Refrigerant Update: Hydrofluoroolefins (HFOs) and Future Architectures

August 30, 2022

Call-in Details 1-202-991-0477 ID: 984 677 119#

Today's Host

Kersey Manliclic, Doctor of Philosophy (PhD)
U.S. Environmental Protection Agency
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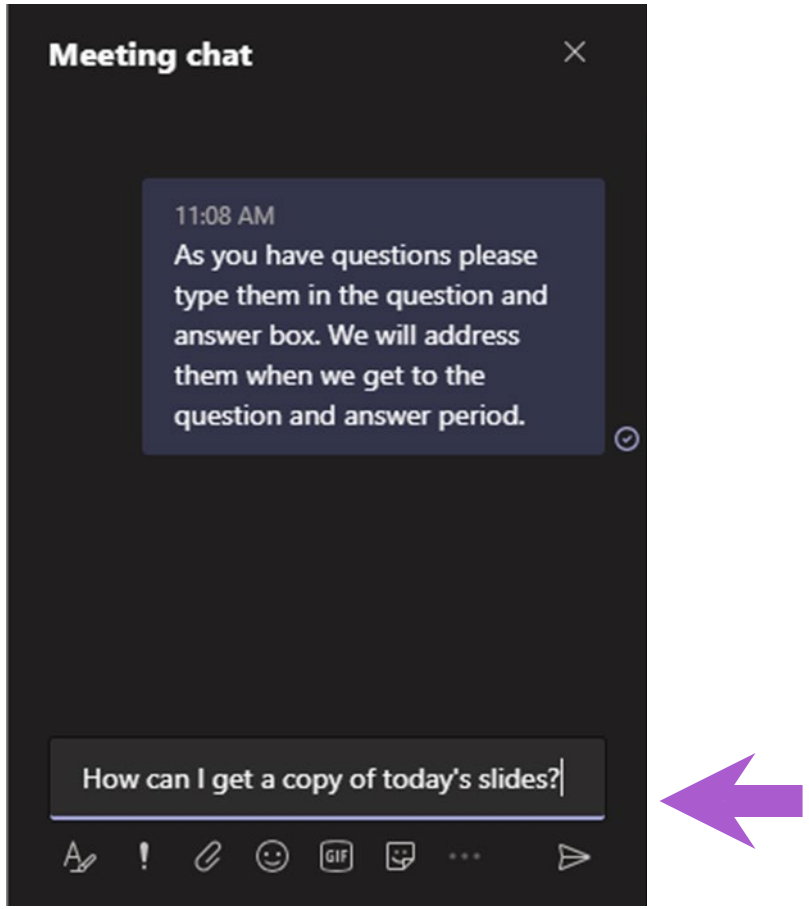
Kersey has worked in various sectors before coming to the U.S. Environmental Protection Agency (EPA) where he is the Program Manager for EPA's GreenChill Advanced Refrigeration Partnership. Most recently, he worked for 3.5 years at the California Air Resources Board implementing an incentive program for cleaner agricultural equipment and ensuring that Cap-and-Trade incentive programs benefitted disadvantaged communities. Prior to that, he worked with state agencies to plan hydrogen fueling infrastructure for fuel cell electric vehicles. He holds a Bachelor of Science (BS) in Mechanical Engineering, a BS in Materials Science & Engineering, a Masters of Science (MS), and a PhD in Environmental Engineering, all from the University of California, Irvine.

Questions and Webinar Feedback

Question and Answer Session

- Participants are muted
- Questions will be moderated at the end
- To ask a question, enter your comment into the chat box



Feedback Form

- We value your input!
- The link to a feedback form will appear in the chat window

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Webinar Materials

Recording and Slides

- Webinar is being recorded
- Materials will be posted on the GreenChill website under Events and Webinars: www.epa.gov/greenchill
- To receive notification when materials are posted email: EPA-GreenChill@abtassoc.com

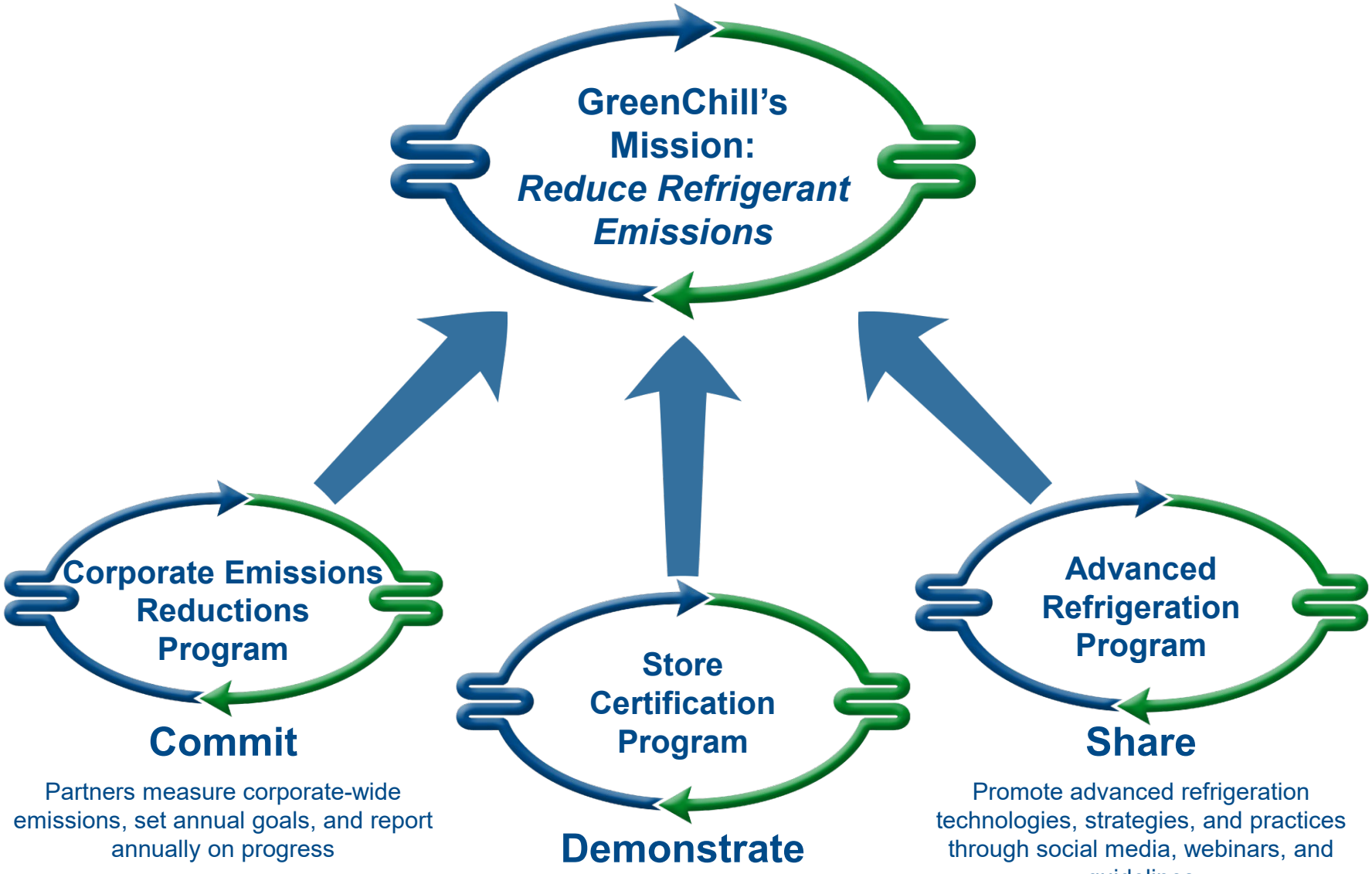
Program Overview

www.epa.gov/greenchill

GreenChill is a voluntary partnership program that works collaboratively with the food retail industry to reduce refrigerant emission and decrease stores' impact on the ozone layer and climate system

GreenChill works to help food retailers:

- Lower refrigerant charge sizes and eliminate leaks
- Transition to environmentally friendlier refrigerants
- Adopt green refrigeration technologies and best environmental practices


GreenChill's Mission: *Reduce Refrigerant Emissions*
Corporate Emissions Reductions Program
Commit
Partners measure corporate-wide emissions, set annual goals, and report annually on progress
Store Certification Program
Demonstrate
Individual stores earn GreenChill certification for meeting highest standards: low charge size, use of less harmful refrigerants, and low leak rates
Advanced Refrigeration Program
Share
Promote advanced refrigeration technologies, strategies, and practices through social media, webinars, and guidelines

Upcoming GreenChill Webinars

- We are planning the remaining of our 2022 and 2023 webinar series. Email GreenChill@epa.gov if you have any ideas for a webinar or would like to present.

- To be added to our webinar invitation list, email EPA-GreenChill@abtassoc.com

Celebrating 15 Years of GreenChill

2022 is the 15th anniversary of GreenChill!

- 15th anniversary report later this year
- Explore GreenChill's Partner accomplishment page
- Email greenchill@epa.gov if you have ideas on how to celebrate!

www.epa.gov/greenchill/partnership-accomplishments

Learn More

www.epa.gov/greenchill

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Today's Speaker…

Doug Starasinic

Doug Starasinic, Professional Engineer (PE)
Honeywell International Inc.
Stationary Refrigerants
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Doug has over 30 years of experience in commercial refrigeration. His experience includes refrigeration design, construction, maintenance, energy management, and technical marketing. Doug is Senior Application Engineer for Honeywell Refrigerants.

Ron Vogl

Ron Vogl
Honeywell International Inc.
Stationary Refrigerants
Email: ronald.vogl@Honeywell.com

Ron is global Technical Services Marketing manager for Honeywell Refrigerants. He has accrued more than 30 years' experience, touching all facets of the industry as a wholesaler, sales engineer, contractor, business owner, energy auditor, designer and consultant. Ron is a graduate of the State University of New York with a major in heating, ventilation, air conditioning, and refrigeration (HVACR) design theory.

Nilesh Purohit

Nilesh Purohit
Honeywell International Inc.
Stationary Refrigerants
Email: nilesh.purohit@honeywell.com

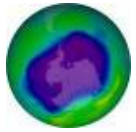
Nilesh has been with Honeywell Refrigerants for 4 years as an Advanced Research and Design (R&D) Engineer responsible for low global warming potential (GWP) (environmentally benign) refrigerant development for commercial and industrial refrigeration applications. He holds a PhD degree in Mechanical Engineering from Birla Institute of Technology and Science, Pilani, India.

ACRONYMS (ALPHABETIZED)

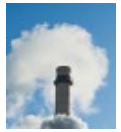
- AIM: American Innovation and Manufacturing
- AHJ: Authority having jurisdiction
- AR5: IPCC Fifth Assessment Report
- ASHRAE: American Society of Heating, Refrigerating, and Air-Conditioning Engineers
- ASHRAE Safety Standards:
  - A1: Nonflammable, lower toxicity
  - A2L: Lower flammability, lower toxicity
  - A3: Higher flammability, lower toxicity
- BTU: British Thermal Unit
- CAPEX: Capital expenditure
- CARB: California Air Resources Board
- CFC: Chlorofluorocarbon
- CO_2: Carbon dioxide
- COP: Coefficient of performance
- DX: Direct expansion
- EER: Energy efficiency ratio
- EU: European Union
- GWP: Global warming potential
- HCFC: Hydrochlorofluorocarbon
- HFC: Hydrofluorocarbon
- HFO: Hydrofluoroolefin
- IPCC: Intergovernmental Panel on Climate Change
- KWh: Kilowatt-hour
- LFL: Lower flammability limit
- LT: Low temperature
- MT: Medium temperature
- OPEX: Operating expenses
- TCO: Total cost of ownership
- TD: Temperature difference
- SST: Saturation suction temperature
- SDT: Saturated discharge temperature
- UL: Underwriters' Laboratories

LOW GWP REFRIGERANTS THERMODYNAMIC PROPERTIES

INTRODUCTION



Montreal Protocol /
Ozone Depletion
Concerns



Kyoto Protocol /
Global Warming Concerns

CFC Phase-out

HCFC Phase-out

HFC Phasedown; Sector-Specific GWP Limits via AIM Act & CARB regulations

CFC's → HCFC's → HFC's → HFC/HFO blends

R502 → R22 → R404A → R448A

System + Refrigerant

Low GWP A1's & A2L's

New Low GWP Refrigerants + System Changes will Meet New Requirements

THERMODYNAMIC PROPERTIES

		Safety classification	GWP (AR5)	Boiling point (°F)	Compressor Displacement	COP	ΔT Discharge (°F)	Mass Flow Rate	Discharge Pressure (psig)	Evaporator Glide (°F)	Condenser Glide (°F)
R-404A like	R-404A	A1	3943	-51	100%	100%	0	100%	541	1	1
	R-448A	A1	1273	-51	93%	110%	29	72%	686	7	8
	R-449A	A1	1276	-50	94%	109%	27	73%	681	6	8
	R-455A	A2L	146	-62	96%	108%	24	74%	667	12	17
	R-454C	A2L	146	-50	105%	109%	16	77%	660	9	12
R-134a like	R-134a	A1	1300	-15	100%	100%	0	100%	589	0	0
	R-513A	A1	572	-21	99%	95%	-16	120%	559	0	0
	R-515B	A1	299	-2	138%	99%	-20	116%	522	0	0
	R-471A	A1	148	2	157%	99%	-19	115%	507	4	4

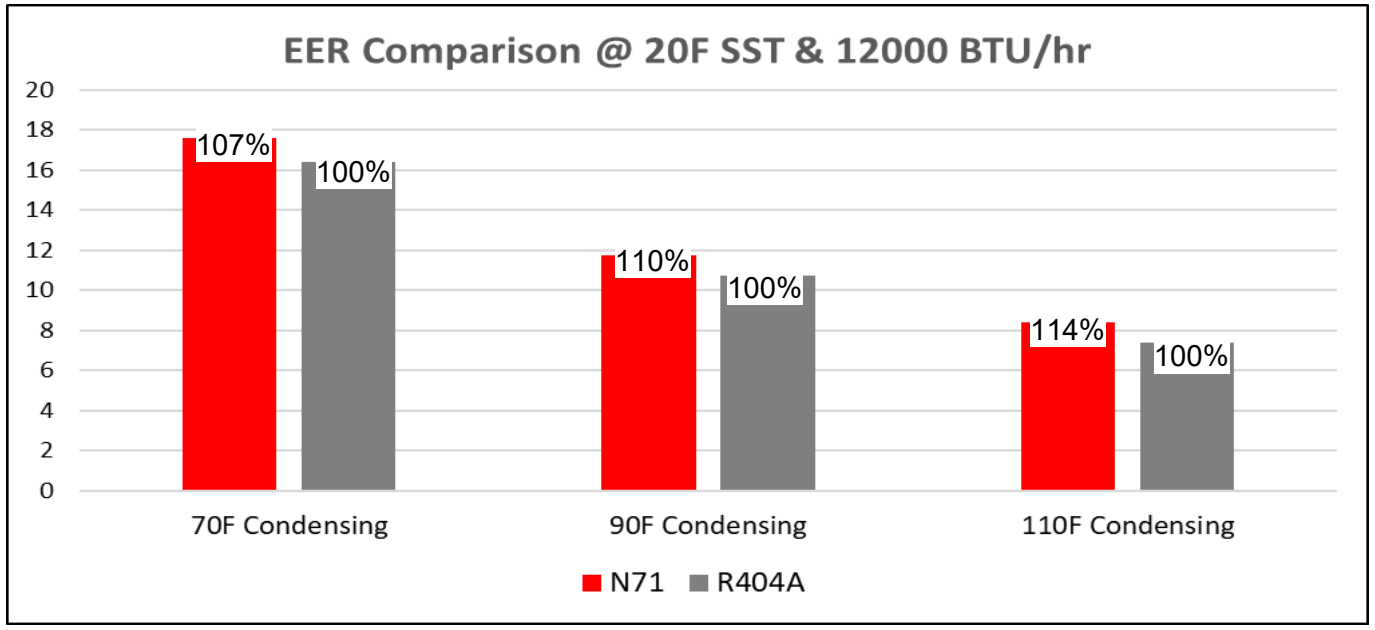
Med Temp Conditions: SST: -17.6°F , SDT: 113°F, Superheat: 10°F, Temp. rise in suction line: 18°F , SC: 0°F, Comp Efficiency: 65% , Vol Efficiency: 100%

R-471A

- **Only < 150 GWP, Non-flammable HFO Refrigerant Blend for MT Applications**
- "Business as usual" direct expansion rack system
- Low pressure refrigerant → lower leak rates
- 13% improved energy efficiency vs. R-404A system*
- 30% improved energy efficiency vs. CO_2*
- Offers better efficiency in high ambient conditions
- No charge size limitations
- Standard service practices and traditional contractor base (vs. CO_2)
- Regulatory compliant with AIM & CARB
- Handling, storage, and transportation same as low pressure nonflammable refrigerants

	Composition (%)	ASHRAE Class	GWP (AR5)	Evaporator Glide (F)	EER	Discharge Temperature (F)	Suction Pressure (psig)	Discharge Pressure (psig)
R 404A	R32 / R134a / R143a (44/4/52)	A1	3940	0.7	100%	181.7	55.8	253.1
R 471A	R1234ze/R227ea / R1336mzz(E) (78.7/4.3/17)	A1	148	4.4	113%	174.4	6.1	86.2

*Med. Temp. Conditions: SST: 20°F , SDT: 105°F, Superheat: 10°F , Temp. rise in suction line: 35°F , SC: 0°F, Comp. Efficiency: 65% , Vol. Efficiency: 100%



Note: R-471A is intended for new equipment and cannot be used as a retrofit, data in table assumes optimized compressor is used

**Based on thermodynamic analysis*

R-471A <150 GWP, A1 Refrigerant

<150 GWP A2L'S / A3'S

- UL 60335-2-89 allowing larger charge size of A2L's up to 260 x LFL
- Low + medium temperature applications
- Close match in capacity to R404A with higher efficiency
- Substantial charge size
- Stronger energy efficiency, higher cooling capacity, and safer compared to R290 (propane)
- A2L's have had successful testing and adoption by OEMs in EU (cabinets, convenience stores, etc.)
- Superior eco-efficiency compared to CO_2 (stronger TCO + energy efficiency)

	Safety Classification	LFL (kg/m3)	Max Charge Size pounds (lbs.)	Capacity vs R-404A
R-290 (Propane)	A3	0.038	1.1	95%
R-454C	A2L	0.29	165	91%
R-455A	A2L	0.43	247	101%

*Maximum charge size based on UL 60335-2-89 guidelines

Low Temp. Conditions: SST: -25°F , SDT: 114°F, Superheat: 10°F , Temp. rise in suction line: 36°F , SC: 9°F, Comp. Efficiency: 65% , Vol. Efficiency: 100%
These are some of mosaic properties that must be considered when selecting a refrigerant.

<150 GWP A2L Refrigerants offer Low + Med Temp

NEW SYSTEM CONSIDERATIONS

KEY FACTORS

Key Factors in Choosing a System Architecture


Life Cycle cost - First cost, Maintenance, Energy


Serviceability


Environment


Codes


Miscellaneous

LIFE CYCLE COST – 1ST, MAINTENANCE, ENERGY

GROCERY STORE EXAMPLE

Life cycle cost

- **Includes equipment and installation (1st cost), yearly maintenance, and yearly energy**
- **A net-present-value analysis shows the impact of these three components of the life cycle cost**

Concentrate on areas of highest NPV benefit for lowest life cycle cost

LIFE CYCLE COST – 1ST, MAINTENANCE, ENERGY

GROCERY STORE EXAMPLE

First Cost	Maint cost (annual)	Energy Cost (annual)	Net Present Value	Life Cycle cost reduction
$500,000	$40,000	$110,000	$2,022,116	
10% Reduction	Same	Same	$1,976,662	$45,455
Same	10% Reduction	Same	$1,980,314	$41,802
Same	Same	10% Reduction	$1,907,161	$114,955
10% Increase	5% Increase	15% Reduction	$1,916,039	$106,077

Concentrate on areas of highest NPV benefit for lowest life cycle cost

3% Inflation,10% Cost of capital,20-year life

SERVICEABILITY

Serviceability

- Simple designs and controls
- Off-the-shelf commodity parts
- Minimize components
- Easy access
- Attention to leak potentials
- Operating pressures
- Training

ENVIRONMENTAL

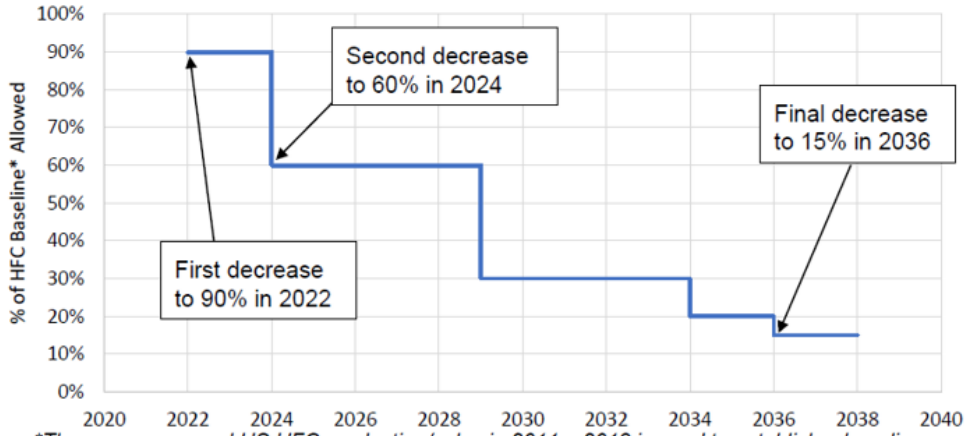
Regulations

- CARB
- AIM Act

Corporate carbon goals

	Restriction	When?	Legislation
New Equipment (California)	Ban on refrigerants >150 GWP for systems >50lbs.	JAN 2022	CARB
Existing Equipment (California)	Company wide average <1400 GWP for install base	JAN 2030	CARB
New Equipment (All of US)	Consideration of restriction on refrigerants >150 GWP, >300 GWP	TBD	AIM

Figure 1: US AIM HFC Phase-down Schedule



The average annual US HFC production/sales in 2011 – 2013 is used to establish a baseline for the phase-down (100%)

CODES

Mechanical standards

- A2L, A3 limits
- Direct and indirect systems
- Municipal adoption / AHJ

Safety standards

- Updated equipment safety standards

Codes are Catching up – Stay tuned

MISCELLANEOUS

Food safety

- Diversified loads (multiple “baskets”)
- Pull down times
- Temperature control

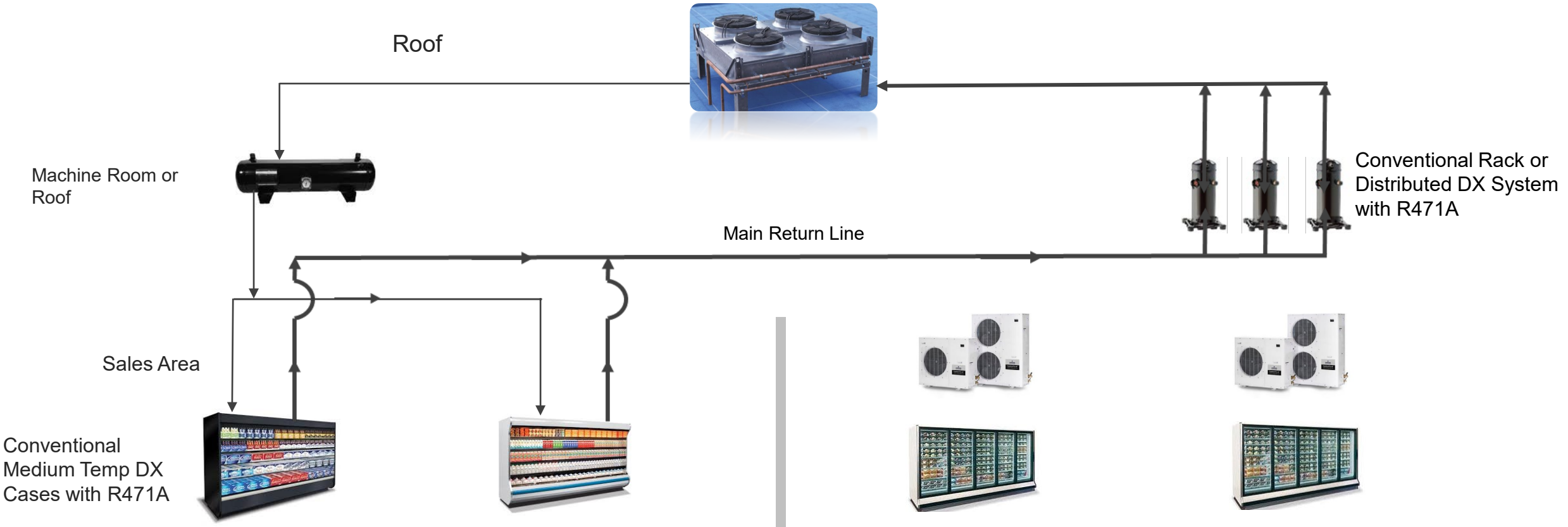
Adaptability to store changes

Sales floor impact

- Slips and falls
- Service

EMERGING SYSTEM ARCHITECTURES

FUTURE SUPERMARKET ARCHITECTURE



Medium Temperature R-471A (~2/3 of Supermarket)

Centralized Rack System

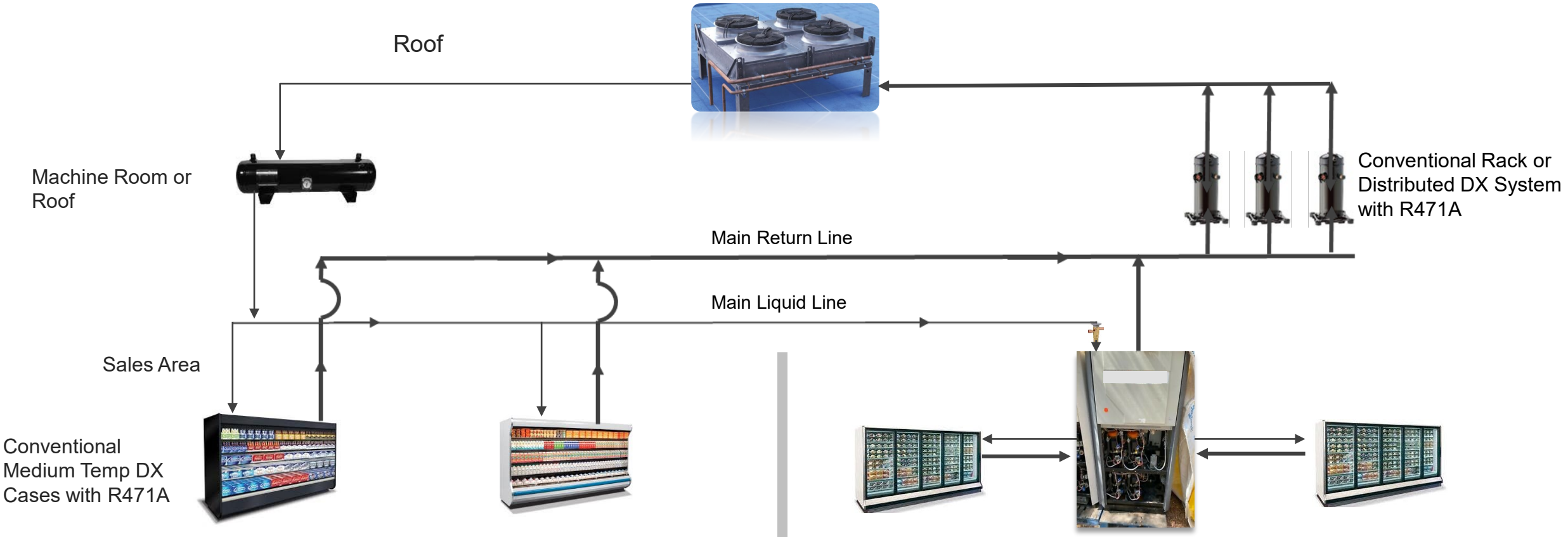
- Traditional rack system (well-known technologies)
- Uses a non-flammable refrigerant of GWP<150 throughout the sales area
- Expect similar performance to typical R134A medium temp systems

Low Temperature 448A / A2L's (R-455A / R-454C)
(~1/3 of Supermarket)

Condensing Units

- < 50lb. condensing units with R-448A
- R-455A or R-454C condensing units ~247lbs. and ~165lbs. respectively based on UL 2-89 guidelines

FUTURE SUPERMARKET ARCHITECTURE



Medium Temperature R471A (~2/3 of Supermarket)

Centralized Rack System

- Traditional rack or distributed system (well-known technologies)
- Uses a non-flammable refrigerant of GWP<150 throughout the sales area
- Expect similar performance to typical R134A medium temp systems

Low Temperature R-455A / R-454C (~1/3 of Supermarket)

Distributed Cascade System using A2L

- Self-contained or distributed systems reject heat to medium temp circuit
- Low charge systems allow use of mildly flammable refrigerants (A2Ls) with GWP<150
- Take advantage of updated UL 2-89 charge sizes of up to 247lbs.
- Cascade concept typically helps improve efficiency
- Redundancy for low temp system
- Systems can be optimized for one operating condition year-round

ECO-EFFICIENCY ANALYSIS

SPECIFICATIONS | SYSTEM DETAILS

Parameter	Assumption
Life span	25 years
Number of trading & nontrading hours	14 trading hours 10 nontrading hours
Installed cooling capacities	Med temp 546 kBTU/hr Low temp 119 kBTU/hr
Supermarket size	45,000 square feet
R-744 system **Running conditions** **(Tevap, min. Tcond)**	Evaporation temperature (Tevap) = 23°F MT, Tevap = -26°F LT min condenser temperature (Tcond) = 50°F adiabatic cooled condensers
R-471A / R-455A system **Running conditions** **(Tevap, min. Tcond)**	Tevap = 23°F MT, Tevap = -26°F LT min Tcond = 60°F air cooled condensers
Store locations	Seattle and Houston
Cooling load distribution	90% of the total installed cooling capacity during the day 70% of the total installed cooling capacity during the night
Electricity cost	$0.11/kWh
Energy efficiency class for condenser / gas cooler	45 kW/kW (low level or class “C” *) for all systems

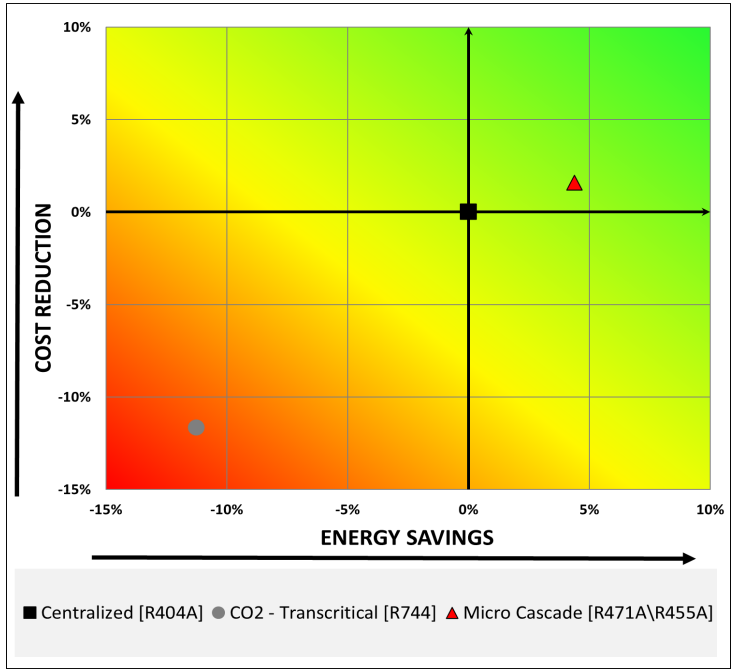
** Class “C” or energy efficiency 45kW/kW, means that in the condenser / gas cooler, 45 kW of heat is rejected with consumption of 1 kW of electricity by the fan.*

High Side TD Assumptions in Condensers / Gas Coolers		
	Sub-critical operation	Trans-critical operation
R744 system	15°F	5.5°F above ambient
R455A system	15°F	Not applicable
R471A system	15°F	Not applicable

RESULTS | SUPERMARKET | SEATTLE & HOUSTON

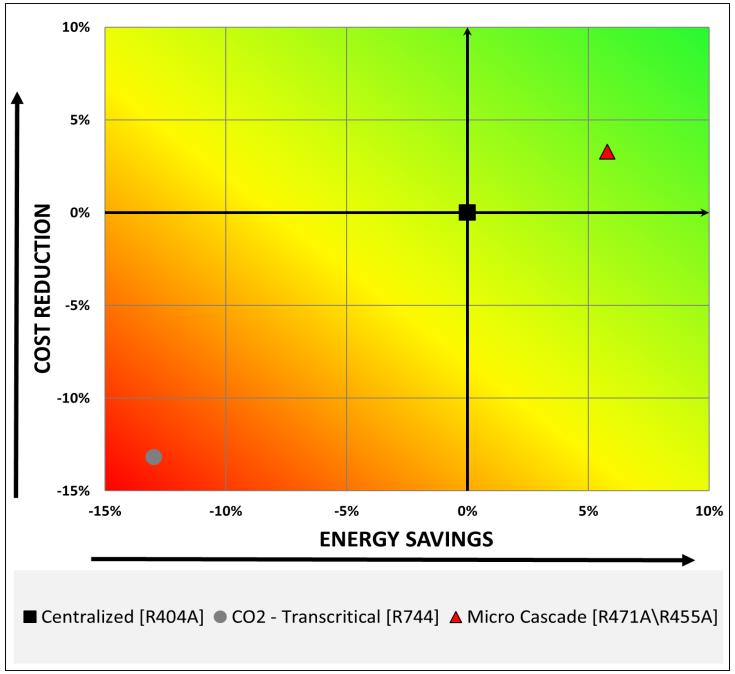
Seattle

	CAPEX	OPEX	Total cost	Electricity
R404A	100%	100%	100%	100%
R744	120%	110%	112%	111%
R455A/R471A	102%	98%	98%	96%

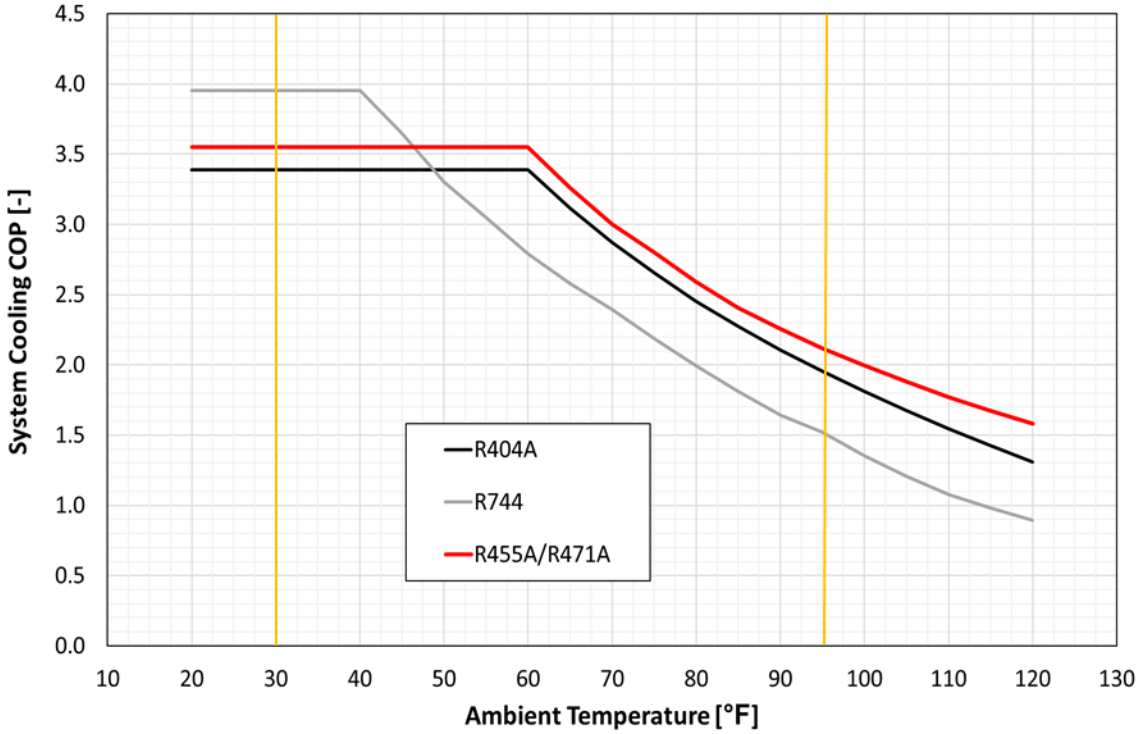


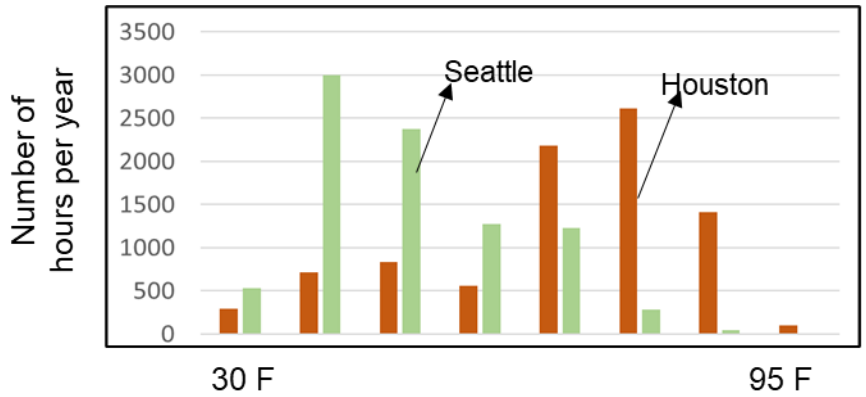
Houston

	CAPEX	OPEX	Total cost	Electricity
R404A	100%	100%	100%	100%
R744	121%	112%	113%	113%
R455A/R471A	102%	96%	97%	94%



COP | ANNUALIZED ANNUAL ENERGY EFFICIENCY





ANNUALIZED ENERGY EFFICIENCY	R404A Centralized	R744 Booster with Adiabatic Condenser	R471A/R455A Micro-Cascade
Seattle, USA	100%	99%	**104%**
Houston, USA	100%	91%	**106%**

- New system with **R471A/R455A** shows the highest energy efficiency
- Efficiency in high ambient temp is critical due to higher refrigeration load and peak charges
- R744 system shows the lowest energy efficiency

SUMMARY

- **Regulations and decarbonization are causing changes across the industry**
- **Refrigerants & system architectures continue to evolve to meet these changes head on**
- **Energy efficiency is major driver and will become more important overtime**

Refrigerant, system architecture, compression technology, control systems, service practices, and leak management are critical and evolving

HONEYWELL
THANK YOU

Honeywell

Contacts and Upcoming Events

Presenter Contacts

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You're Invited!
GreenChill 2022 Recognition Event

September 20, 2022
Orlando, FL

In conjunction with the Food Industry Association
Energy & Store Development Conference

Join our webinar invitation list or request today's slides: EPA-GreenChill@abtassoc.com

Access past webinar slides: www.epa.gov/greenchill/events-and-webinars