Low Global Warming Potential Refrigerants for Direct HVAC Applications

- Helen Walter-Terrinoni, VP Regulatory Affairs, Air-Conditioning, Heating, and Refrigeration Institute
- Richard Lord, Sr. Carrier Fellow, ASHRAE Fellow, Carrier Corporation

http://www.ahrinet.org/SafeRefrigerant

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Industry Research & Videos related to the Development of Safety Standards

- Used to help guide standard development
  - IEC/UL 60335-2-40 3rd edition
  - ASHRAE 15 (2019) application standard (residential and commercial)
  - ASHRAE 15.2 simplified for residential application only
- Significant body of research completed
  - Additional research and work accomplished for indirect systems (machine rooms), appliances, A3 refrigerants and refrigeration that can be reviewed in future meetings
  - Research was conducted by AHRI, ASHRAE, refrigerant producers, individual equipment manufacturers, and other industry organizations
  - Research and testing also done by NFPA and in Europe, Japan, and other countries where A2L refrigerants are already in use

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Extensive Research Completed on Flammable Refrigerants

- Testing
  - AHRTI-9007: Benchmarking Risk by Whole Room Scale Leaks and Ignitions Testing
  - AHRTI-9013: A2L Consequence Study
  - AHRTI-9012/Oak Ridge National Laboratory (ORNL): Real-world Leak Assessments of Alternative Flammable Refrigerants
  - AHRTI-9008: Investigation of Hot surface Ignition Temperature (HSIT) for A2L Refrigerants
  - AHRI-8017: Investigation of Energy Produced by Potential Ignition Sources in Residential Application
- Modeling
  - ASHRAE-1806: Flammable Refrigerants Post-Ignition Simulation and Risk Assessment Update
  - ORNL: Investigate the Proper Basis for Setting Charge Limits of A2L, A2, and A3 for Various Types of Products
  - NIST: Modeling tools for low-GWP Refrigerant Blends Flammability
- Servicing
  - ASHRAE-1807:Guidelines for Flammable Refrigerant Handling, Transporting, Storing and Equipment Servicing, Installation and Dismantling
  - ASHRAE-1808: Servicing and Installing Equipment using Flammable Refrigerants: Assessment of Field-made Mechanical Joints
- Detection
  - AHRTI-9009: Leak Detection of A2L Refrigerants in HVACR Equipment

*This is not a comprehensive list (excludes NFPA, Japan, Europe, Manufacturers etc)

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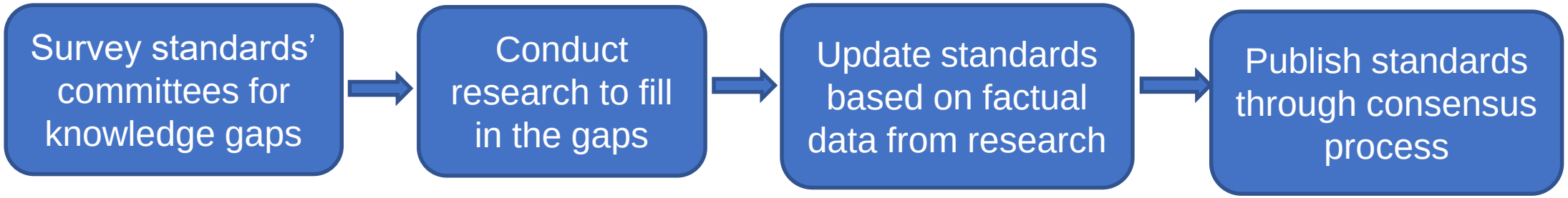
Safety Standards Updated Based on Extensive Research



- Significant research is available through third party testing
  - More than a decade of research is available from testing for Japan and Europe
  - Nearly $7 million has been invested in the U.S. to understand low-GWP refrigerants plus additional research conducted by refrigerant and equipment manufacturers
  - Objective: produce technical results to support code revisions related to use of flammable refrigerants
- Research informed conservative modifications to safety standards. For example:
  - A detector trip time of 30 seconds was not fast enough, so a shorter response time is required in the standard
  - Propane charge reduced to 114 g compared to Europe which just approved 500 g
  - Research also showed that potential common household ignition sources do not ignite A2Ls
  - The charge size for cord-connected equipment was not relaxed
  - 4x safety factor used for room exposure levels
- Current research all over the world will support optimization for future products

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Refrigerants: Definitions and Properties

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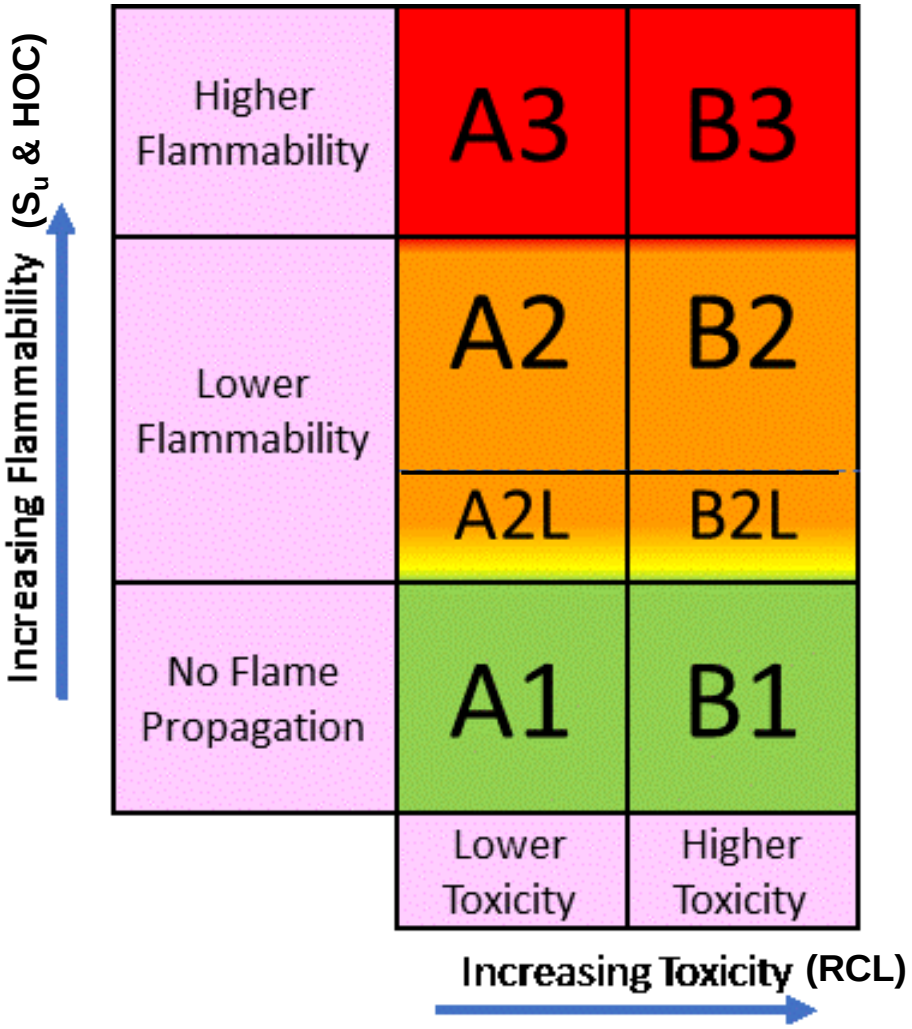
ASHRAE 34 and ISO 817 Refrigerant Classification



Class 3 Requirements

1. Exhibit flame propagation @ 60°C & 101.3 kPa
2. LFL ≤ 0.10 kg/m^3 or HOC ≥ 19,000 kJ/kg

Class 2 Requirements

1. Exhibit flame propagation @ 60°C & 101.3 kPa
2. LFL > 0.10 kg/m^3
3. HOC < 19,000 kJ/kg

Class 2L Requirements

1. Same as Class 2 requirements & S_u ≤ 10 cm/s

Class 1 Requirements

1. No flame propagation @ 60°C & 101.3 kPa

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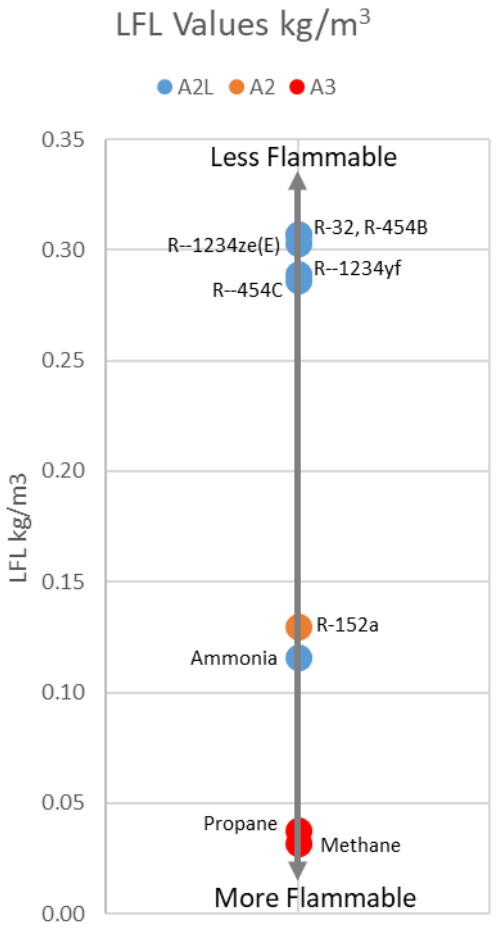
ASHRAE Classification
ASTM E-681: Flammability Limits

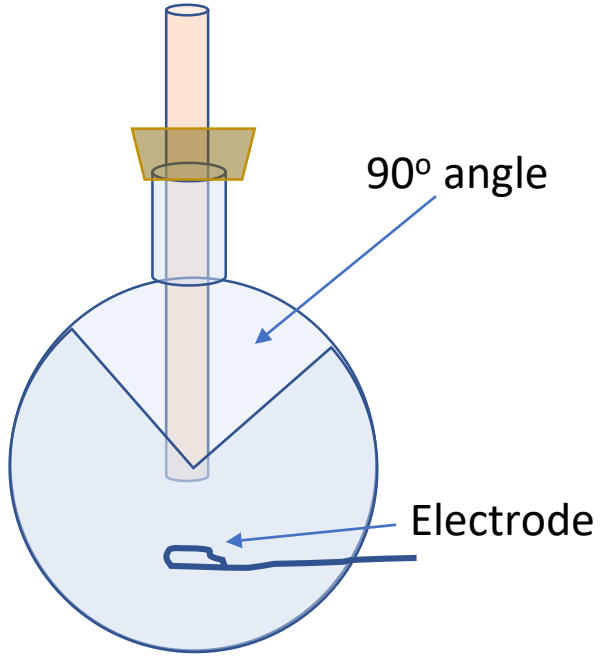


Apparatus

- 12L glass flask
- Ignition- 15 kV/30 ma, 0.4 sec duration

Testing

- 23°C and **at 60°C**, with RH of 50% ± 0.1% at 23.0°C.
- Absolute humidity of air-0.0088 grams H2O/dry air @ 23°C.
- Tested increments of 1 vol % or less of refrigerant in air.



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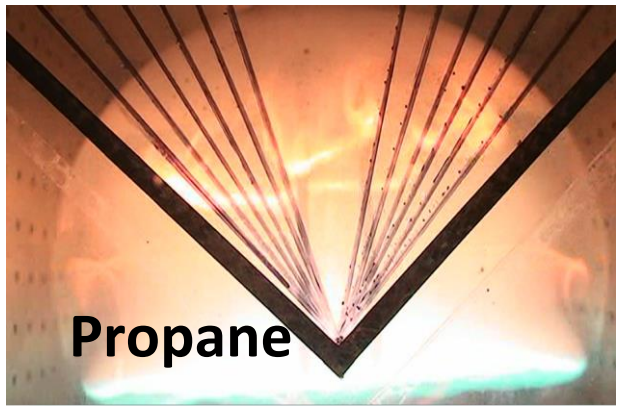
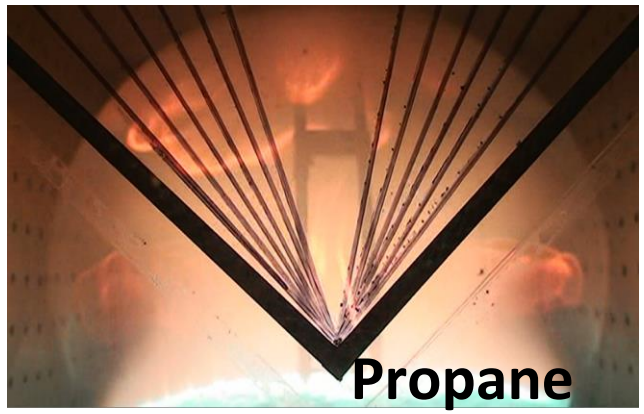
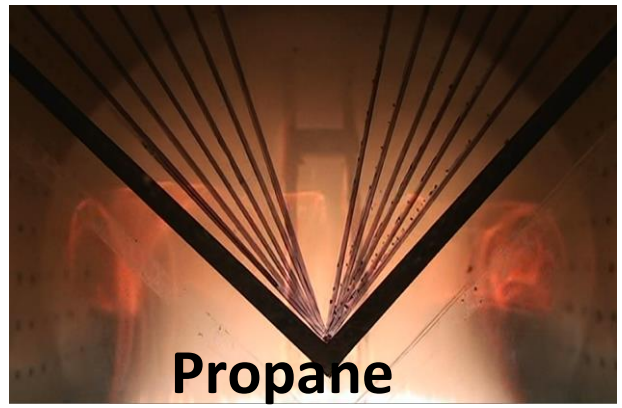
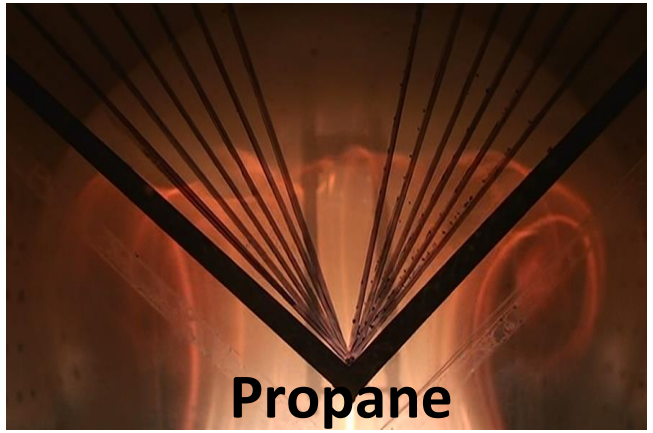
ASTM E681- Class 3 (e.g. propane)





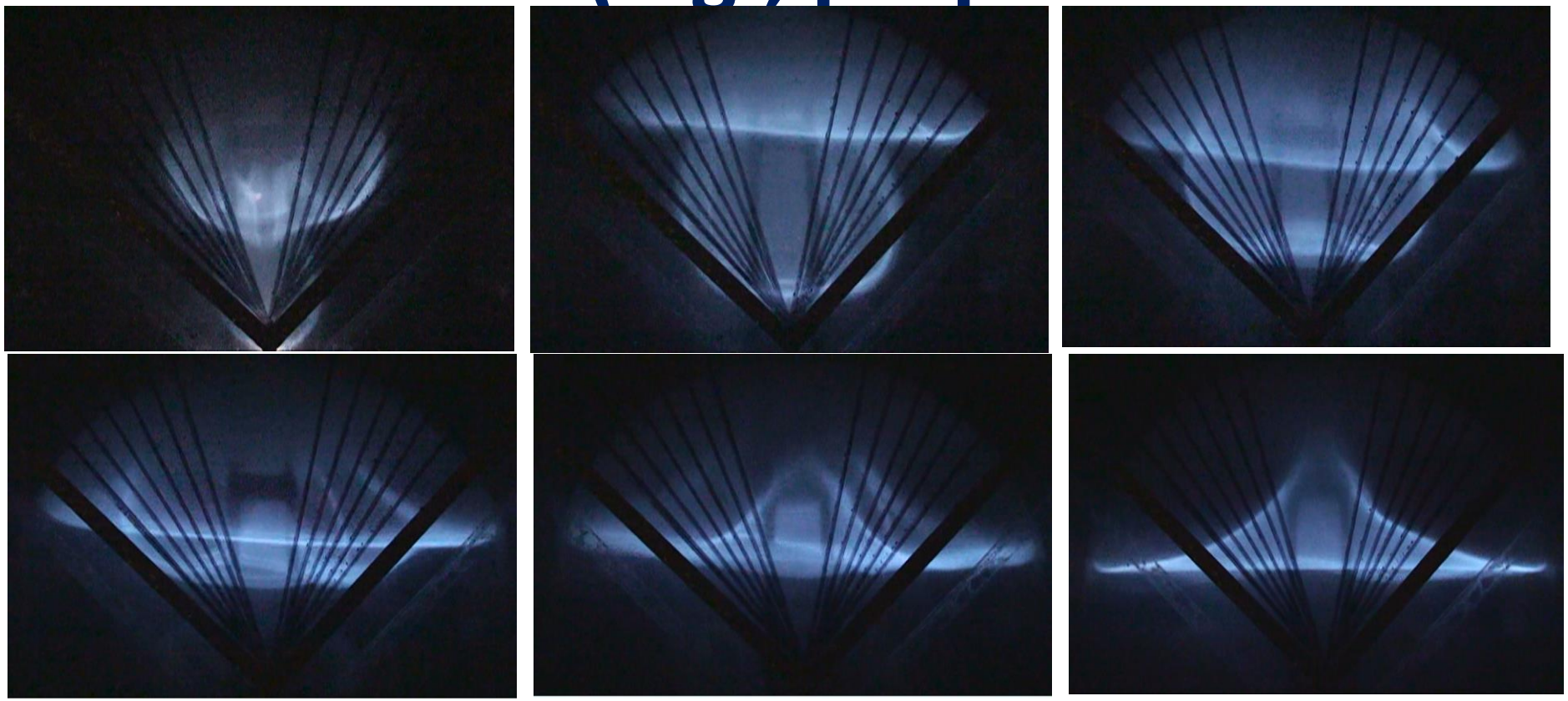




The flame must be a solid flame stretching out over a 90 degree span. If the flame breaks on one side or the other only the largest degree span is counted.

Class 3 has addl. parameters (LFL<0.1kg/m3 and HOC> 19,000kJ/kg)

ASTM E681- Class 2 (e.g., propellant in Hairspray)



The flame must be a solid flame stretching out over a 90 degree span. If the flame breaks on one side or the other only the largest degree span is counted.

Class 2 has addl parameters (LFL>0.1kg/m3 and HOC <19,000kJ/kg)

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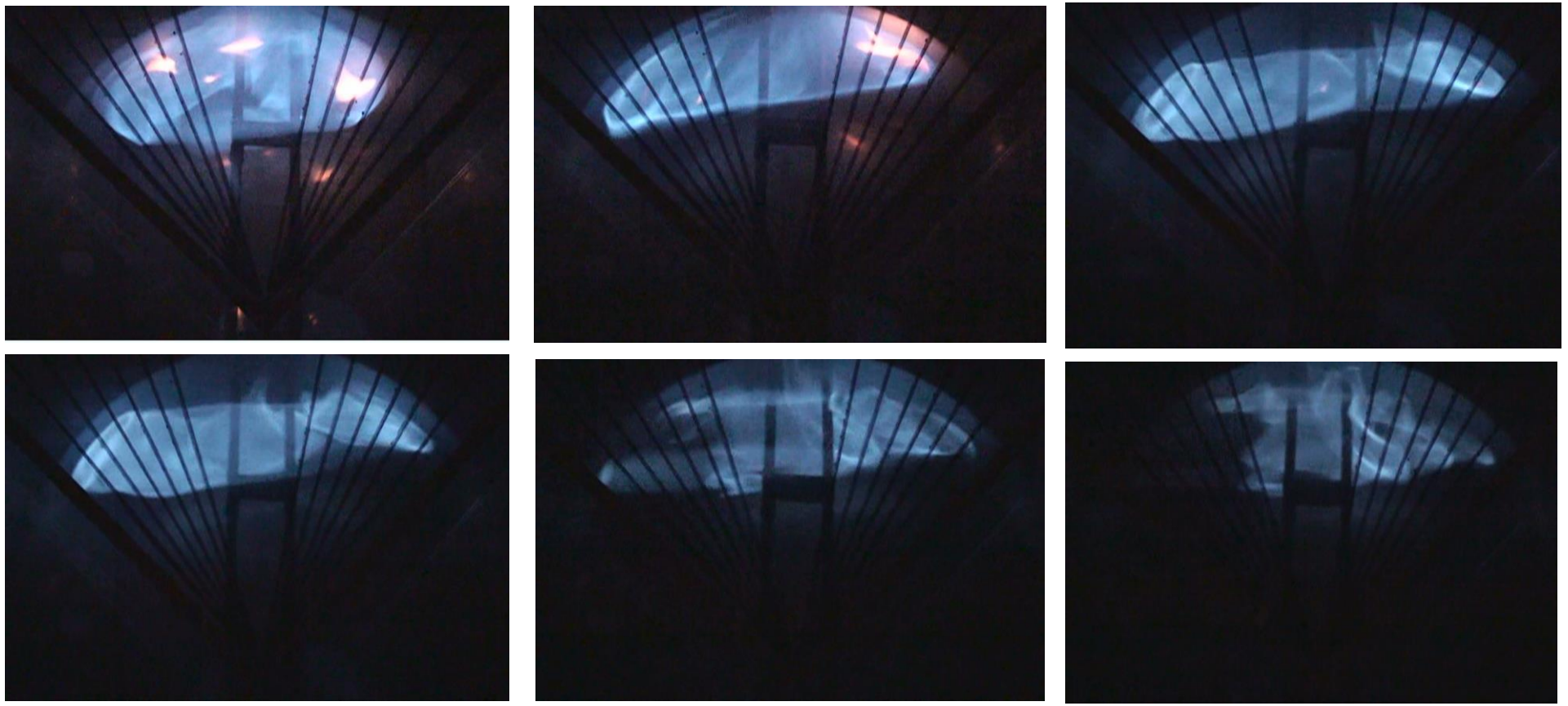
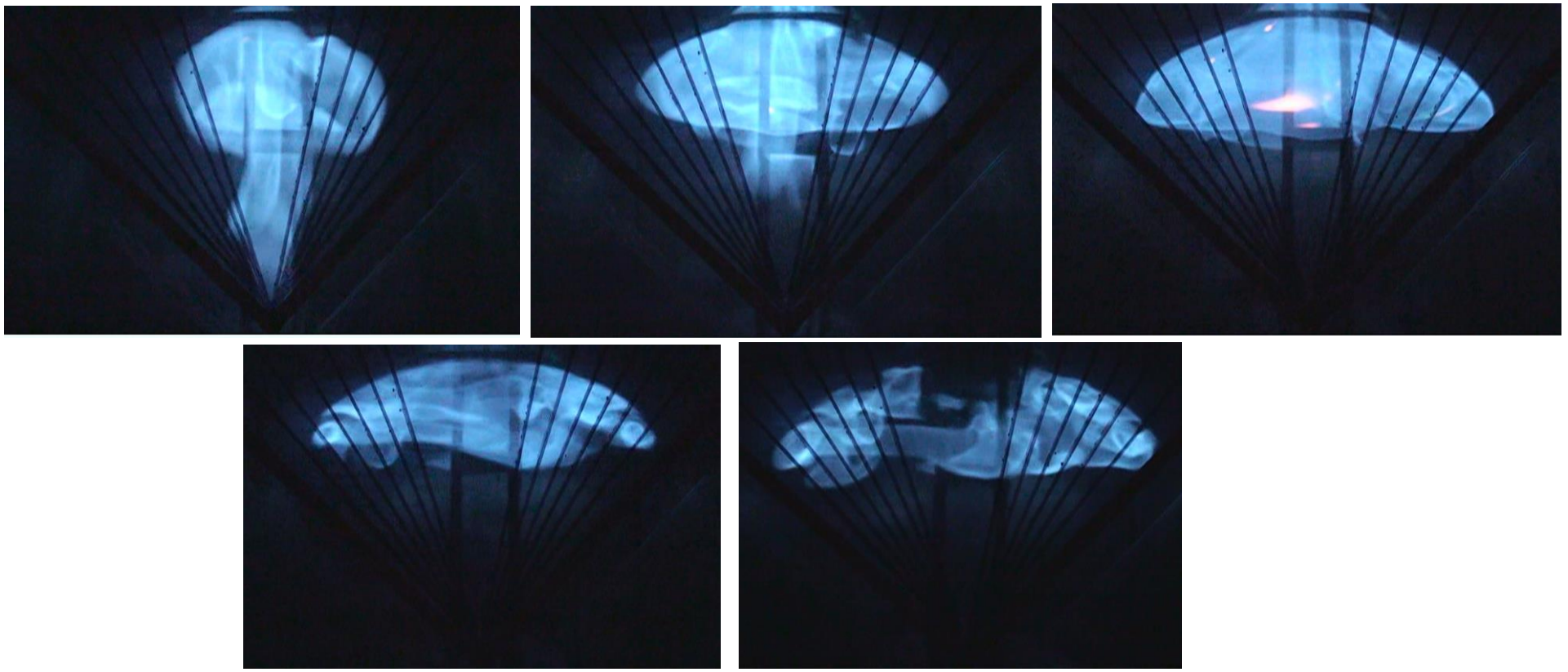
ASTM E681- Class 1 – Does Not Propagate Flame



The flame must be a solid flame stretching out over a 90 degree span. If the flame breaks on one side or the other only the largest degree span is counted.

ASTM E681- Class 2L (Lower Flammability)



The flame must be a solid flame stretching out over a 90 degree span. If the flame breaks on one side or the other only the largest degree span is counted.

Class 2 has addl parameters (BV<10cm/sec, LFL>0.1kg/m3 and HOC 19,000kJ/kg)

Refrigerant Concentration Limit (RCL)

Refrigerant Concentration Limits are used to determine the maximum concentration limit allowed in an occupied space of a refrigerant

- RCL is based on toxicity and / or flammability

What's the same?

- RCLs are still used to determine allowed concentrations in occupied spaces
- Mitigation is required when concentrations exceed RCL

What's different?

- R-410A has an RCL of 140,000 ppm
- Low GWP A1 and A2L refrigerants have RCLs between 16,000 and 50,000 ppm.

What do I need to know?

- Mitigation will be needed if 25% of LFL is reached (effective room volume).
- Refrigerants with RCLs based on toxicity limits may require similar mitigation

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Some Fluorocarbon Refrigerant Safety…

When working with refrigerants, similar to other compressed gases…

- Potential for frost bite
- Displace oxygen (RCL basis)

Hydrogen fluoride (HF) is a combustion product of old A1 refrigerants (in use for 90 years) and new A2L refrigerants

- HF forms when any fluorocarbon refrigerant, including those used today, undergoes combustion, partial combustion, or thermal decomposition
- HF gas is a lung irritant and HF acid, depending on concentration, is a skin irritant

What do I need to know?

- A1 and A2L refrigerants have the same combustion products, so personal protective equipment should be worn by technicians and first responders regardless of refrigerant when there is potential for exposure until decontamination is complete
  - PPE should be used in any type of release
  - Neoprene gloves should be used for acid clean-up
  - Leather gloves should be used with liquid refrigerants
- Machine rooms are required for large charge sizes with precautions related to large charge sizes of compressed gases

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Selection of Lower GWP Refrigerants

Selection of new lower GWP refrigerants is a complex process and includes;

- **Direct** Global Warming Potential (**GWP**) (EPA focus)
- **Indirect** Global Warming – **Energy Efficiency** (power plant emissions) (DOE focus)
- **Toxicity**
- **Flammability** (safety classification 2L, 2, 3)
- **Material compatibility** and stability
- Compressor, heat exchanger, and **line sizing**
- Heat Transfer
- Refrigerant cycle characteristics for cooling, heating, and extreme operating conditions
- Operating pressures and glide for mixtures
- Product application type (residential, commercial packaged, VRF, chillers, refrigeration, etc.)
- Applied Cost

- Extensive work has been done by the refrigerant manufacturers and equipment manufacturers. For example, one company alone has evaluated 431 refrigerants for 20 different system types
  - This included A1, A2L, A2, A3, B1, and B2L safety category (ASHRAE 34)
  - Many of the new refrigerant options are mixtures (ASHRAE 34 “400” series and “500” series)

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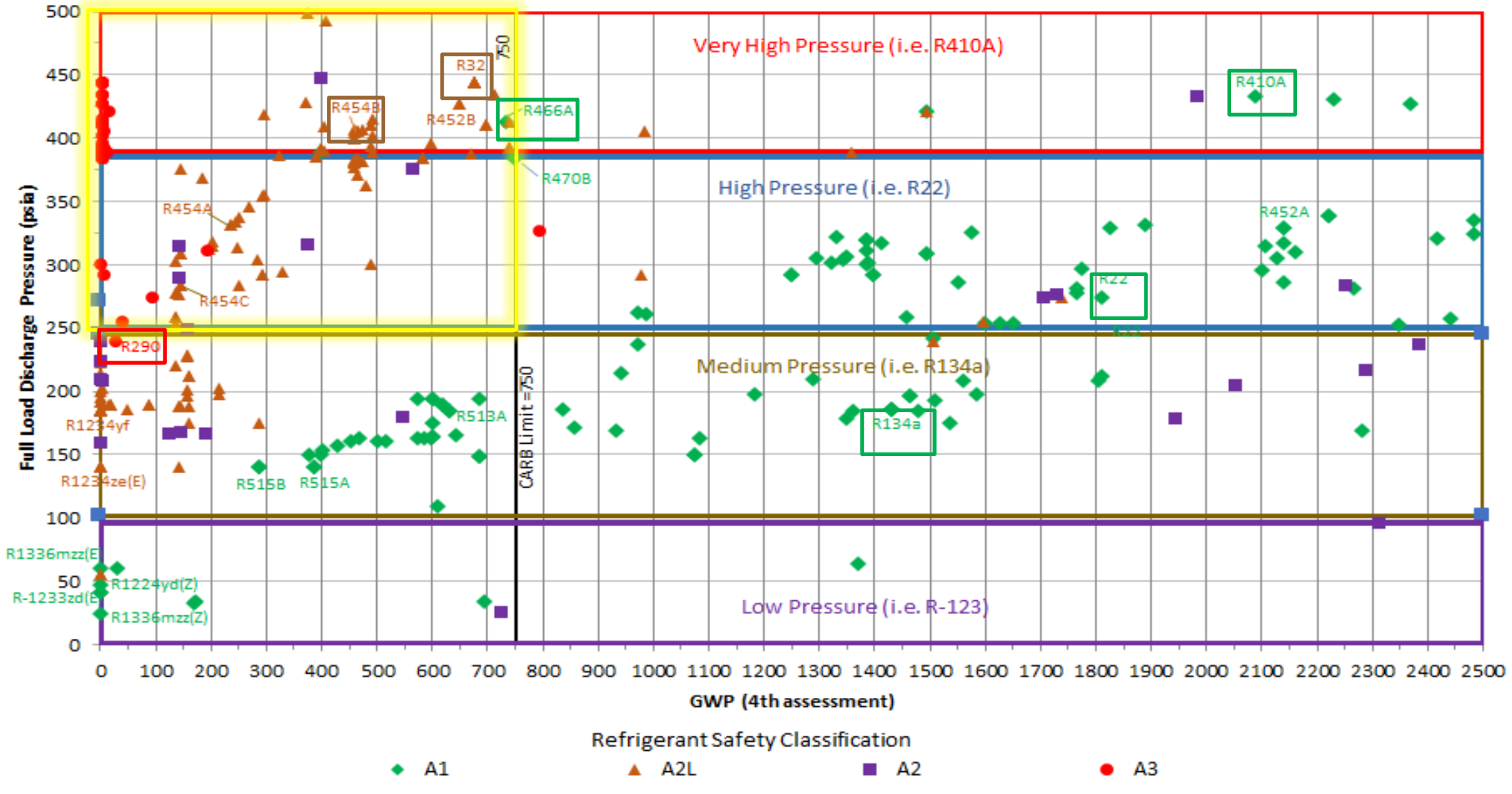
Possible Refrigerant Options for Residential and Light Commercial



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Air Conditioning Refrigerants

- A1: Current AC refrigerant R-410A (GWP 2088)
  - 50% HFC-32 (A2L) + 50% HFC-125 (fire suppressant)
  - HFC-125 has a high global warming potential (GWP) of 3500 (RCL 75,000 ppm)

- A2Ls: HFC-32 (R-32) and HFO-1234yf are pure refrigerants
  - R-32 is used in home AC (GWP 675) (RCL 36,000)
  - HFO-1234yf (or YF) is used in automobiles and could be used in some chillers in machine rooms (GWP 2) (RCL 16,000)

- A2L: R-454B is a blend of 68.9% HFC-32 and 31.1% HFC-1234yf (GWP 465)

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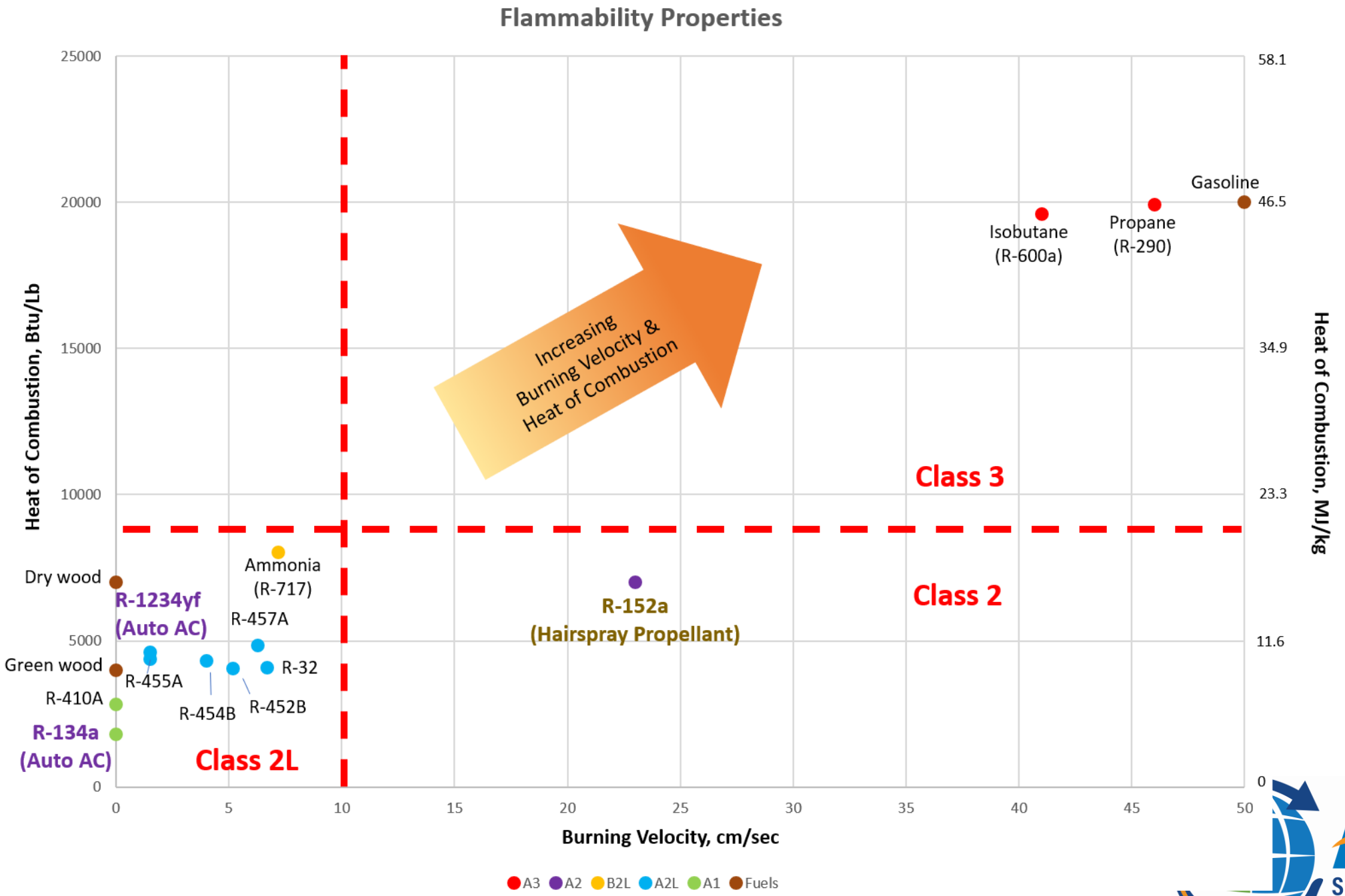

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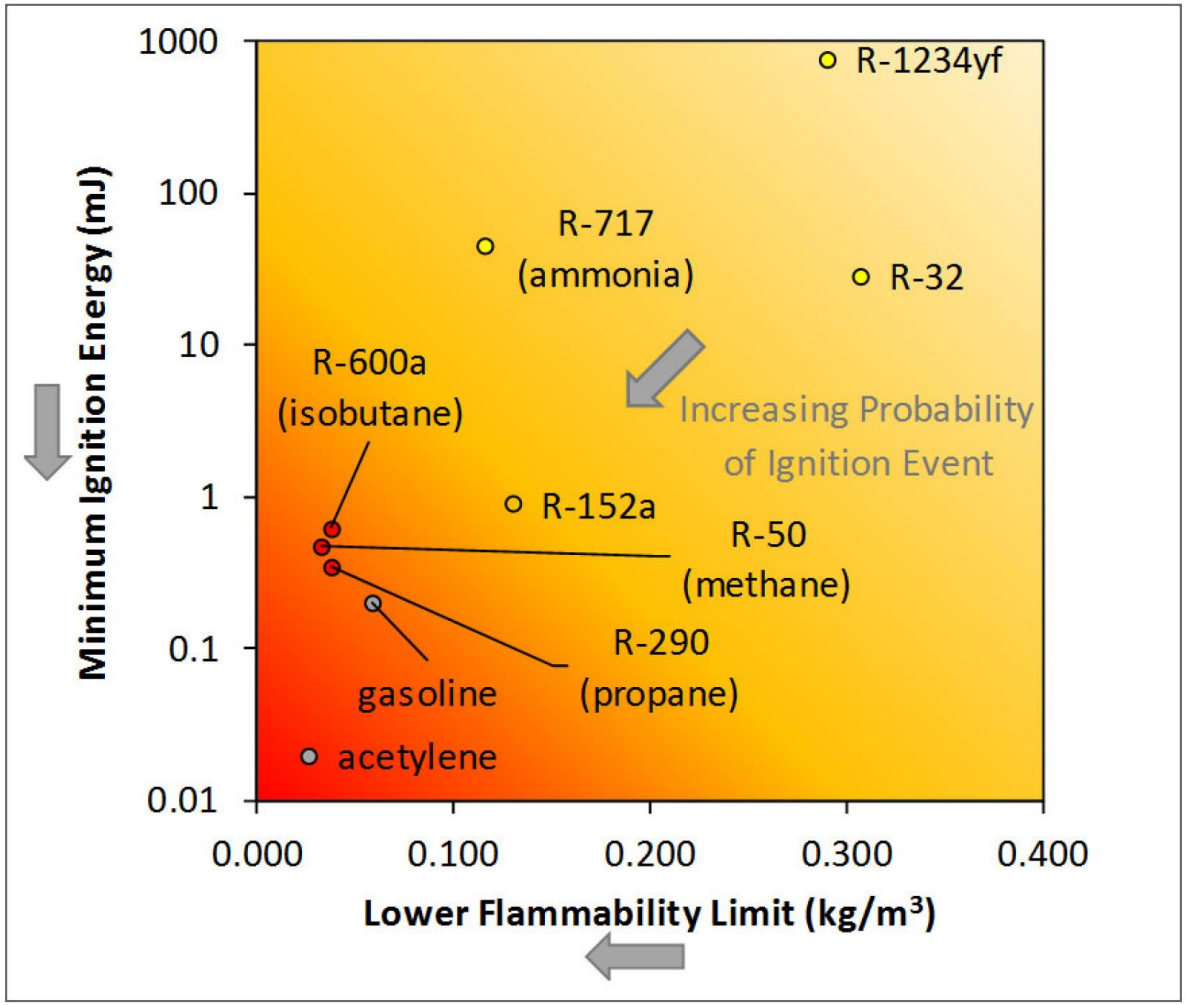
Flammability – Minimum Ignition Energy (MIE)



- Hydrocarbons require relatively low energy levels to ignite
- MIEs of A2Ls are much higher than hydrocarbons
- Many potential ignition sources for hydrocarbons (e.g., static spark) will not ignite A2Ls
- Many common household items (toasters, electric heaters, etc.) will not ignite A2Ls

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AHRTI – 8017 A2L Potential Residential Ignition Sources

Competent Ignition Sources

1. hot wire,
2. safety match
3. lighter flame insertion,
4. leak impinging on candle,

No Ignition

- cigarette insertion
- barbeque lighter, plug & receptacle
- light switch
- hand mixer
- cordless drill
- friction sparks
- hair dryer
- toaster
- hot plate insertion
- space heater insertion.

Bottom Line: Live flames are competent ignition sources for A2L refrigerants.

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A2L Refrigerant Ignition Properties

A2L Refrigerants are difficult to ignite

- Require high ignition energy to ignite
- Require high levels of concentration to be flammable
- Hot surface ignition temperatures typically higher than 800^{o}C

They also have lower flammability characteristics

- Low burning velocities
- Low heat of combustion
- Do not always fully combust

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Fire Service / UL / AHRI Technical Panel

- Fire Service / UL / AHRI Technical Panel established
  - Education between fire service and industry to ensure best outcome
  - Answer questions for fire service training development
  - Project test plan in development: release of refrigerant in a structural fire
- Develop training for fire service
  - Refrigerant properties
  - Safety standards
  - PPE

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Key Points About the Transition

- Most of the basic chemical/physical properties of next-generation refrigerants are very similar to previous generation (CFC/HCFC/HFC) refrigerants
- Class A2L refrigerants are already being used safely
  - Global auto industry (including U.S. and Canada)
  - Air conditioning and refrigeration equipment in the European Union, Australia, Japan, Thailand and other countries
  - Small appliances as approved by the Environmental Protection Agency (EPA)
- Flammable refrigerants will only be used in new systems/applications that are designed to mitigate risks, and where allowed by appropriate codes and standards
- Safety Data Sheet (SDS) requirements for handling should be followed for all refrigerants
- A1 and A2L refrigerants:
  - Form HF
  - Low fuel load (heat of combustion) especially when mitigation measures are employed

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A2L Equipment System Level Testing

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Whole room scale testing videos

Important Notes:

- Research was developed to better understand severity, rather than the probability of an ignition event
- Low probability (unrealistic events) were forced to occur
  - The ignition sources used in this project were intentionally continuously operating open flames and high energy ignition sources
  - Multiple ignition sources were used simultaneously and placed in locations where combustible mixtures were most likely to occur
  - The refrigerant release rates used were much higher than safety standards allow (based on 4 minute complete release)
- The safety standards were then designed to prevent these scenarios from happening

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Room 2L Release Research Testing

- Some the initial research testing evaluated refrigerant leaks into a room and exposure to ignition sources
- This work was used to develop standards designed to prevent flammable cloud formation in the event of a refrigerant leak
  - 4x safety factor
  - Factory installed and qualified location for refrigerant detectors
  - Active mitigation by means of circulation
  - Minimum room area
  - Control and qualification of ignition sources in units

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PTAC with propane (PTAC16)

UL Test Code	PTAC16 Report-09007-02
Test Series Description	Evaluate m1 per UL 60335 2-40 (no mitigation required)
Test Series Description	R-290 Refrigerant released from PTAC into simulated motel room with no mitigation Target charge: 114g; Actual release: 110g R290, 20 g/sec; LFL = 2.1% v/v
Room Size	The simulated room was 4.0 x 4.8 x 2.4 m (13 x 16 x 8 ft) in size. The enclosed room volume was 46 m^3 (1620 ft^3). A mock bed was positioned in the room
Obstruction Present	Platform in room to simulate a bed
Leak Location	Corner of wall
Refrigerant Source	The source of the refrigerant leak was from a pressurized tank of liquid refrigerant (outside the test room). No refrigerant oil was used. The leaked refrigerant emerged from a 1/4" tube at the right side of the evaporator coil face, angled outward.
Ignition Sources	The ignition sources were placed at two locations. Each location included two electric arcs in a tree assembly at 0.025 m and 0.15 m (1 in. and 6 in.) above the floor. The spark ignitors were activated 5 second after the end of refrigerant release

Propane flame propagates at floor level; two deflagration vents burst and one melted open

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PTAC-07

UL Test Code	PTAC07 AHRTI Report-09007-01] No Mitigation
Test Series Description	47.4 g/sec leak from PTAC into Simulated Motel Room
Test Description	R-452B Refrigerant released from PTAC into simulated motel room. Target charge size was 1.82kg which is the m1 charge per UL 2-40 (no mitigation required). The actual release was 1.92kg (47.4g/sec)
Room Size	4.0 x 4.9 x 2.4 m (13 x 16 x 8 ft) with a gross volume of 47 m^3 (1664 ft^3) and net volume of 45.6 m^3.
Obstruction Present	Platform in room to simulate a bed
Leak Location	Center of wall
Refrigerant Source	Pressurized tank of liquid refrigerant (outside the test room) without refrigerant oil. The leaked refrigerant emerged from a 1/4" tube at the left side of the evaporator coil face, angled outward
Ingition Sources	4 candles and 3 electric sparkers. The ignition sources were energized 83 seconds after the start of discharge

Visual fog from condensed water vapor due to the low temperature of the refrigerant
LFL = 11.9% v/v

Bottom Line: Small blue flame extinguished right away, no further propagation

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Comparison of UL 60335-2-40 m1 Condition

Comparison of A2L and A3 refrigerant testing

- A2L ignition is localized without propagation throughout the room
- There is a visual fog in the room which is condensed water vapor due to the low temperature of the refrigerant (-60°F)

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Research and the Safety Standards: Ignition Source Protection

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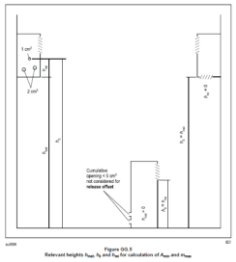
Safe Application of A2L Refrigerants Summary

UL60335-2-40 3rd Edition Summary for a **Residential Ducted Unit (direct system)** A2L Refrigerant Requirements

Minimum Area Check (A_{min})
- Safety factor of 4
- Or safety factor of 2 with additional measures
- Per Annex GG



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Service Training
and Education Annex DD, Annex HH

8

Ignition Source Isolation
Per UL 60335-2-40
Annex FF

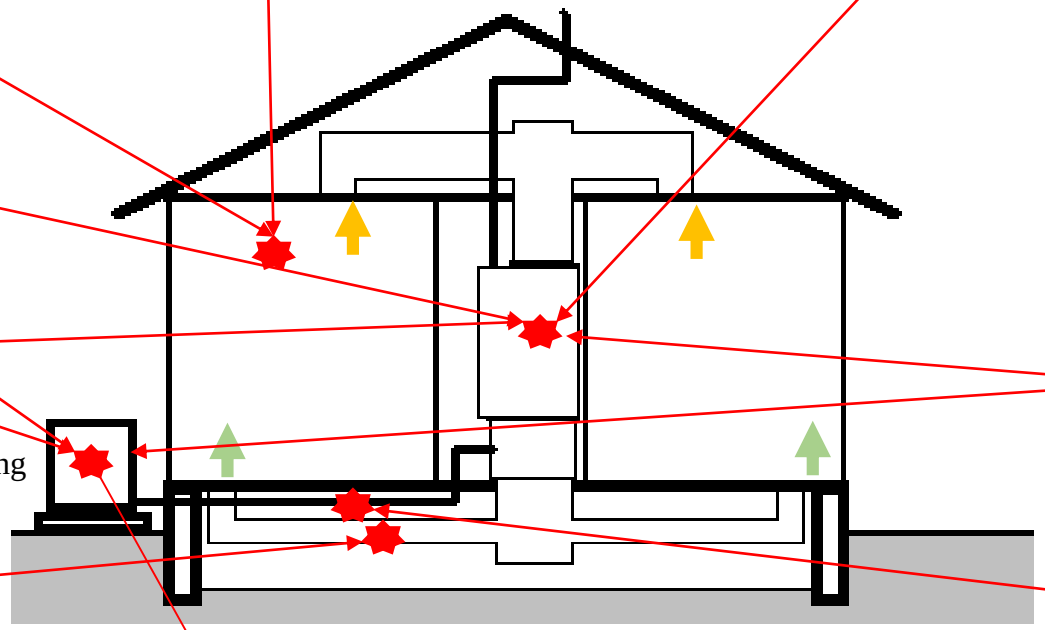
1

No Competent Ignition
Sources in unit and ducts
Per 22.116, Annex KK, 22,117

1

6 **Active mitigation for leaks**
detect, circulate an dilute
Annex GG

Residential Down Flow
Air Conditioners with Gas Heat



Condensing Unit

2 **Refrigerant Charge Limits** (UL60335-2-40)
m1, m2, m3 per Annex GG1.2
R-32 m1=4.1 lbs., m2=26.8 lbs., m3=134.1 lbs.
R-454B m1= 4.0 lbs., m2= 26.0, m3=130.2 lbs.

5 **Factory Installed Refrigerant Detector**
- UL60335-2-40, IEC60079-29-1 and Annex LL, Annex MM
- UL qualification testing
- UL approved
- Safety Circuit approved
- Factory Calibrated
- Self Test Routine (one time/hr.)
- Fail safe mode with fan on
- Field inspection enable feature

4 **Labeling and Literature**
Per UL60335-2-40
Per 101, Annex DD

3 **Refrigerant Piping** (UL60335-2-40)
Per 22.116, 101.DVG
- Protected lines
- Qualified joints (ISO 14903)
- Field pressure test
- Additional requirements for VRF

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UL60335-2-40 22.112DV.4

“Appliances shall have protective means such as a fusible plug, a rupture member, soldered or brazed tubing joints, special terminals, or pressure relief valves, or shall be so constructed that some part of the system will safely relieve the pressure in case of fire.”

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Air Conditioning, Heating, and Refrigeration Institute

- AHRI is the trade association representing manufacturers of heating, cooling, water heating, and refrigeration equipment (more than 300 members).
- AHRI is internationally recognized and develops standards for and certifies the performance of many of the products manufactured by our members (Core Mission).
  - AHRI is actively engaging in the development of refrigerant policy beyond codes to communicate technical challenges
  - AHRI has been actively engaged in discussions with respect to building codes with other stakeholders for years
- The majority of AHRI members are original equipment manufacturers (OEMs)
- Industry, Economic, and Regulatory Policy Dynamics

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AHRI Safe Refrigerant Transition Task Force

- AHRI has formed a **Safe Transition Task Force** which has 7 working groups that are open to interested participants
- Goals are to **evaluate end-to-end supply chain to enable the safe commercialization of low GWP refrigerants** in a timely manner and support the effort to reverse the **global warming trend**.
  - Communications
  - Safety Training
  - Codes and Standards
  - Transportation/Storage/Packaging/Handling
  - Bulk Storage and Manufacturing Facilities
  - Installation/Operation/Maintenance
  - Recovery/Reclaim/Destruction
- Establish structure to ensure continuous improvement
  - Incident investigation
  - Continuous maintenance standards
  - Training upgrades
- Leverage learnings around the world
  - **Widespread use of A2L refrigerants already in global HVAC&R industry** in European Union, Japan, India and Australia and auto industry (including US and Canada)

There is a new website where additional information can be found at the following address;

http://www.ahrinet.org/SafeRefrigerant

Contact one of the following people if interested in working with the Safe Transition Task Force

Helen Water-Terrinoni HWalter-Terrinoni@ahrinet.org
Christophe Bresee CBresee@ahrinet.org

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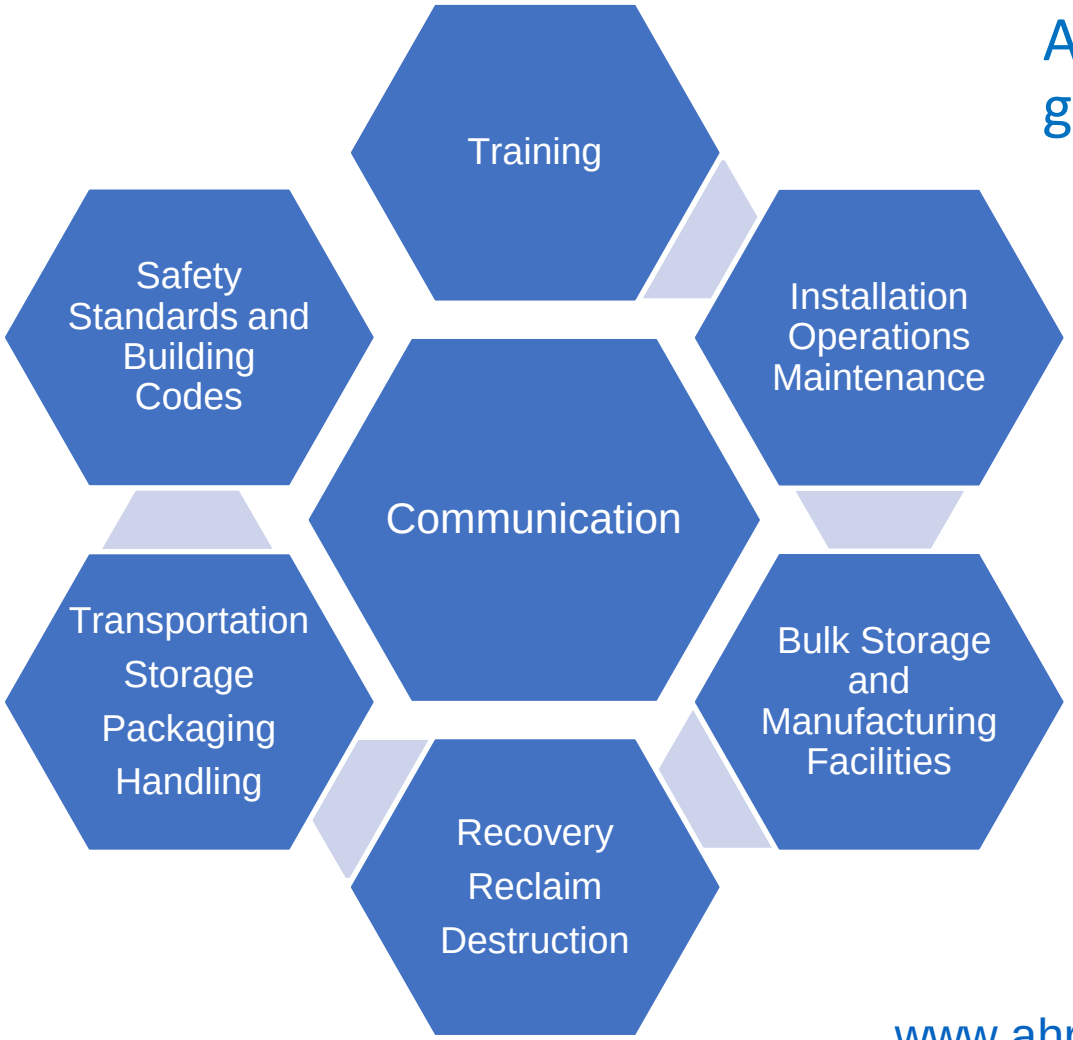
Regulatory Policy "Writing on the Wall" Lead to the Creation of the AHRI Safe Refrigerant Transition Task Force



AHRI Safe Refrigerant Transition Task Force working groups are open to volunteers

- Over 150 members from more than 60 organizations
- Identifies and resolves issues related to transition
- Develops communications, training materials and information to support regulatory compliance and the safe use of low global warming potential (GWP) refrigerants
- Building on refrigerant training programs already in place in Europe, Australia, and Japan; and from several companies who are training in the U.S.

www.ahrinet.org/SafeRefrigerant

AHRI SAFE REFRIGERANT TRANSITION TASK FORCE

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Industry Regulatory Challenge

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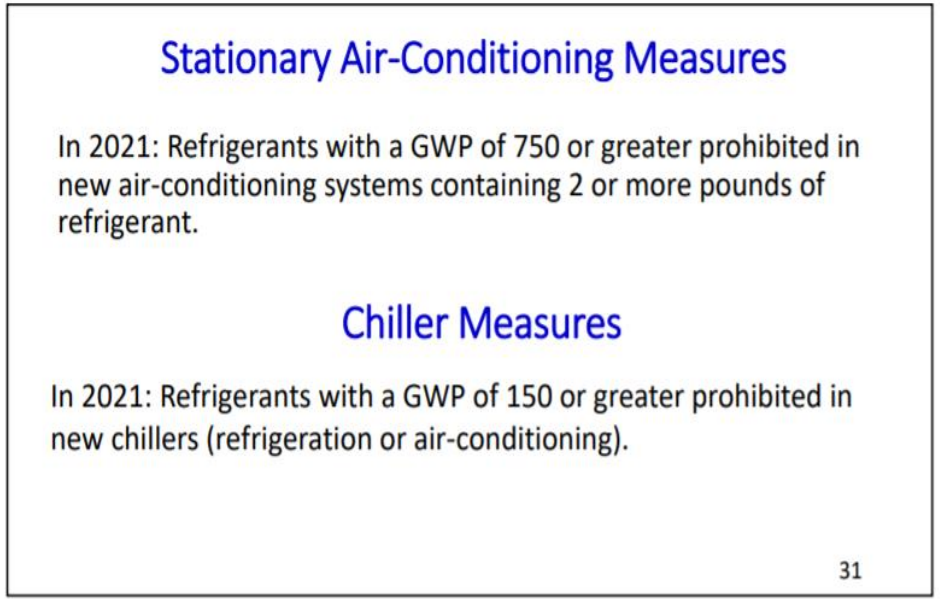
California

In 2017, the California Air Resources Board (CARB) proposed high global warming potential refrigerant bans*

- Chillers: Jan 1, 2021
- Air-Conditioning: Jan 1, 2021
- Commercial Refrigeration: Jan 1, 2022



* Public Workshop on Rulemaking Proposal: High Global Warming Potential Refrigerant Emissions Reductions California Air Resources Board October 24, 2017
https://ww3.arb.ca.gov/cc/shortlived/meetings/10242017/public_workshop_snap-california_10-24-17_presentation.pdf?_ga=2.182187808.621576105.1573738237-276427812.1565094831

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Industry Request for Additional Time

AHRI counterproposals:

- Chillers 2024 (accepted)
- Air conditioning: 2023
  - Two additional years
  - Harmonize with new minimum energy efficiency standards going into effect in 2023
- Commercial Refrigeration: Maintain a medium-GWP (rejected)
- Commercial Refrigeration: 2024 low-GWP (no feedback from CARB yet)
  - Safety standard development is just now underway

September 14, 2018

Chair Mary Nichols
California Air Resources Board
1001 I Street

http://www.ahrinet.org/Portals/_Appleseed/documents/news/AHRI_NRDC_CARB_Letter_regarding_SLCP_HFC_measures.pdf

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AHRI is concerned about meeting the 2023 deadline

- There is still work to be completed to ensure a safe transition (e.g. DOT standards differentiating between A2L and A3 refrigerants)
- Supply Chain:
  - Component and other suppliers may need to build facilities to supply sensors, compressors, etc.
  - Design, testing and certification must comply with state and local building codes.
  - We do not know what will be in the final building code and cannot complete design, testing and certification
  - Supply chain must be filled. Equipment must be manufactured and shipped for distribution to supply the state

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AHRI is concerned about not meeting the 2023 schedule

- California law requires CARB to reduce HFC emissions by 2030
- AHRI has had discussions with CARB about compliance issue with building codes for 1/1/23 transition timing
- AHRI has been informed that if there is a delay, we must find a way to compensate (e.g. lower GWP limit)
  - A2Ls will be allowed under the current proposed GWP limit
  - Only AC refrigerant known with very low GWP other than A2Ls is propane
  - Sufficient propane charges are not currently allowed for most AC equipment
  - There is no other known refrigerant to comply with a very low GWP limit

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AHRI is concerned about meeting the 2023 deadline and the consequences if unable to meet the 2023 deadline

Meet the deadline	Don't meet the deadline
• Need all stakeholders to work together to ensure a safe transition. • Stakeholders are not unified • Necessary codes are not updated for supply chain readiness • Work unrelated to supply chain needs to be identified and completed	• The only ASHRAE-listed AC refrigerant with very low GWP is propane • Allowed charge sizes are insufficient for most equipment types • There are no good alternatives

Bottom Line: Stakeholders need to work together for best possible outcome

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Back up charts

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R-466A

- A1: R-466A (GWP 733)
  - Blend of 49% HFC-32 and 11.5% HFC-125 and 39.5% CF3I (fire suppressants)
  - RCL = 30,000ppm
- CF3I is a fire suppressant
  - Approved by EPA as a flooding agent for use only in unoccupied spaces
  - CF3I has low GWP, some Ozone Depletion Potential
  - RCL = 2,200 ppm

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Refrigerant Safety Classifications Properties

Refrigerant	Components Composition%	Safety Classification ASHRAE 34	Exposure Limit (RCL)	GWP (4th)	Applied GWP relative to R-410A	Operating Pressure @ 120 F SDT	LFL nominal composition	UFL nominal composition	Burning Velocity (Su)	Minimum Ignition Energy (MIE)	Heat of Combustion (HOC)	Auto Ignition Temperature (AIT)	Hot Surface Temperature (HOC)
			ppm	CO_2e	CO_2e	psia	% v/v	% v/v	cm/sec	mJ	KJg	°C	°C
R-410A	R-32/R-125 50/50	A1	140,000	2,088	2,088	433.6	-	-	-	-	5.91	>750	-
R-134a	1,1,1,2-tetrafluoroethane 10000%	A1	50,000	1,430	1,632	185.9	-	-	-	-	?	>750	-
R-404A	R-125/R-134a/R-143a 44/4/52	A1	126,000	3,922	3,878	325.8	-	-	-	-	?	<750	
R-466A	R-32/R-125/CF3I 49/11.5/39.5	A1	30,000	733	855	412.6	-	-	-	-	?	?	
R-513A	R-134a/R-1234yf 44/56	A1	72,000	629	679	184.98	-	-	-	-	?	?	
R-1234yf	2,3,3,3-tetrafluoropropene 100%	A2L	16,000*	0.31	0.32	185.0	6.20%	12.30%	1.5	8000	10.7	405	700
R-32	difuoroemethane 100%	A2L	36,000*	675	612	444.0	14.4%	29.30%	6.7	21-24	9.38	648	700
R-452B	R32/R125/R1234yf 67/7/26	A2L	30,000*	697	612	410.1	11.9%	21.60%	3.3	100-300	9.45	?	700
R-454B	R-32/R-1234yf 68.9/31.1	A2L	30,000*	465	433	405.5	11.8%	21.50%	5.2	100-300	10.3	?	700
R-152a	1,1 difluoroethane 100%	A2	12,000*	124	106	166.1	4.80%	8.0%	23	0.38	16.3	455	355
R-290	propane 100%	A3	5,300*	3.30	1.55	242.5	2.10%	9.5%	46	0.25	46.3	470	370

LFL = Lower Flammability Limit (%v/v)
UFL = Upper Flammability Limit (%v/v)
Su = Laminar Burning Velocity (cm/sec)
HOC = Heat of Combustion (KJ/g)
AIT = Auto Ignition Temperature (°C)
HST = Host Surface Temperature (°C)
RCL = refrigerant concentration limit doe roxicity risk reduction, * = 25% of LFL for flammable refrigerants

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