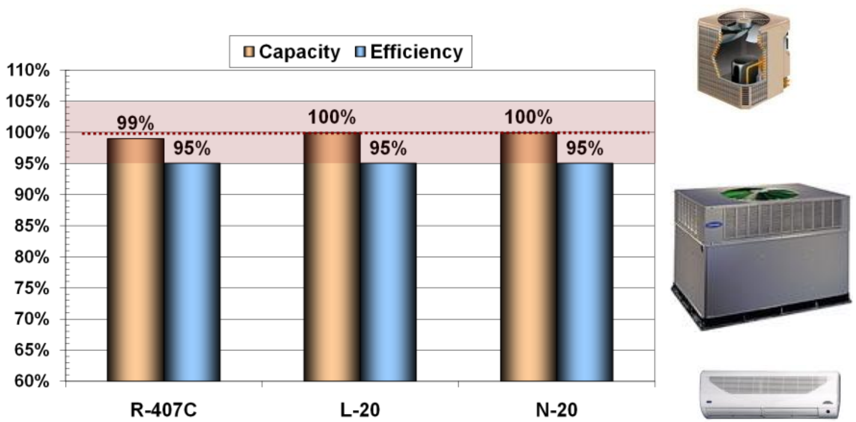
All options offer significantly improved efficiency & GWP reduction compared to R-404A

"Low Global Warming Replacements for HCFCs in Stationary Air Conditioning / Refrigeration Equipment." Mark Spatz, Honeywell Presentation, Montreal, Canada. August 3, 2011

R32 + HFOs Blends Perform Well Compared To Today's HFCs – Air Conditioning

Stationary Air Conditioning: L-20 & N-20 as Replacements in Equipment Designed for R-22

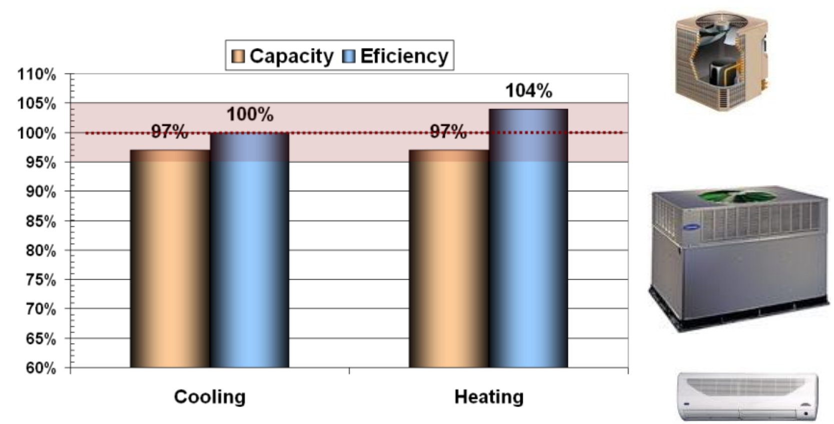
Honeywell



L-20 offers a significant GWP reduction with respect to R-22 (over 80%
Non-flammable N-20 offers close to 50% reduction

Stationary Air Conditioning: L-41 as Replacement for R-410A

Honeywell



Energy Efficiency similar to R410A

Additional Improvements are possible with minor design changes

L-41 offers a significant GWP reduction with respect to R-410A (over 75%)

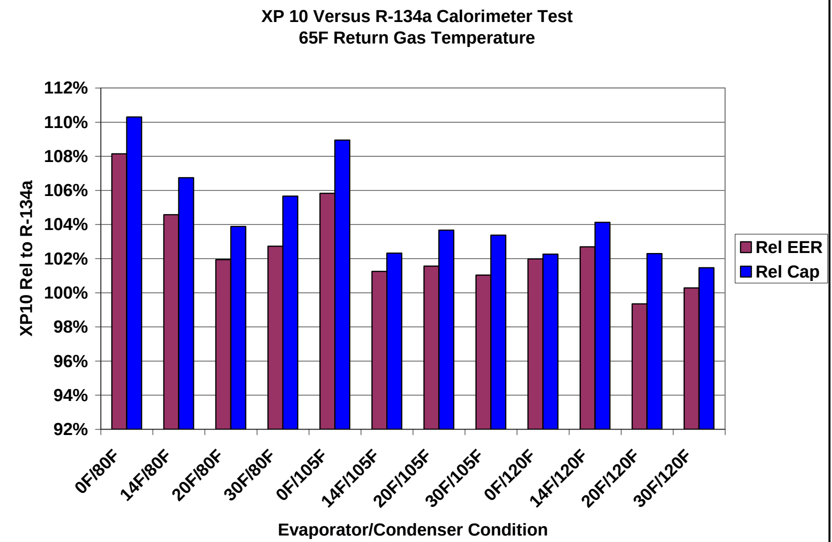
"Low Global Warming Replacements for HCFCs in Stationary Air Conditioning / Refrigeration Equipment." Mark Spatz, Honeywell Presentation, Montreal, Canada. August 3, 2011

DuPont 's XP10 Compared To R134a

	R-134a	XP10
Chemical Formula	CF_3CH_2F	Azeotrope
100 yr GWP (AR4)	1430	near 600
Toxicity/Flammability	A1	A1 expected
Boiling Point °C (°F)	-26 (-15)	-29 (-20)
Critical Point °C (°F)	101 (214)	98 (208)
Temperature Glide °C (F)	0	Negligible (Azeotrope)

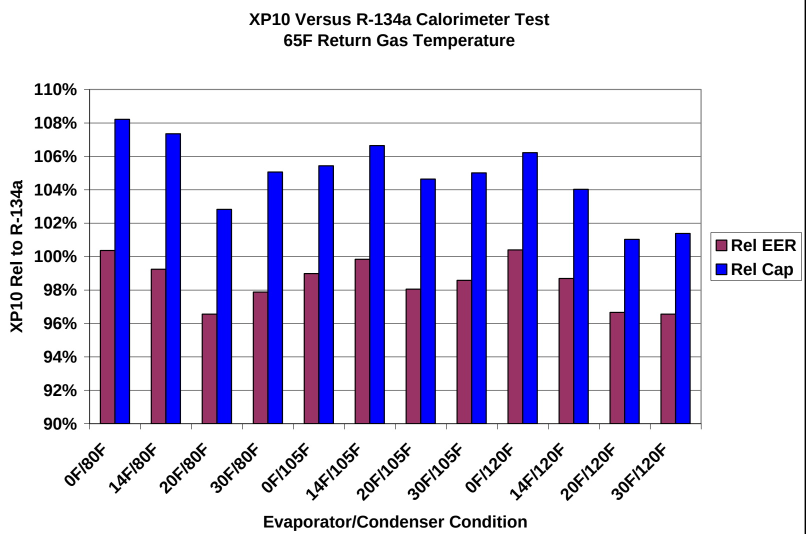
Calorimeter Testing in a Recip Compressor

- EER 2% higher, Capacity 5% higher on average



Calorimeter Testing in a Scroll Compressor

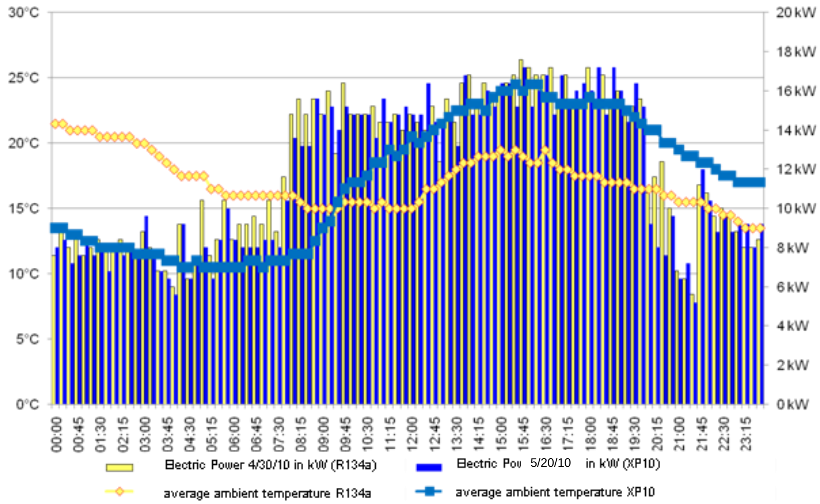
- EER 1% lower, Capacity 5% higher on average



Experimental Study Of R134a Alternative In A Supermarket Refrigeration System
by Barbara Minor, Dr. Frank Rinne, Dr. Katan Salem.
Ashrae Annual Meeting, Montreal, Canada, June 26-29, 2011

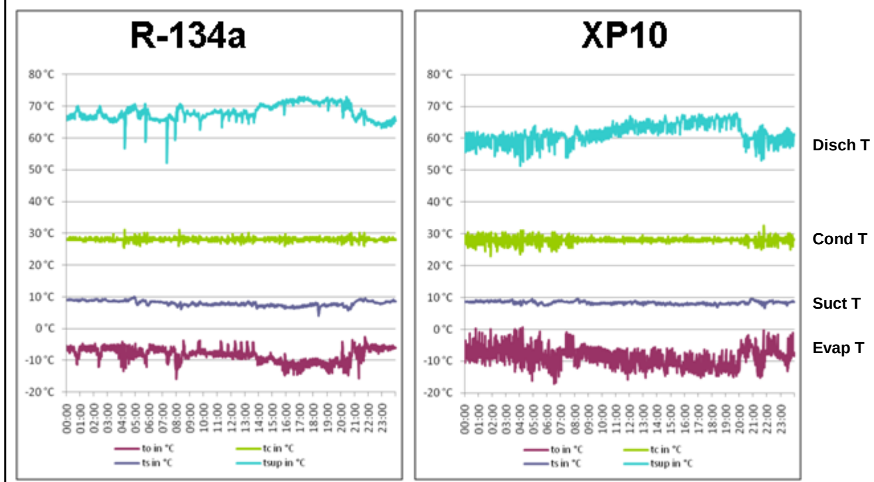
DuPont's XP10 Compared To R134a

Energy Consumption Comparison

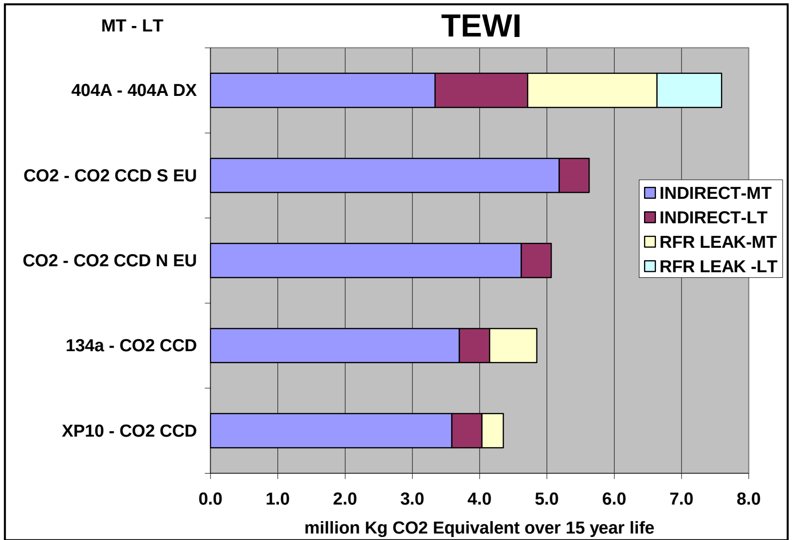


XP10 energy consumption is 3.3% lower than R-134a

System Operating Temperatures



Operating temperatures are similar

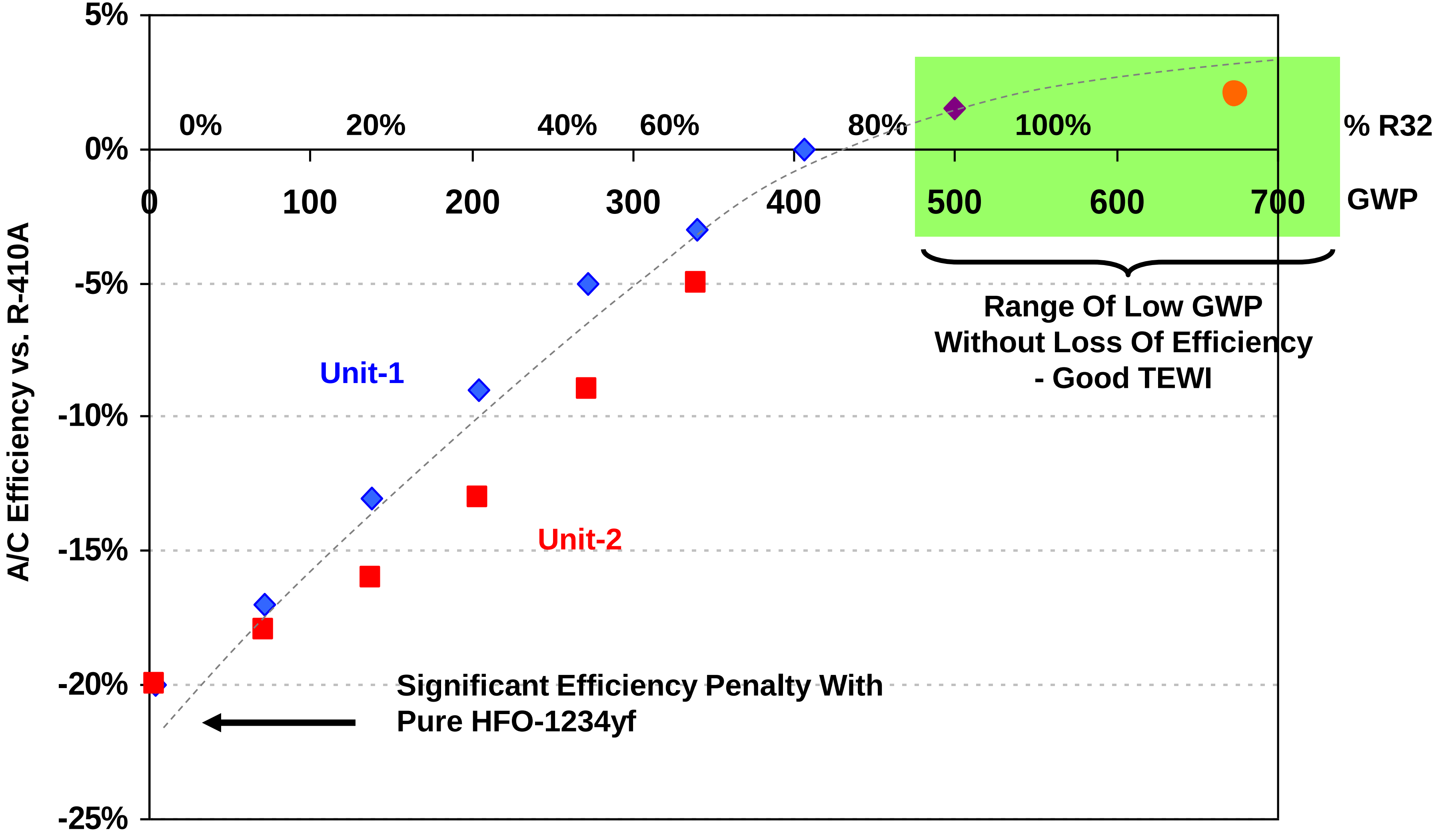


Data Becoming Available From Chemical Manufacturers On Lower GWP Options

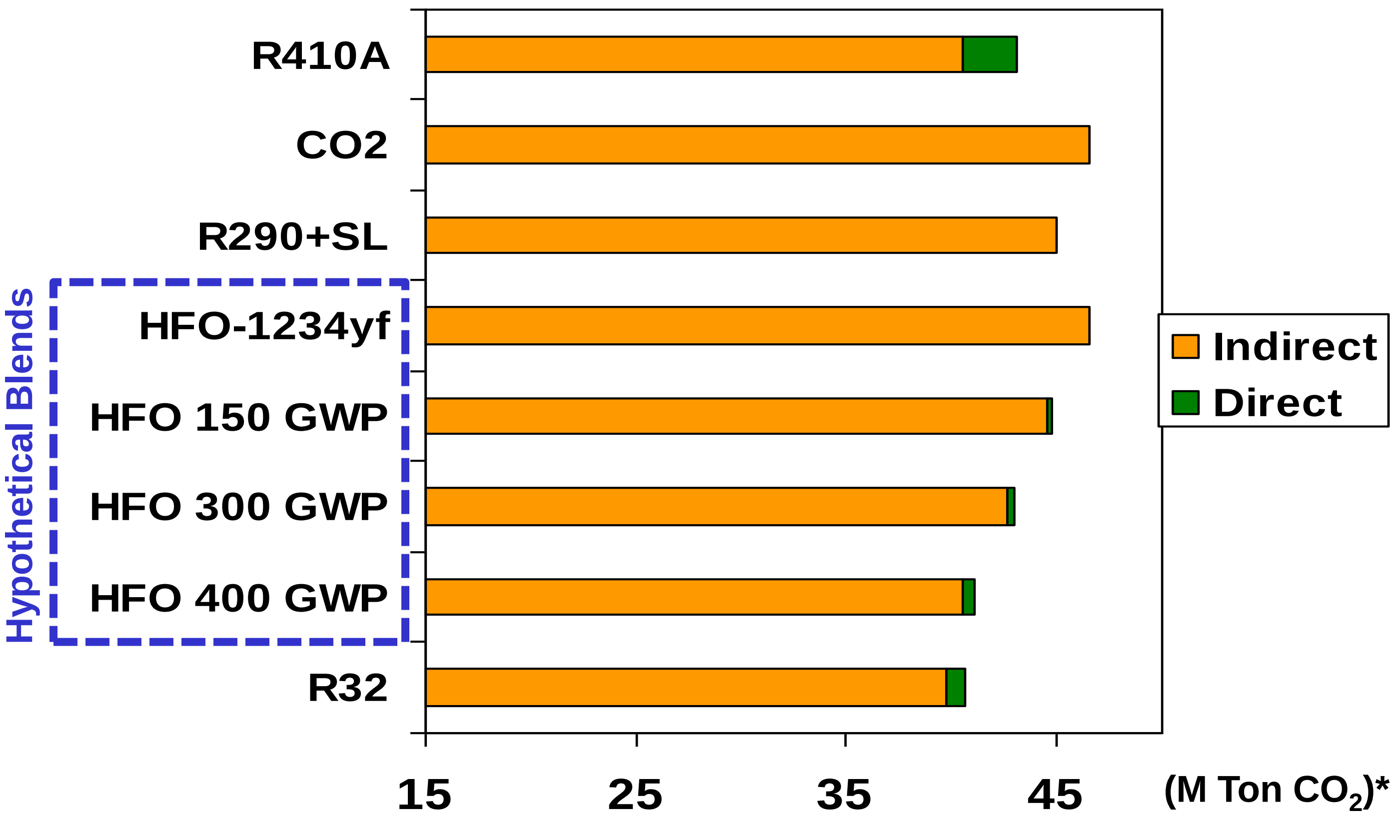
Experimental Study Of R134a Alternative In A Supermarket Refrigeration System by Barbara Minor, Dr. Frank Rinne, Dr. Katan Salem. Ashrae Annual Meeting, Montreal, Canada, June 26-29, 2011

Public R-32/1234yf Blend AC System Data – Trade Off Between GWP & Efficiency

Source : Panasonic, Mitsubishi , Daikin, DuPont, Honeywell Papers from Univ. Tokyo, NEDO Symposium 2/17/2010 Japan & Purdue Refrigeration Conf July 2010



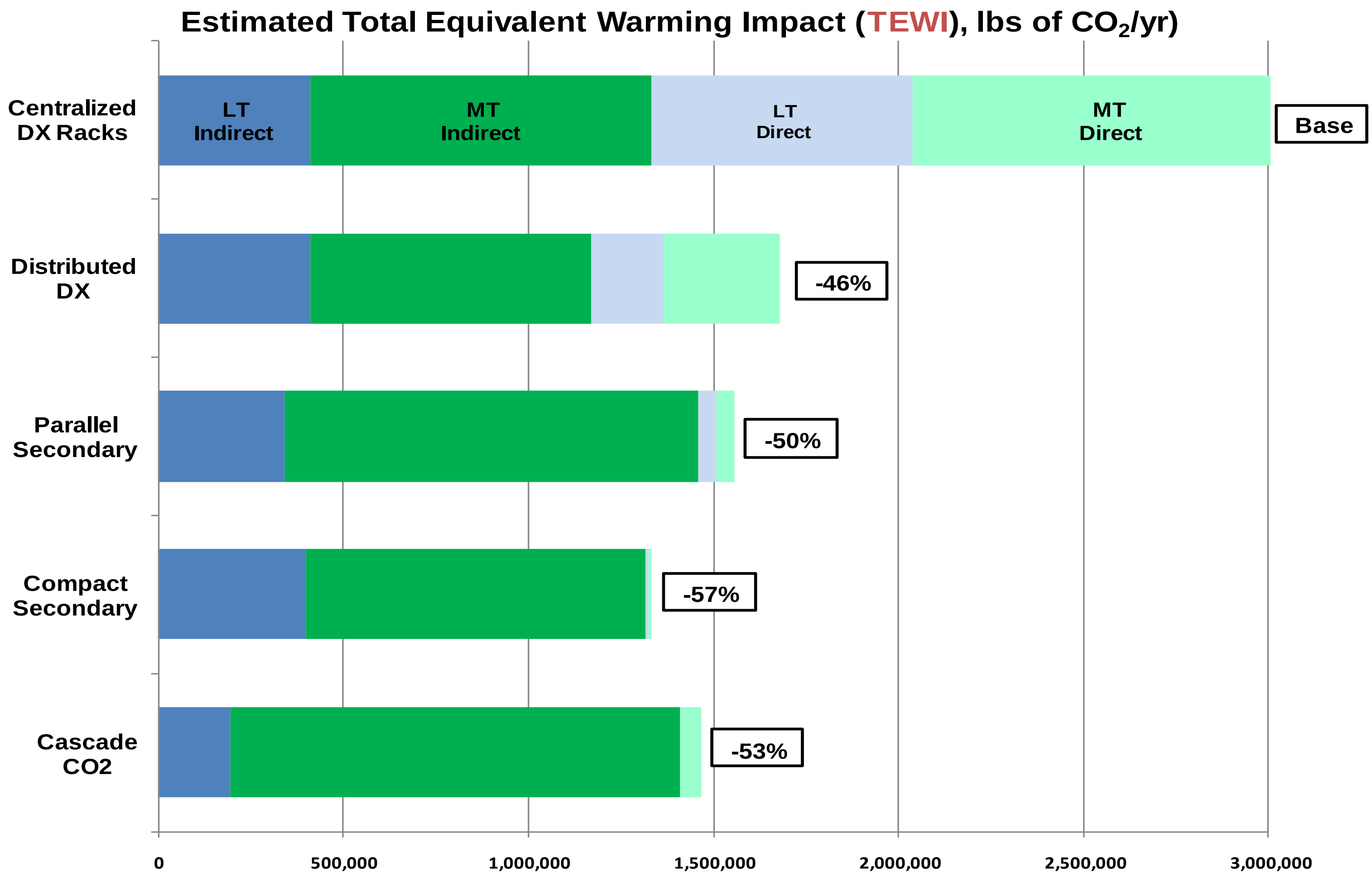
Lower GWP Options From A Life Cycle Performance Point Of View



Energy Consumption Becomes The Largest Driver Of Emissions – Lowest GWP Does Not Equal Best Life Cycle Performance

* 3-ton A/C, 2% Leak, 15-yr Life, 0.65 kg CO2/kwh

Supermarket Example - Architecture Can Reduce Equivalent CO_2 Emissions By 46 – 57%



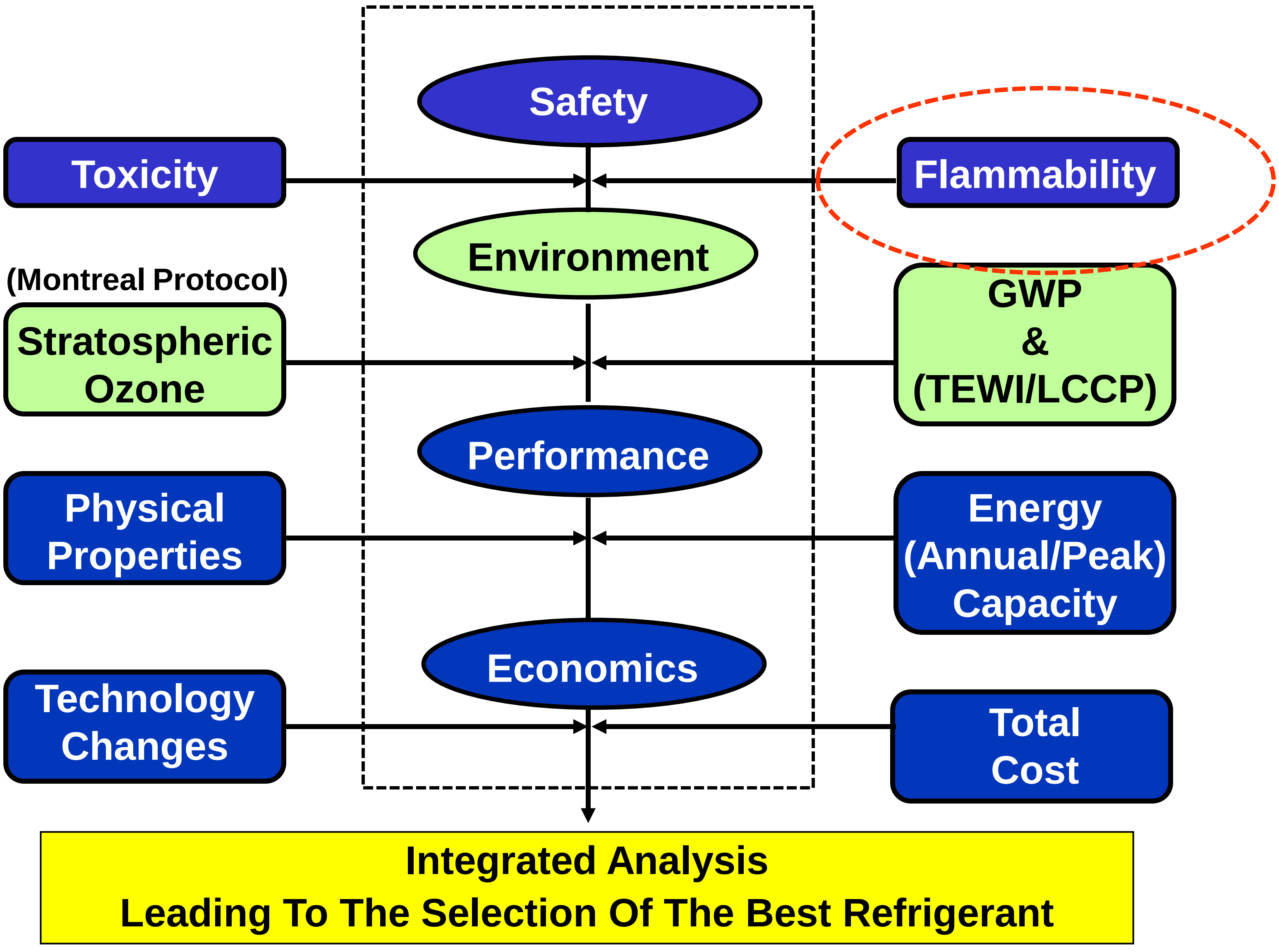
•Comparison Contains Multiple Assumptions & Should Be Used For General Comparisons. Emerson Recommends Completing Similar Analysis On Specific Store Cases Before Making Decisions As Results May Change Based On Store Specifics.
•Fixed Load; US Avg 0.65 kg CO2/kWh; Parameters Held Constant Expect For Architecture.

AHRI Study Announced For Low GWP Refrigerants

- Low GWP AREP Objectives
  - Identify Potential Replacements For Today's High GWP HFCs
  - Test & Present Performance In A Consistent & Standard Manner
  - A/C, Heat Pumps, Dehumidifiers, Chillers, Water Heaters, Ice Makers, Refrigeration
- Testing Approach For Evaluation
  - Compressor Calorimeter
  - System Drop-In
  - Soft-Optimized System
  - Heat Transfer
- Global In Scope; Started July 2011, Complete December 2012 – Over 36 Candidates Submitted For Study

Reports Will Be Released For Public Use By AHRI

Holistic Approach To Refrigerant Selection



Refrigerant Safety Groups

Reference: UL White Paper "Revisiting Flammable Refrigerants", 2011

Refrigerant Safety Groups (ASHRAE 34 and ISO 817)		
	Lower Toxicity	Higher Toxicity#
No Flame Propagation	A1	B1 (includes R123)
2L	A2L (includes HFO 1234 YF)	B2L (includes ammonia)
Lower Flammability	A2	B2
Higher Flammability	A3 (includes hydrocarbons)	B3

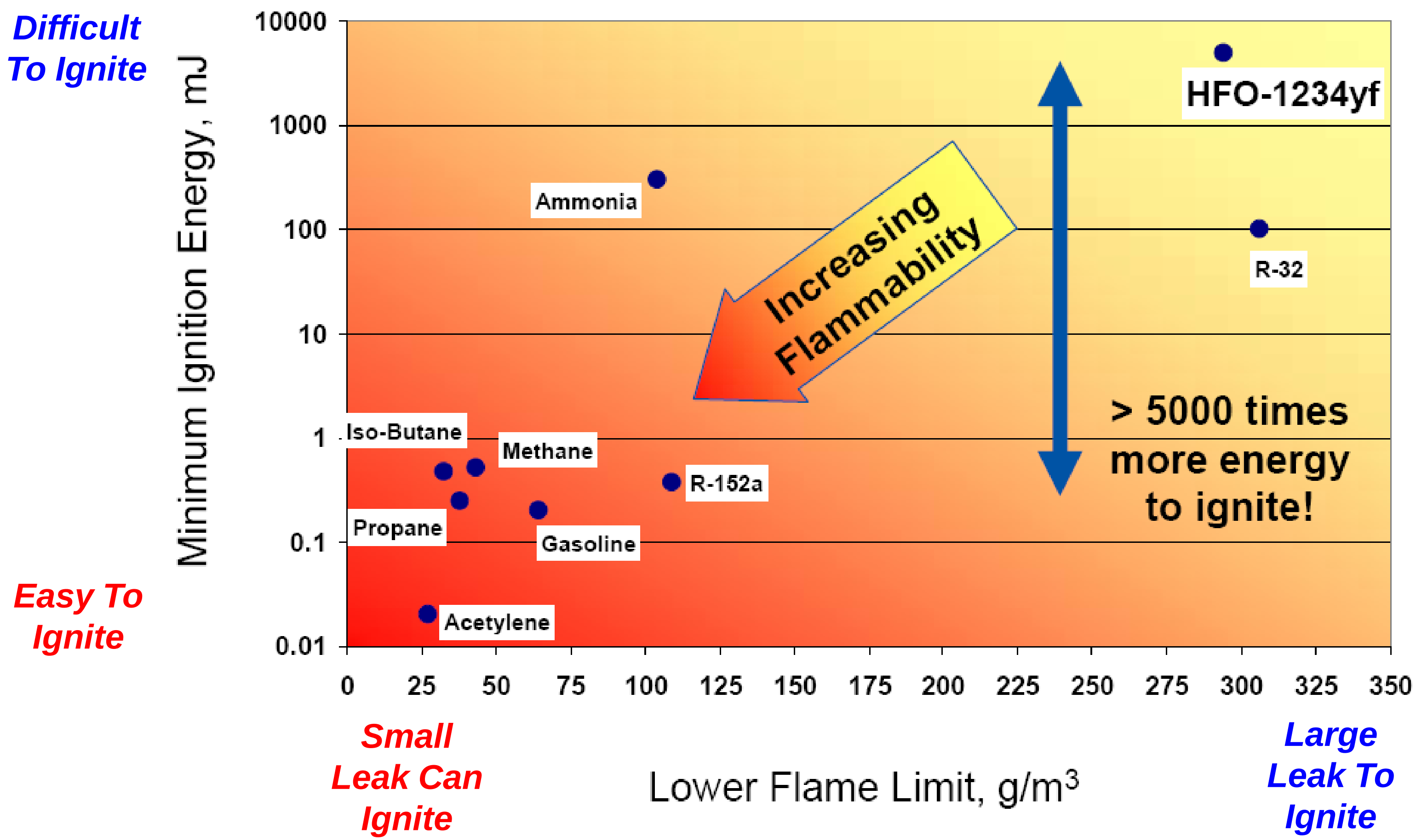
Except for ammonia, refrigerants classified as Bx are not permitted in appliances.

New Classification – Applies To Most Low GWP Candidates

Minimum Ignition Energy (MIE) And Lower Flame Limit (LFL)

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

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

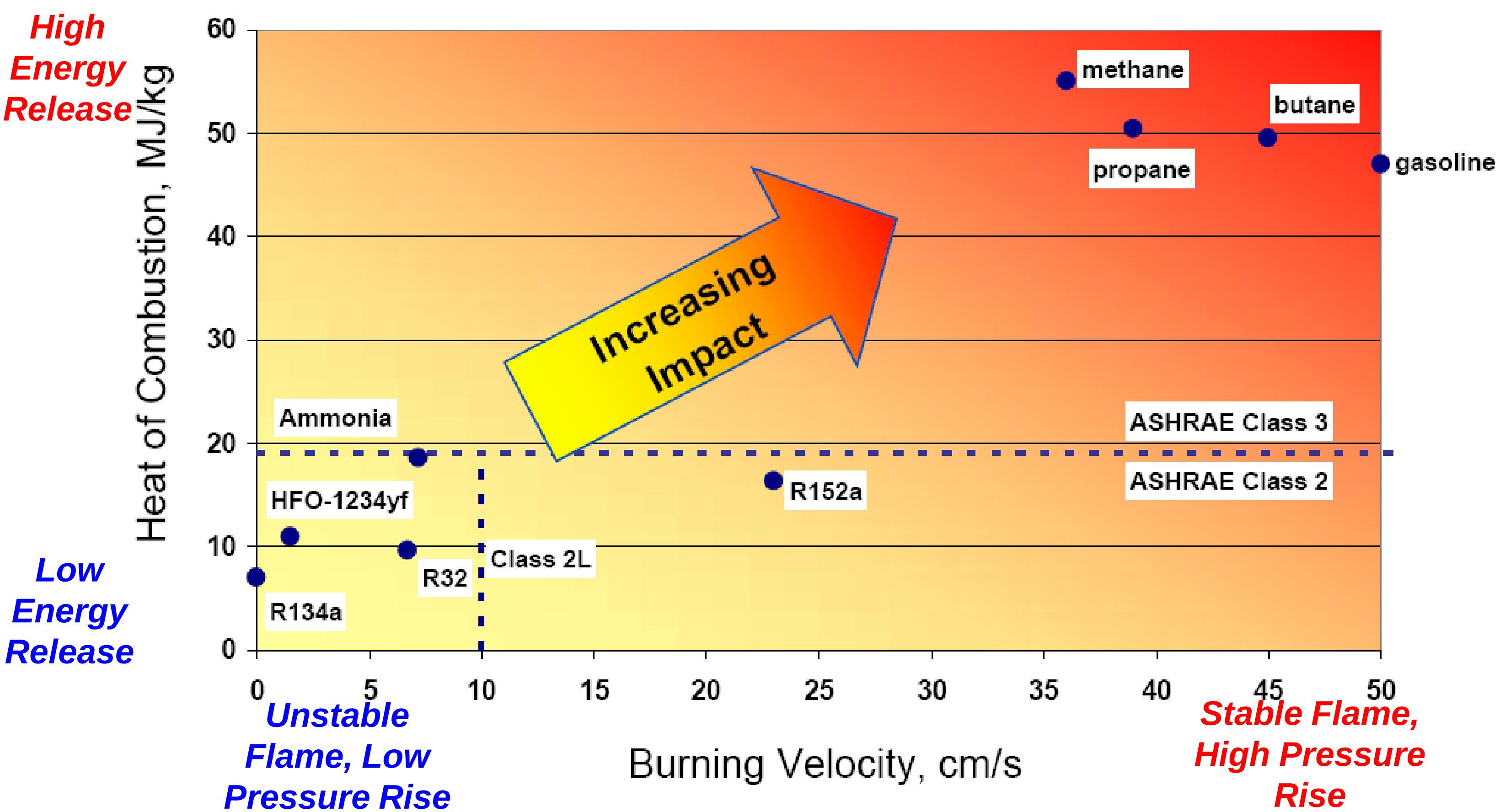


Reference: Low GWP Refrigerant Options For Unitary AC & Heat Pumps – Mark Spatz, ASHRAE Jan 2011

Burning Velocity – Basis For 2 & 2L Classification

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

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

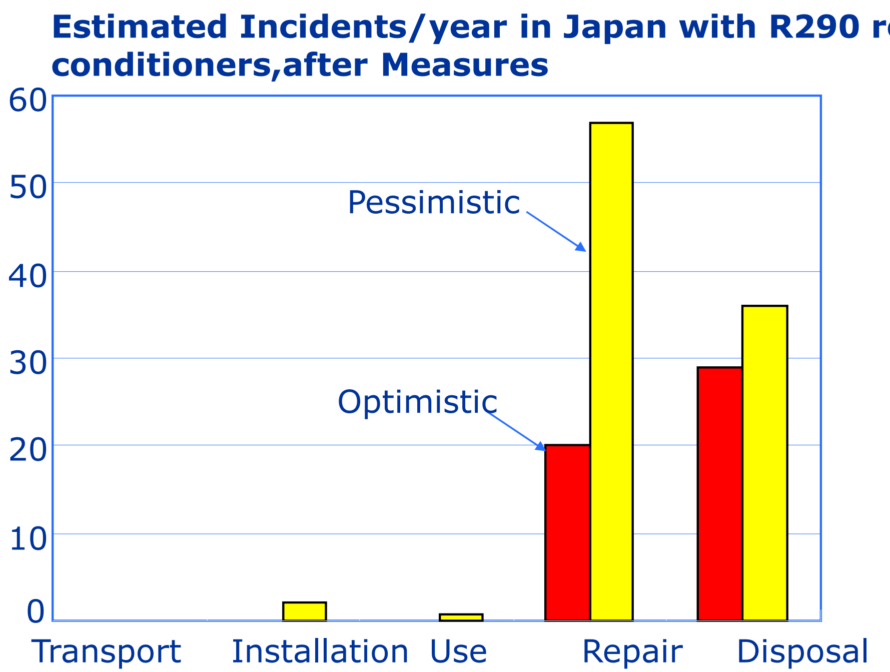


Reference: Low GWP Refrigerant Options For Unitary AC & Heat Pumps – Mark Spatz, ASHRAE Jan 2011

Flammability Impact During Life Of System: R290 Risk Assessment In Japan

While risk of R290 (propane) can be addressed with several measures (eg forced fan operation to lower concentration below LFL), repair and disposal risks remain considerable high.

Source : Risk assessment work on HC refrigerant carried out by JRAIA Non Fluorocarbon Refrigerant WG in 1999-2000.



Reason :

-Human errors during repair & disposal, which is beyond the control of manufacturers

- During repair & disposal there is no power supply for the unit, so measures such as forced fan operation do not work.

16

Repair & Disposal Pose Biggest Challenge

Global A2L Regulatory Activities

	Standards Working Group	Focus Of Standards Activity For A2L Refrigerants
ISO (Intl.)	ISO 5149	Safety & Use; General equipment requirements
	IEC 60335-2-40	AC & Heat Pump application equipment & use requirements
	IEC 60335-2-89	Commercial refrigeration application equipment & use requirements
CEN (EU)	EN 378	Safety & Use; General equipment requirements
	EN-IEC 60335-2-40	AC & Heat Pump application equipment & use requirements
	EN-IEC 60335-2-89	Commercial refrigeration application equipment & use requirements
ASHRAE (US/Intl)	Standard 15	Safety & Use; General equipment requirements
UL (US)	Working Group #1	AC & Heat Pump application equipment & use requirements (UL 1995)
	Working Group #2	Commercial refrigeration application equipment & use requirements (UL 250, UL 471)
	Working Group #3	Refrigerant chemistry & requirements
China	R32 A2L Committee	Develop R32 specific application requirements – AC, Heat Pump, Ref

A2L Refrigerant Use Rules Only Now Being Developed Worldwide

Refrigerant Options To Replace HFCs – High Level Summary (AC & Ref)

	Current HFCs	R32 (HFC)	HFO Blends	Carbon Dioxide	Hydrocarbons
Global Warming Potential (GWP)	~2,000 To 4,000	675	4-650	1	<10
Compressor Design & Cost					
Energy Efficiency					
Safety		Mildly Flammable			Highly Flammable
Refrigerant Cost					
System Cost					

Future Refrigerants May Differ By Application & Region, More Than Today's

Summary

- Many New Lower GWP Refrigerant Candidates Becoming Available For Air Conditioning, Heat Pump And Refrigeration Applications
- Minimizing System's Life Cycle Impact On Environment Should Be The Goal In Narrowing Choice
  - Reducing Leaks & Charge Through Systems Technology Changes Is Of Benefit Today & In The Future As Refrigerant Costs Increase
  - End Of Life Refrigerant Management Is Very Important
  - In Selecting Future Refrigerants, System Efficiency Impacts Energy Consumption, Its Cost Of Operation, And The Environment Should Be Kept Flat At A Minimum
- Important For Industry To Stay Engaged In:
  - "Low GWP AREP", The AHRI Sponsored Study That Will Help Guide The Selection Process
  - International & National Working Groups' (eg., UL) Development Of A2L Refrigerant Use Rules Impacting New & Existing Equipment
  - Government Regulations That Will Affect Systems Architecture, Refrigerant Choice & Life Cycle Cost

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