Low Global Warming Potential Refrigerants for Direct HVAC Applications

- Helen Walter-Terrinoni, VP Regulatory Affairs, Air-Conditioning, Heating, and Refrigeration Institute

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Disclosure

- Although Helen Walter-Terrinoni is a member of the United Nations Montreal Protocol Technical and Economic Assessment Panel (TEAP), this presentation and work is independent of the work of the TEAP

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Overview

- Introduction
- Refrigerant regulatory landscape
- Low-global warming potential (GWP) refrigerants, including the new A2L safety category
- Technical research and development informing the standards
- Safety standard upgrades for flammable refrigerants (UL60335-2-40 and ASHRAE 15/15.2)

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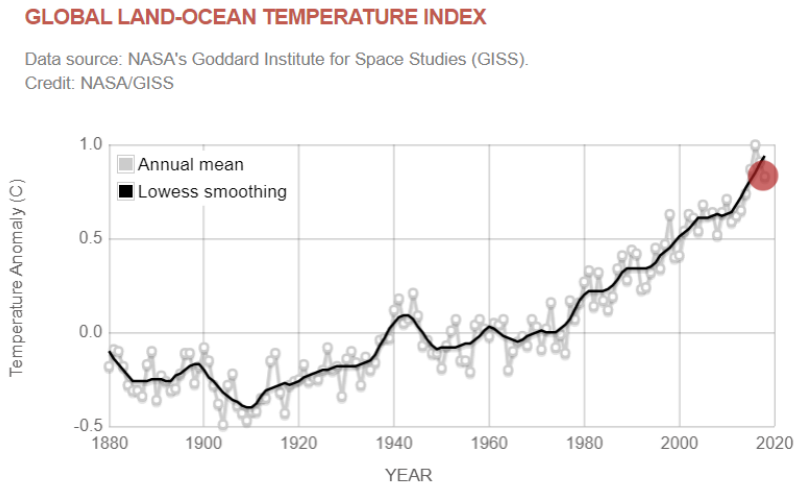
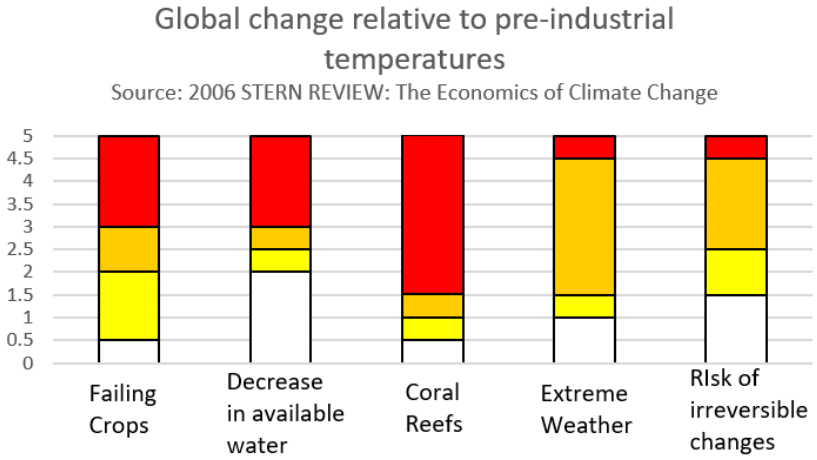
What is the Global Goal?

Reduce greenhouse gas emissions to cap global temperature **increase to +2°C**

- Current increase is +0.94°C
- Aspirational goal is no more than 1.5°C
- 1.5°C → +2°C temperature rise
  - 250 million more people exposed to drought and its consequences
  - 1.7 billion more people exposed to extreme temperatures (> 1/5 of the current global population)
- HFC transition is estimated to reduce temperature rise by up to +0.5°C
  - Refrigerants can have up to **14,000 times the greenhouse** gas impact of carbon dioxide which is the base for GWP





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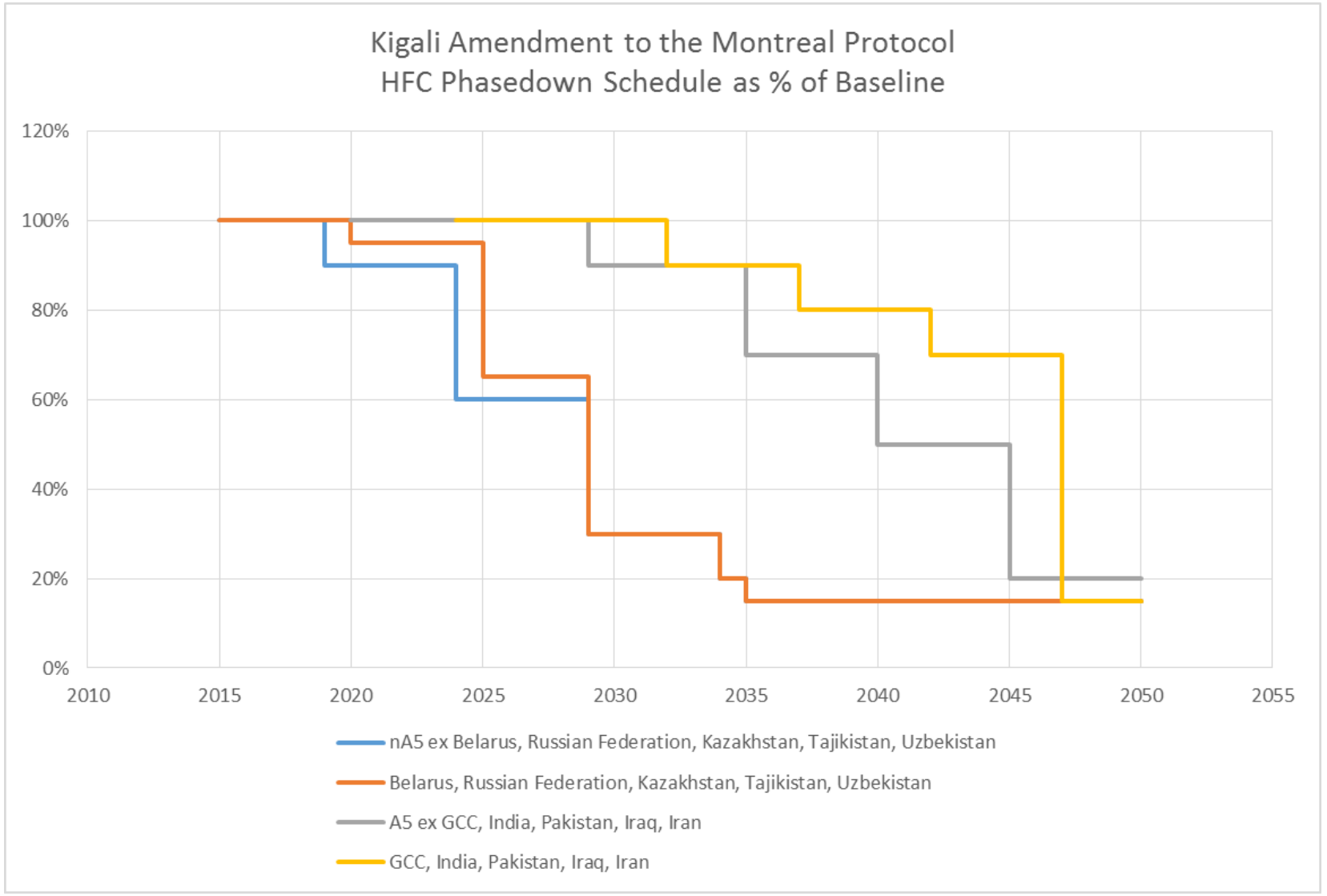
2016 Kigali Amendment to the Montreal Protocol phases down HFCs



- 92 parties have deposited their instrument of ratification
- Each party implements the phase-down in their own way
- GWP limits, refrigerant bans, quota & allocation, and refrigerant management (reclaim, leak reduction) are tools regulators typically use to fit their unique market and situation.

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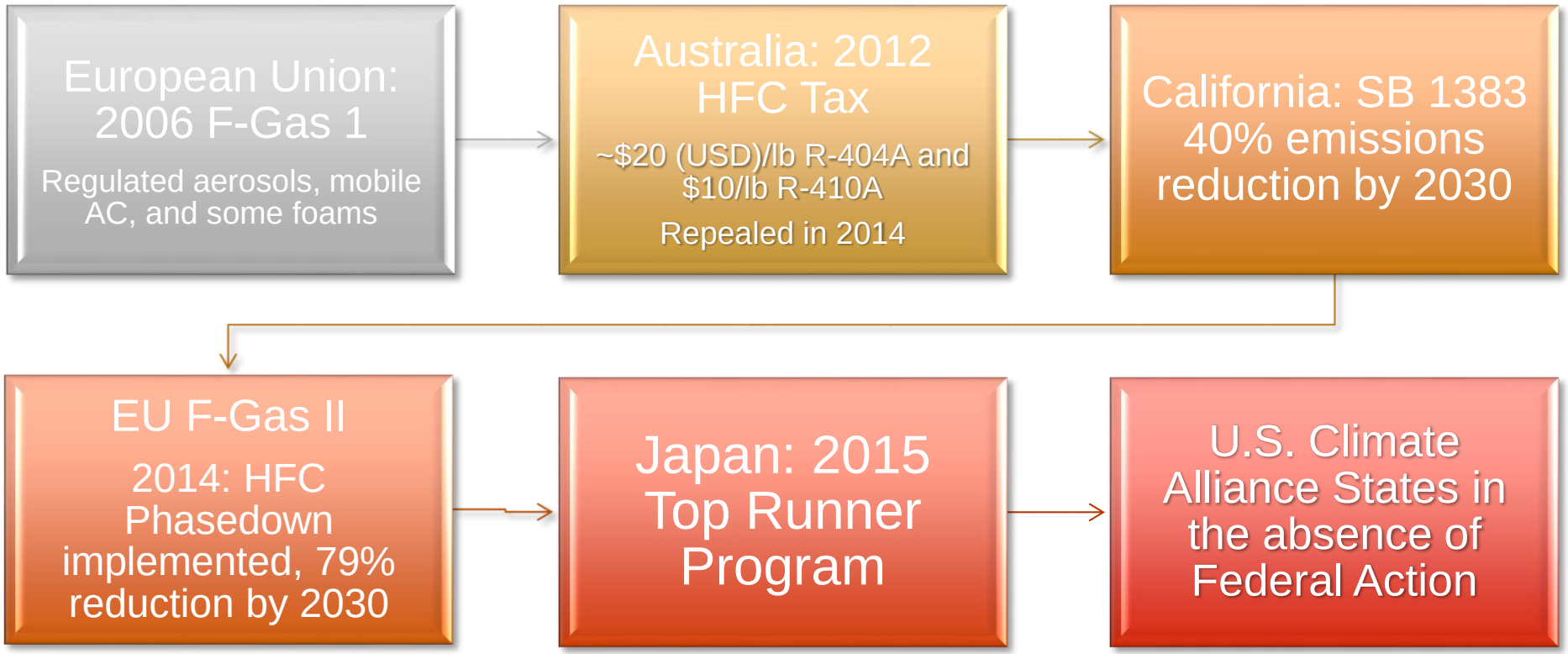
Governments are Regulating Hydrofluorocarbon (HFC) Refrigerants in their own way



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US HFC Phase-down Legislation

- U.S. has not ratified the amendment yet
- Legislation to authorize the U.S. Administration to implement an HFC phase-down of the production and consumption of HFC's proposed 4Q 2019
  - Senate Bill S2754 American Innovation and Manufacturing Act
  - House Resolution 2397 American Innovation and Manufacturing Leadership Act
- Legislation provides industry with an orderly federal transition

If you are interested in supporting the legislative effort, contact Samantha Slater, AHRI Sr. VP Government Affairs

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Regulation of HFCs

- August 4, 2017: U.S. submits formal notice of withdrawal (at the earliest, Nov. 4, 2020) from Paris Climate Agreement
- United States Climate Alliance States commit to reduce emissions commensurate with U.S. commitment.
  - 392 mayors also committed to the Paris agreement reductions
- 11 states have now included refrigerants in their greenhouse gas reductions
- California, Washington, New Jersey, Vermont have adopted HFC transition dates based on former EPA SNAP regulations, with some delays and exceptions
- Oregon, Colorado, Massachusetts, Connecticut, Delaware, Maryland, New York have made commitments and/or taken steps toward adopting regulatory programs. Final regs expected in 2020/2021

Bottom Line:

24 States and Puerto Rico are moving forward with climate regulation due to federal inaction

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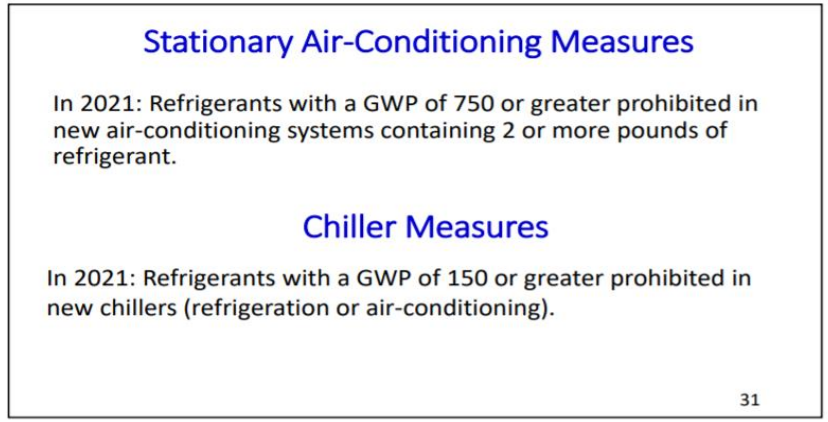
California

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

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 (rejected)



* Public Workshop on Rulemaking Proposal: High Global Warming Potential Refrigerant Emissions Reductions California Air Resources Board October 24, 2017

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Safe Refrigerant Transition

- Differences in properties of low-GWP refrigerants (e.g., low levels of flammability and toxicity) may require changes made to current commercial practices and building codes to minimize risk while meeting climate regulations
- In some cases, these are historic products (e.g. butane) that have not been used in many of these equipment types in some time, if at all.

AHRI Safe Refrigerant Transition Task Force

- Invitation to interested stakeholders to participate in an evaluation of the end-to-end supply chain to determine any gaps in planning the transition to safe use of low-GWP refrigerants.
- Initial North America focus with a commitment to socialize learnings internationally

Contact: Chris Bresee if interested in participating

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AHRI Safe Refrigerant Transition Task Force

Purpose

- **Evaluate end-to-end supply chain to enable the safe commercialization of low-GWP refrigerants**
- **Ensure continuous improvement.**
- **Leverage learnings around the world**
  - Over 150 members from more than 60 organizations
  - Building on refrigerant training programs already in place in Europe, Australia, and Japan, as well as several companies who are training in the U.S.

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Transition to Low-GWP Refrigerants

What's the same?

- The majority of the physical and chemical properties of these new Class A2L refrigerants are no different from traditional A1 (CFC, HCFC, and HFC) refrigerants

What's different?

- Low-GWP refrigerants include some lower flammability (Class A2L) and higher toxicity refrigerants

What do I need to do about it?

- Stakeholders must be aware of and properly trained in the mitigation of risks due to the lower flammability or higher toxicity properties associated with the new refrigerants

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Refrigerants: Definitions and Properties

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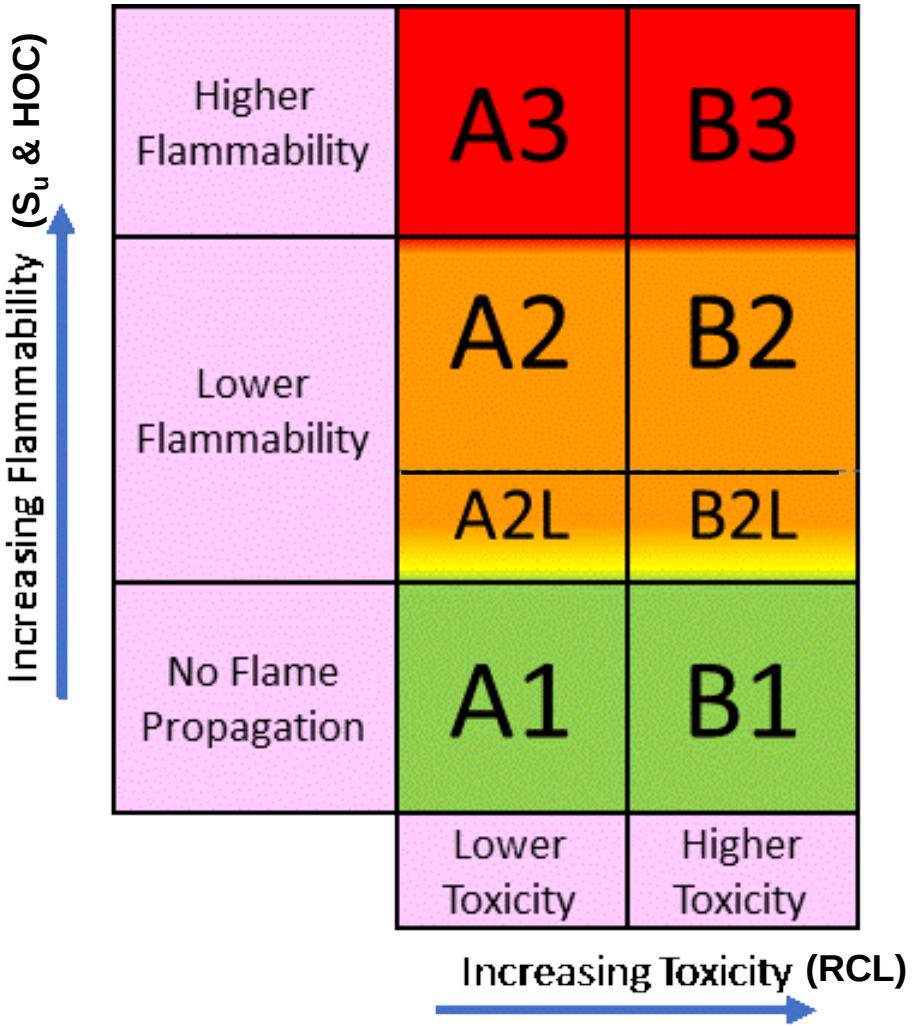
ASHRAE 34 and ISO 817 Refrigerant Classification



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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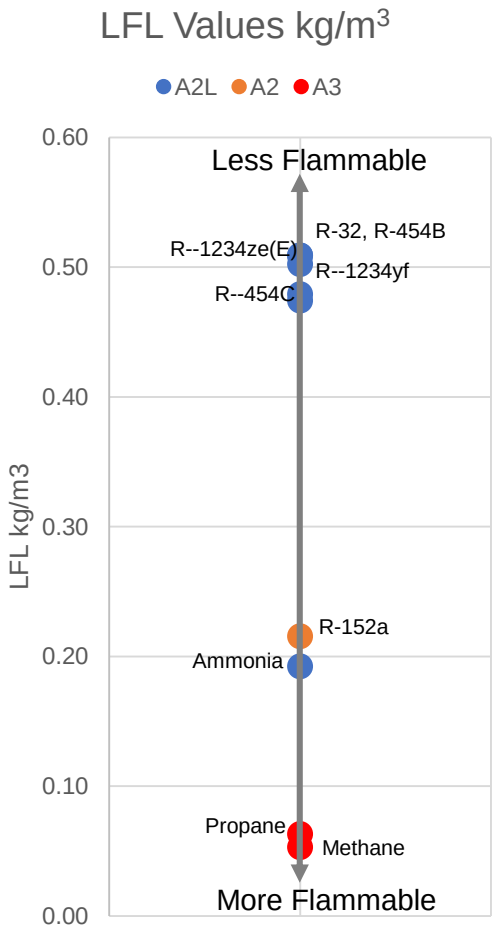
ASHRAE Classification
ASTM E-681: Flammability Limits

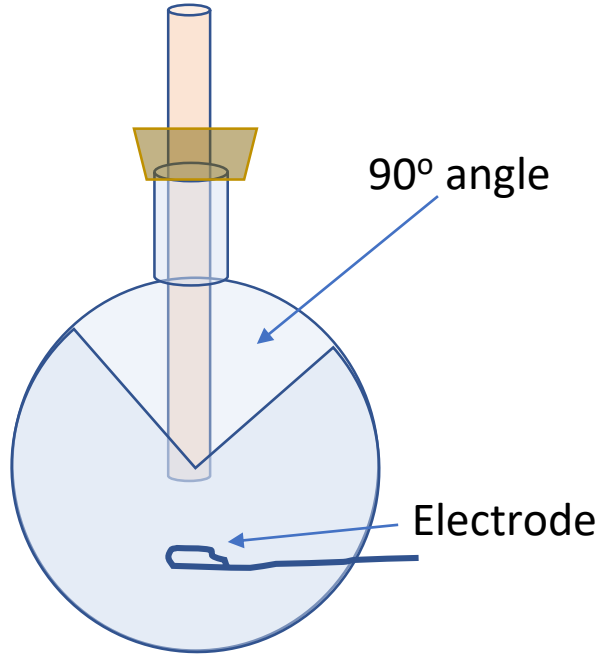


Apparatus

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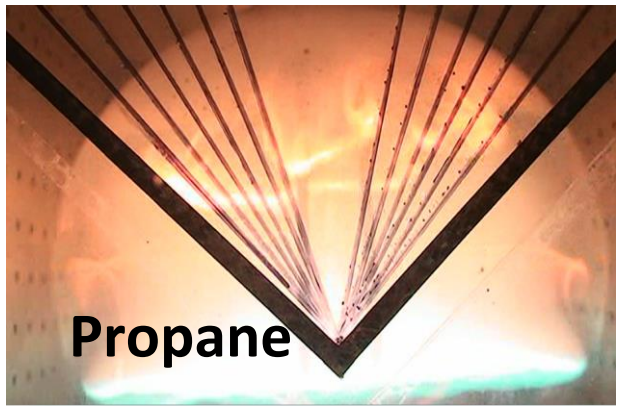
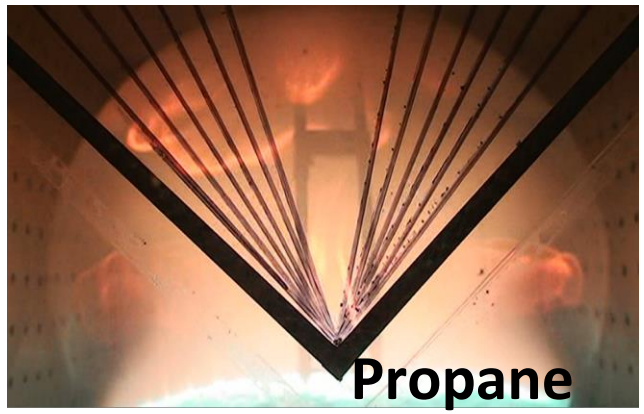
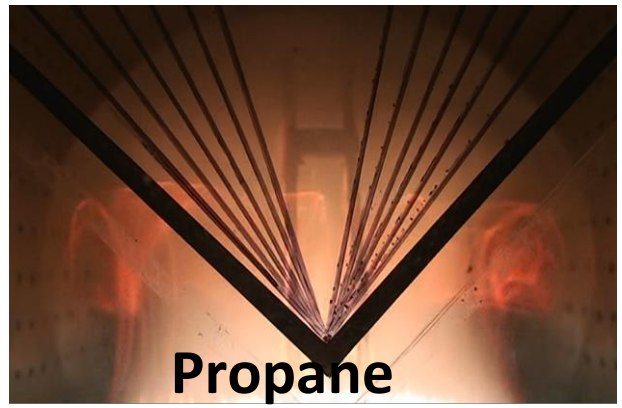
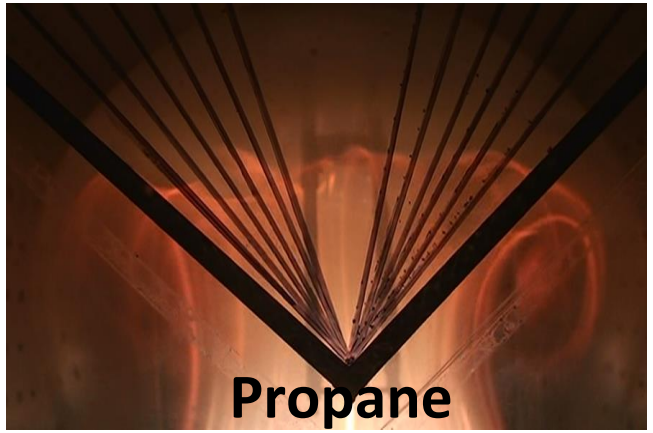
ASTM E681- Class 3 (e.g. propane)





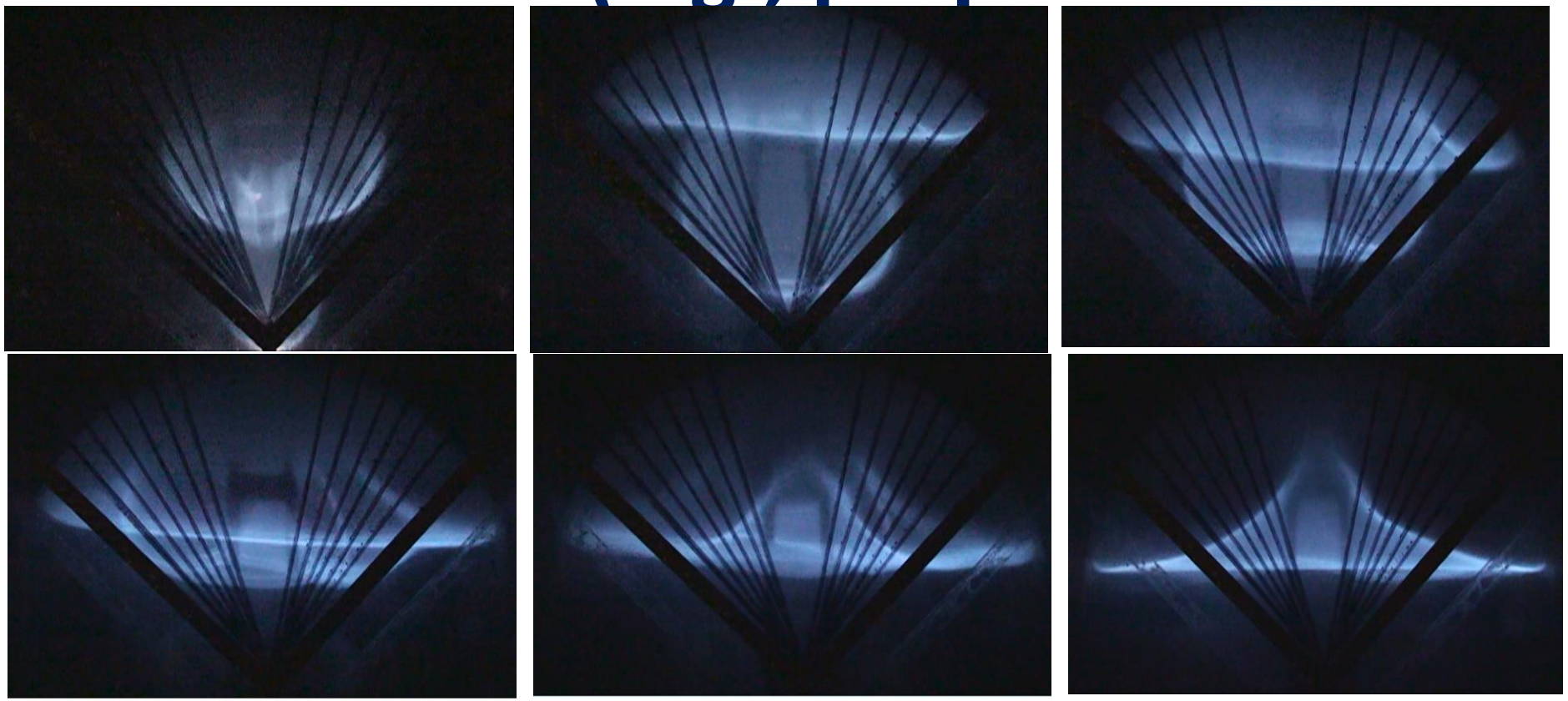




The flame must be a solid flame stretching out over a 90 degree span. If the flame breaks on one side or the other only the largest degree span is counted.

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

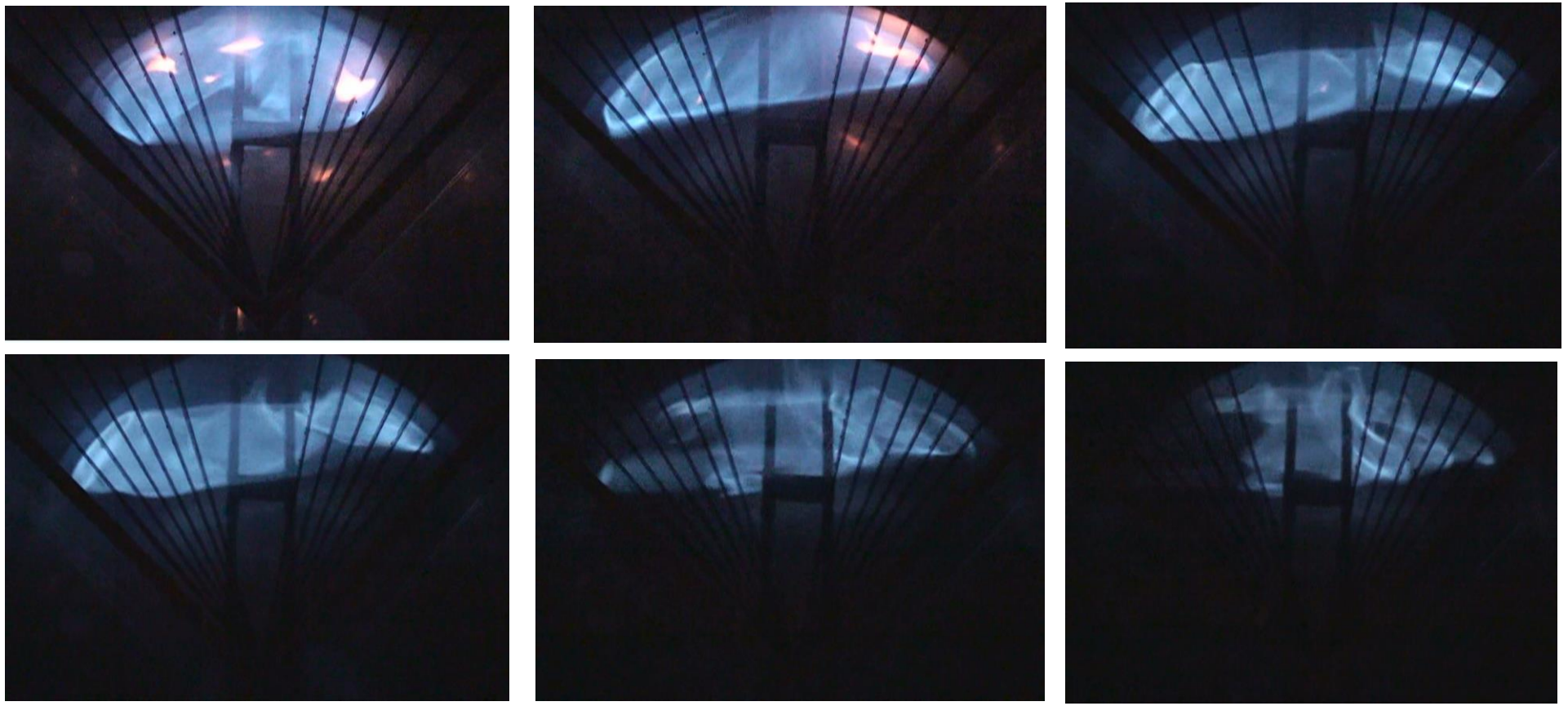
ASTM E681- Class 2 (e.g., propellant in Hairspray)



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.

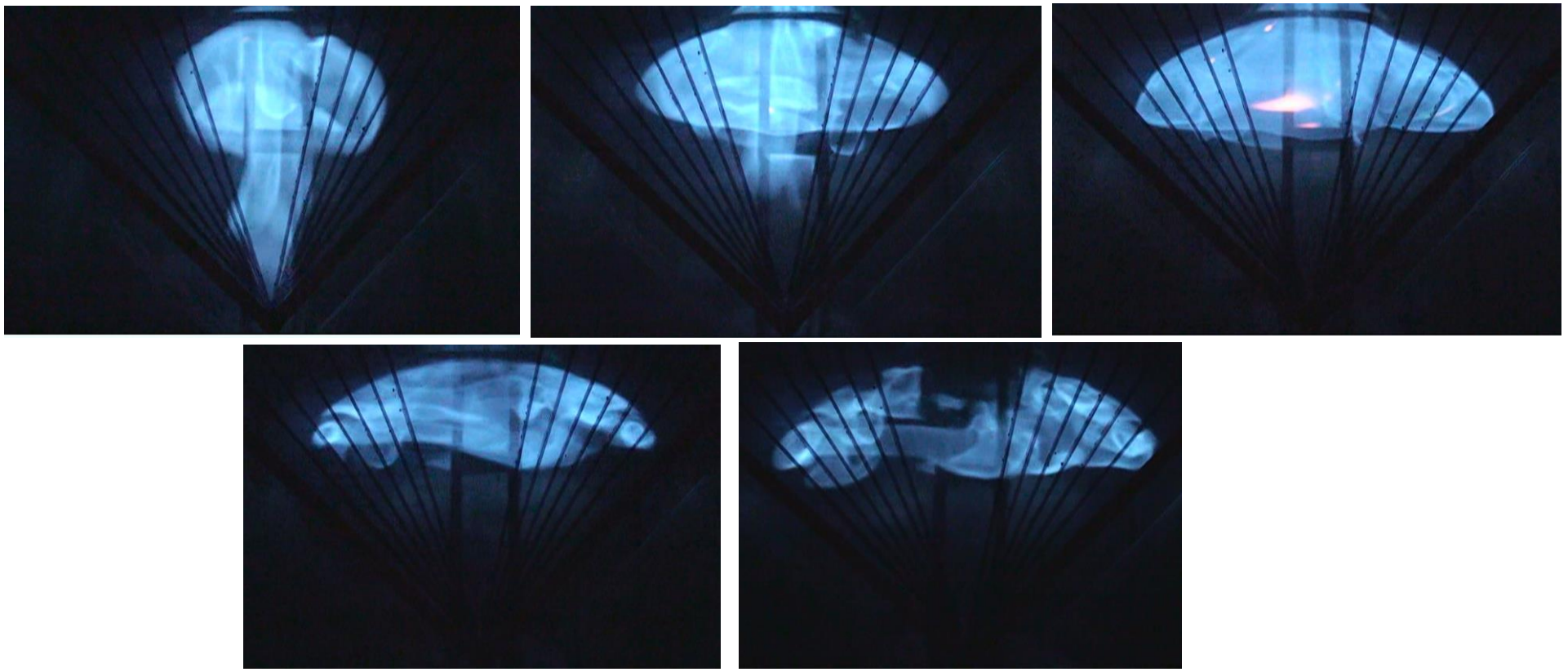
Class 2 has addl parameters (LFL>0.1kg/m3 and HOC <19,000kJ/kg)

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

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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Some Fluorocarbon Refrigerant Safety…

What do I need to know?

- Personal protective equipment should be worn by technicians and first responders regardless of refrigerant when there is potential for exposure until decontamination is complete
  - Neoprene gloves should be used for acid clean-up
  - Leather gloves should be used with liquid refrigerants (frost bite)
- Machine rooms with special controls are required for large refrigerant quantities due to hazards associated with large charge sizes of compressed gases
- Safety Data Sheet (SDS) requirements for handling should be followed for all chemicals including refrigerants

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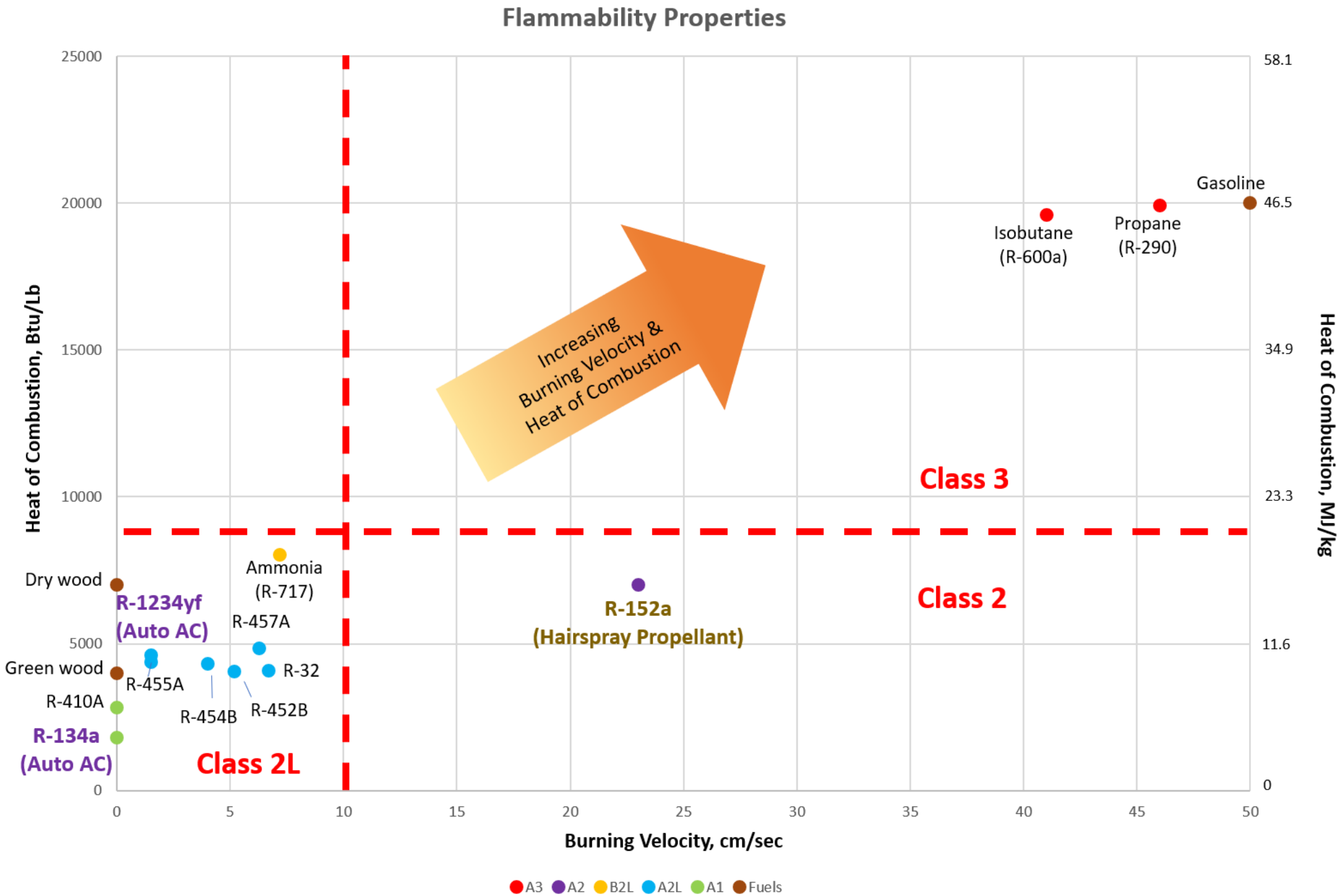
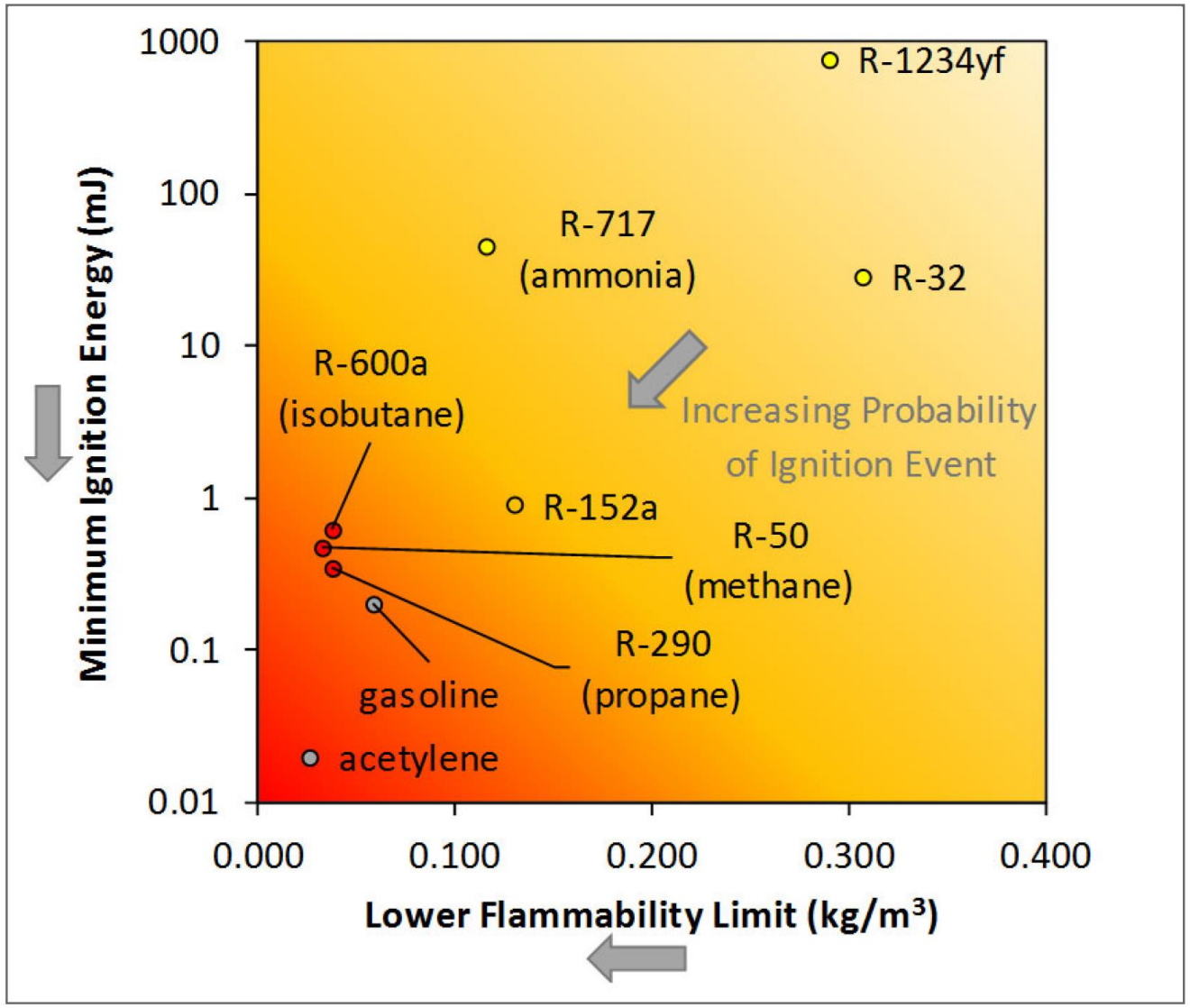

Flammability Properties
Heat of Combustion, Btu/Lb
Heat of Combustion, MJ/kg
Burning Velocity, cm/sec
25000
20000
15000
10000
5000
0
58.1
46.5
34.9
23.3
11.6
0
0
5
10
15
20
25
30
35
40
45
50
Increasing
Burning Velocity &
Heat of Combustion
Class 3
Class 2
Class 2L
Isobutane
(R-600a)
Propane
(R-290)
Gasoline
Ammonia
(R-717)
R-152a
(Hairspray Propellant)
Dry wood
R-1234yf
(Auto AC)
R-457A
Green wood
R-455A
R-32
R-410A
R-454B
R-452B
R-134a
(Auto AC)
A3
A2
B2L
A2L
A1
Fuels

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

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

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

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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

They also have lower flammability characteristics

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

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Key Points About the Transition

- Low GWP refrigerants are already being used safely
  - 80% of new cars sold in the US contain a low GWP refrigerant
  - Nearly all new European cars contain low GWP refrigerant
  - Air conditioning and refrigeration equipment in the European Union, Australia, Japan, Thailand and other countries contain low GWP refrigerants
  - Small appliances in the US as approved by the Environmental Protection Agency (EPA) contain low GWP refrigerants
- Low GWP refrigerants will only be used in new systems/applications that are designed to mitigate risks, and where allowed by appropriate codes and standards

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Research

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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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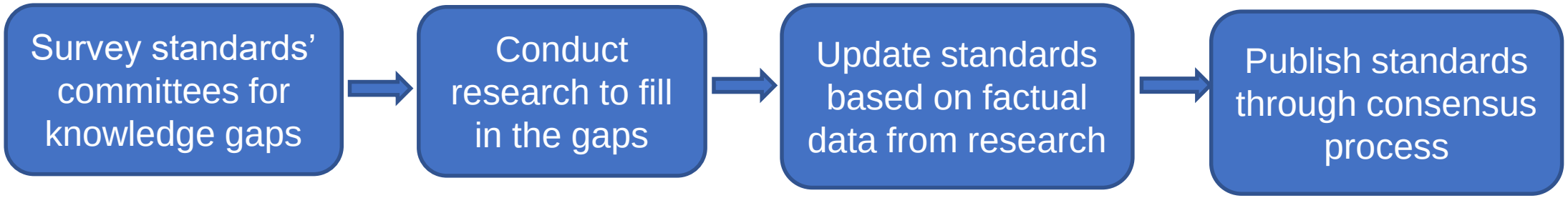
Safety Standards Updated Based on Extensive Research



- 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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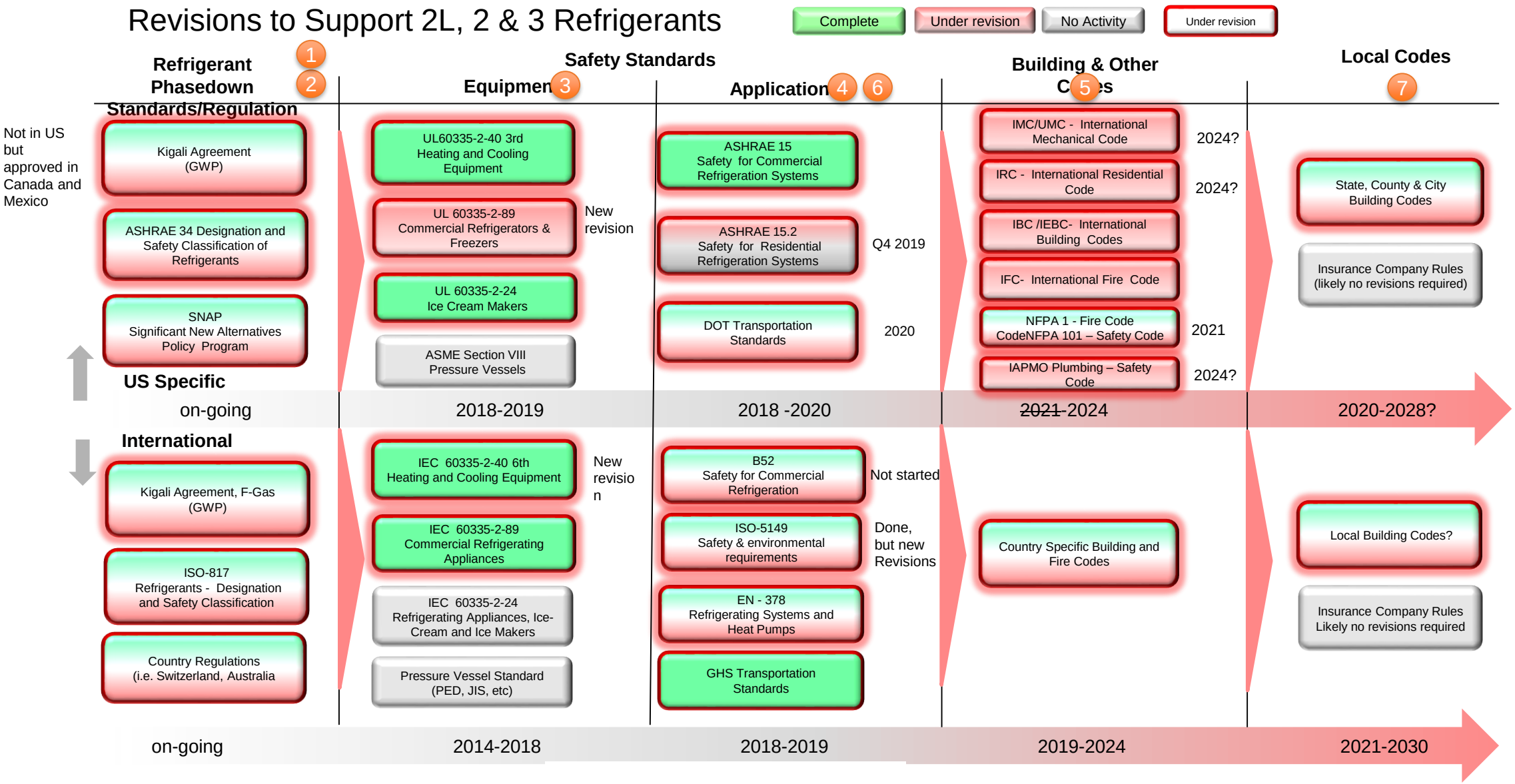
GLOBAL A2L STANDARDS AND CODES – STATIONARY PRODUCTS



Storage

- National Fire Safety Storage Requirements
  - Permit from fire code official
    - Hazardous Materials Management Plan
    - Hazardous Material Inventory Statement
  - Requires visible hazard identification signs (NFPA 704 sign)
  - No smoking signs
  - No open flames or high temperature devices (could include warehouse heaters)
- Empty tanks/cylinders (Heels)
  - Must be free of residual material and vapor before storage for reuse
- Safety Data Sheets
  - SDS must be available on site
- Upright storage
  - Exception for nonflammable gases secured to a pallet

Sample NFPA 704 Sign

Refrigerant Selection

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Selection of Lower GWP Refrigerants

- **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

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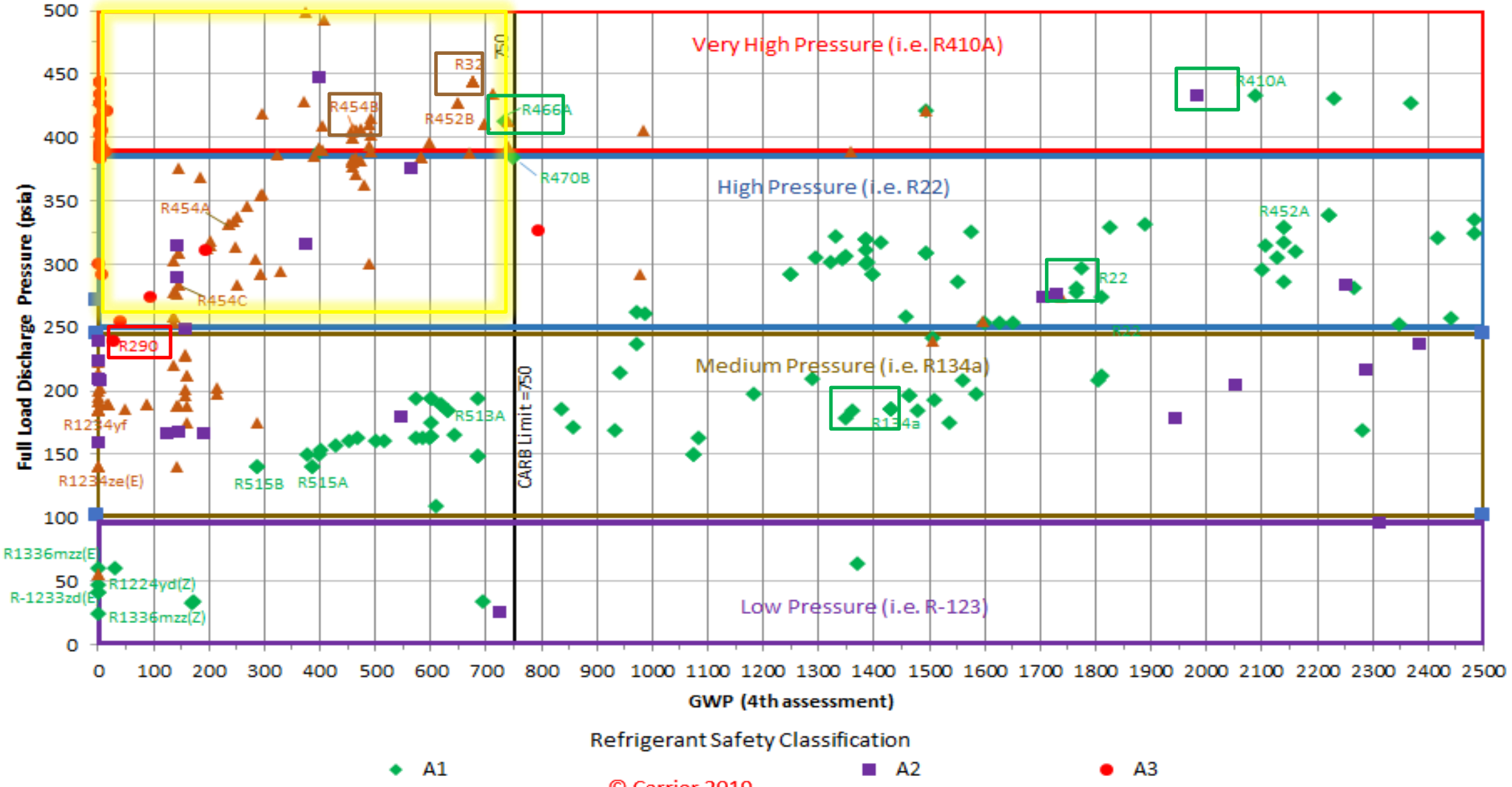
Possible Refrigerant Options for Residential and Light Commercial



Research and the Safety Standards: Ignition Source Protection

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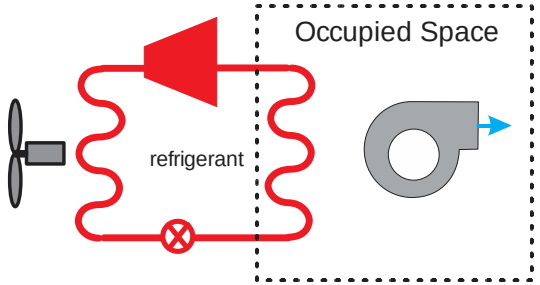
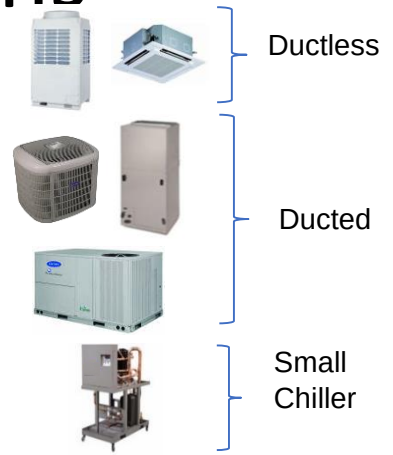
Safety Standard Application Classifications

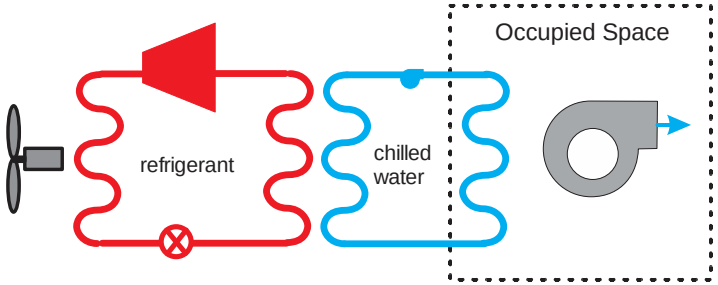
Direct System
Refrigerant can leak into the occupied space



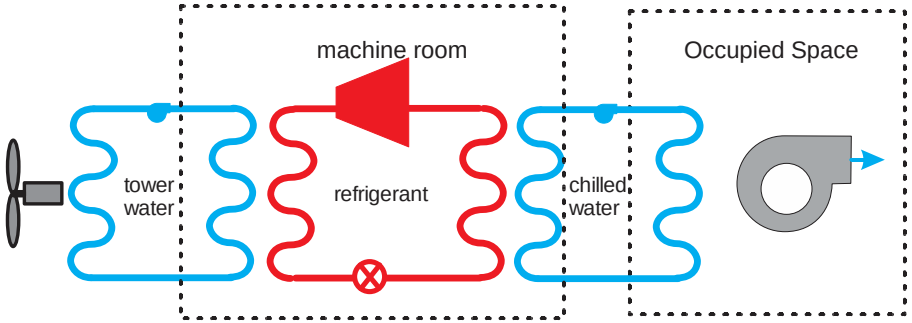


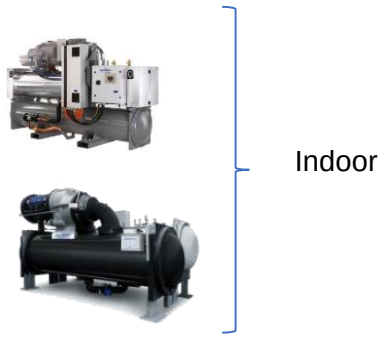
Indirect Systems

Refrigerant leak isolated by secondary loop



Equipment outdoors or in a machine room





Comfort Cooling Product Safety Standard

Product standard requirements are followed in manufacturing equipment for "listing" and are labeled by Underwriters Laboratories LLC (UL).

- Building codes or application standards generally require that a product standard is followed
- Adopted into Washington State building code

UL/CSA 60335-2-40 3rd edition (approved, published)

- Based on IEC60335-2-40 6th edition and is a modification of UL60335-2-40 2nd edition
  - ANSI process
  - Two public reviews with comments and modifications
- More conservative than the global IEC60335-2-40 6th edition source standard
  - Reflects the results of research and the conservative approach to insure the safe use of A2L refrigerants
- Replaces UL 1995 on 1/1/2024 and covers all safety for HVAC products and not just low GWP refrigerants
- Users guides and installation instructions under development by equipment manufacturers are reviewed and required for UL certification

Comfort Cooling Application Safety Standards

Application safety standards inform the safe installation of equipment in buildings.

- Building codes generally require that an application standard is followed
- Application standards often require that a product is “listed” which means that it complies to a product standard
- Adopted into Washington State building code

American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) 15-2019 (approved)

- Updated for use with A2L refrigerants in direct systems thru addendum d and for machine rooms thru addendum h (published September 2018)
- The complete standard was republished as the 2019 version on 7/30/2019 along with an updated version of ASHRAE 34
- Reflects the results of research and the conservative approach to insure the safe application of A2L refrigerants.

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Application Safety Standards

ASHRAE 15.2 (proposed)

- Includes the requirements from ASHRAE 15 and UL 6-335-2-40 for residential systems only
- Combines requirements from product and application standards into a single document
  - Everything in the proposed ASHRAE 15.2 standard is included in UL 60335-2-40 and ASHRAE 15
- ASHRAE 15.2 was created to align with the International Residential Code for residential products

Goal of Standards: Prevent Ignition

- In order for a refrigerant ignition to occur, there must be 2 failures:
  - There must be a refrigerant leak that is large enough to exceed the lower flammability limit (LFL)
    - 10 to 14% concentration
    - Large refrigerant release
  - There must be a “competent” ignition source (minimum ignition energy) in an area that exceed LFL
    - Open flame or very high energy ignition source
- Goal of the standard:
  - Prevent the LFL concentration from being reached
    - Refrigerant charge limits or mitigation requirements
    - Mitigation may include circulation or ventilation to reduce refrigerant concentration
  - Remove “competent” ignition sources

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Safe Application of A2L Refrigerant

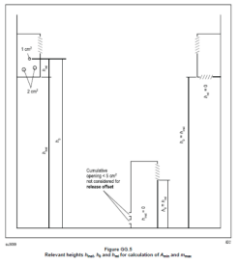
Fundamental Approach is to prevent ignition and combustion

1. Control of competent ignition sources and isolation from flammable refrigerants
2. Refrigerant Charge limits (m1, m2, m3) combined with item 7
3. Minimum occupied area (A_{min}) combined with charge limits in item 2
4. Factory Installed UL60335-2-40 application approved Refrigerant Detectors in all units above m1 charge
5. Active mitigation using circulation and dilution
6. Refrigerant Piping Design qualification and protection
7. Labeling and Literature
8. Service Training and Education

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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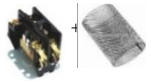
Service Training
and Education Annex DD, Annex HH

8

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



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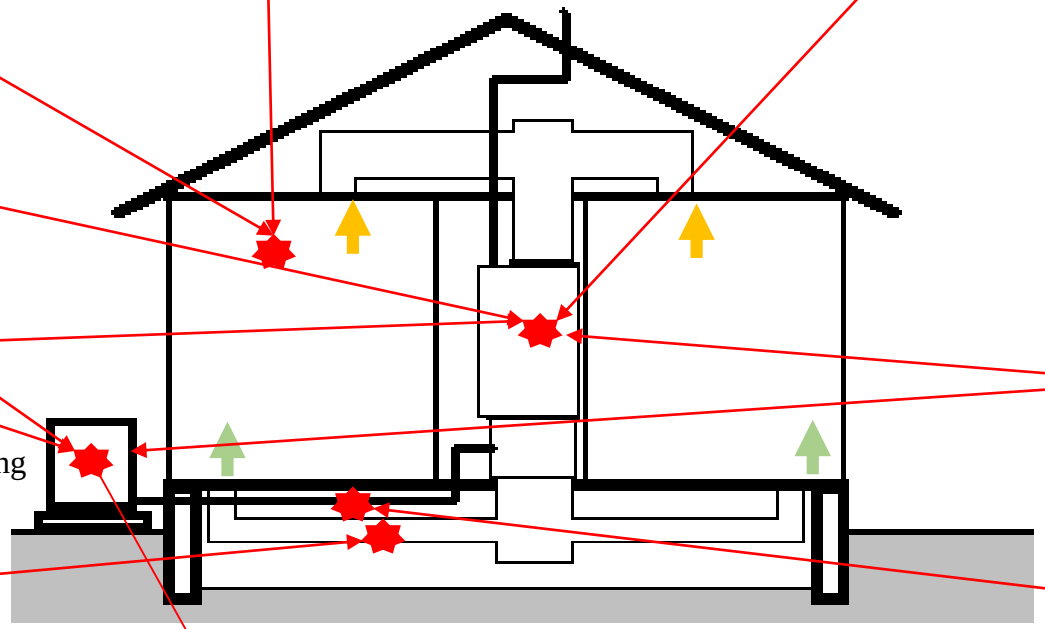
No Competent Ignition
Sources in unit and ducts
Per 22.116, Annex KK, 22,117

1

5

Active mitigation for leaks
detect, circulate an dilute
Annex GG

Residential Down Flow
Air Conditioners with Gas Heat



4 **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

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

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

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.

Service and Training Requirements: UL 60335-2-40 annexes DD and HH

Product standard requirements are followed by manufacturers for equipment listing.

- Standard requires that the service and installation instructions include requirements of Annex DD.
  - Annex DD is an outline of the service and installation requirements.
  - Annex HH defines requirements for competent service personnel
- Although there are no regulatory requirements for transition for air conditioning in North America yet,
  - Some manufacturers have developed training and started training technicians (in-person hands-on and internet-based courses)
  - North American Training Excellence (NATE) Exam.
  - There is significant training material available around the world where low GWP technologies have been adopted.
  - Additional organizations are developing training material.

UL60335-2-40 DD.9 Servicing Refrigerant System Summary - Example

Requirement	A1	A2L	A2&A3	Comment
Safely Remove Refrigerant following local and national codes	Required	Required	Required	EPA Rule 608, which requires recovery except for Natural refrigerants
Purge Circuit with Inert gas (i.e. oxygen free nitrogen)	Not required	**Required**	Required	Repeat as necessary
Evacuate	Not required	**Required**	Required	Insure outlet of pump is not near an ignition source
Purge with Inert Gas for 5 min	Not required	Optional	Required	Second purge
Evacuate again	Not required	Optional	Required	Included in Annex HH
Open the circuit by cutting or brazing	Final step	Final step	Final step	Final repair preparation. Should also state not to leave the system open for long periods
Repair the systems and for brazing purge with nitrogen during brazing	Required	Required	Required	Included in Annex HH
Leak Test and Pressure Test the unit	Not required	**Required**	Required	Part of DD.10
Evacuate the system	required	required	required	Follow industry practices for evacuation
Charge the system (See DD.10)	required	required	required	See DD-10 and mfg. charging procedures

Summary

- World is transitioning to low-GWP refrigerants, including A2L lower flammability refrigerants.
  - 12 U.S. states are regulating HFC refrigerants
  - California proposed regulation for 2023 for AC
- AHRI Safe Refrigerant Transition Task Force working to help ensure a safe North American transition to A2L refrigerants.
- Extensive research on A2L flammability has been completed.
  - Results of this research has now been incorporated into approved standards: UL 60335-2-40, 3rd ed. and ASHRAE 15.
- Training materials are already available from some manufacturers in US even though transition is still years away

AHRI Safe Refrigerant Transition Task Force

- AHRI has formed a Safe Refrigerant Transition Task Force with seven 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.
  - Communications
  - Safety Training
  - Codes and Standards
  - Transportation/Storage/Packaging/Handling
  - Bulk Storage and Manufacturing Facilities
  - Installation/Operation/Maintenance
  - Recovery/Reclaim/Destruction

Helen Water-Terrinoni _____

Christopher Bresee _____

- Establish structure to ensure continuous improvement
  - Incident investigation
  - Continuous maintenance standards
  - Training upgrades
- Leverage learnings around the world

Thank-you for joining us!

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TRANSITION TASK FORCE