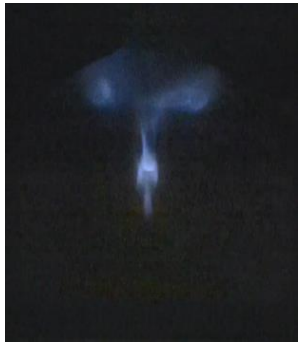
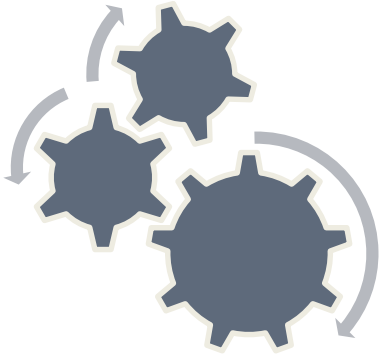
U.S. DEPARTMENT OF ENERGY

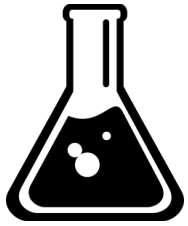
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Use of Cost-Effective Additives to Reduce Flammability in 2L Refrigerants





Mechanistic understanding



New designs

Arkema Inc.
Jessica DeMott, Research Scientist
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Project Summary

Timeline:

Start date: May 15, 2018

Planned end date: May 15, 2020

Key Milestones

1. Down select additive candidates; Sep 2018
2. Measurement of refrigerant flammability characteristics in presence of additives; May 2019
3. Evaluation of the presence of additive on the refrigerant performance; May 2020

Budget:

Total Project $ to Date:

- DOE: $127,593
- Cost Share: $37,393

Total Project $:

- DOE: $597,943
- Cost Share: $160,536

Key Partners: Trane U.S. Inc

Project Outcome:

- Develop and validate new low-cost, low-toxicity additives for A2L refrigerants to reduce flammability
- Reduction in flammability will be achieved by increasing the lower flammability limit, reducing the burning velocity and increasing the minimum ignition energy of refrigerants and blends

Team

Arkema Inc.

- **Jessica DeMott**
  - PI, Research Scientist for next generation refrigerant development
- **Lucy Clarkson**
  - Fluorochemicals R&D Director
- **Sarah Kim**
  - Research Scientist for next generation refrigerant development
- **Corporate R&D Support**
  - Mark Aubart and Steve Carson
- **Analytical Support**
  - Modeling, Characterization

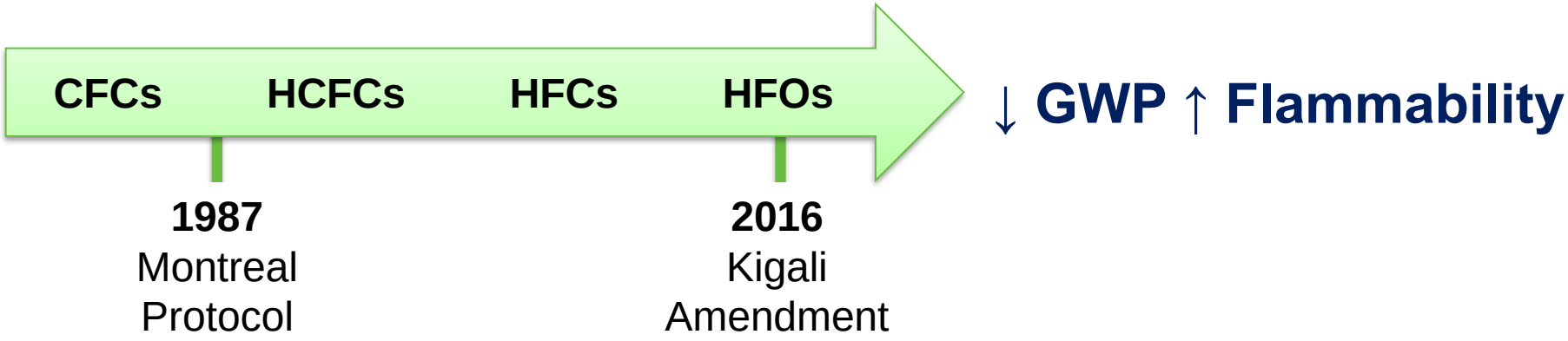
Trane US Inc.

- **Steve Kujak**
  - Director of Next Generation Refrigerant Research at Ingersoll Rand
- **Kenneth Schultz**
  - Thermal System Engineer, performance validation testing in rooftop unitary systems

Challenge

Problem Definition:

- Global industry is moving towards low Global Warming Potential (GWP) refrigerants
- Building codes and other safety standards discourage the use of non-A1 refrigerants
- Most next-generation, low GWP refrigerants and blends are flammable (A2L)

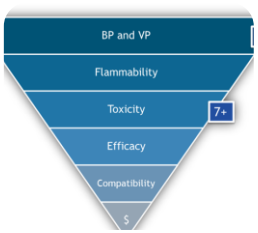


Advice:

- Develop a refrigerant with reduced flammability using flame inhibition additives

Approach

Current	Next Steps



Screen Additive Candidates

Demonstrate Efficacy through Flammability Testing

Improve Capabilities and Understanding

Validate Performance

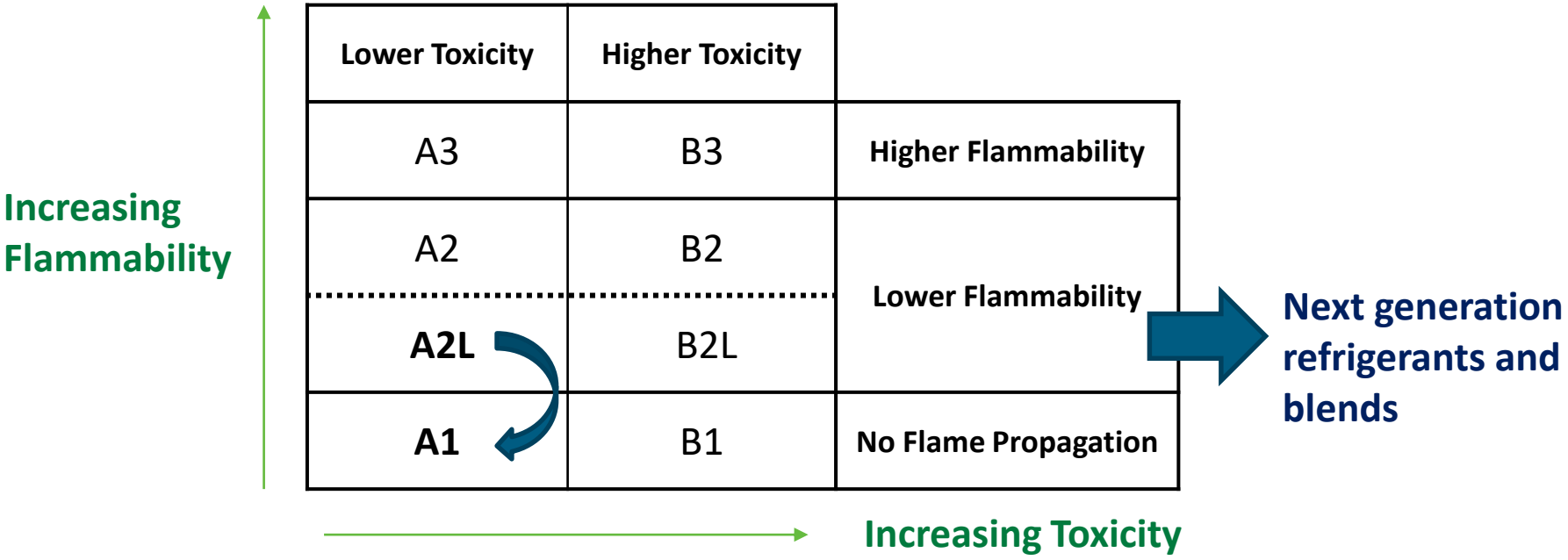
Establish Commercial Feasibility

Identify or design agents that will modify the flammability characteristics of A2L refrigerants

Approach

Flammability Characteristics to be Modified:

- **Flammability Limit**
  - Increase the concentration required for flammability
- **Burning Velocity**
  - Slow flame propagation
- **Minimum Ignition Energy**
  - Make the molecule harder to ignite



Impact

New Refrigerant Development

- Accelerates adoption of low cost, low GWP options
- Avoids compromising performance efficiency in order to meet low GWP requirements
- Circumvents adjustments to charge limits by mitigating flammability risks

Safety Risks

- Provides transferable technology that would mitigate flammability risks for A2L, A2 and A3
- Incorporates agents that are compatible with leak detection technologies

Modeling and Evaluation Tools

- Introduce predictive modeling through structure-function analysis of minimum ignition energies of fluorinated refrigerants

Progress: Overview

Current Project Stage: Mid

Key Accomplishments:

- 7+ candidates identified for testing
- Top candidate shows favorable modification of flammability limit and reduction in burning velocity
- Elucidating mechanistic understanding

In-Progress:

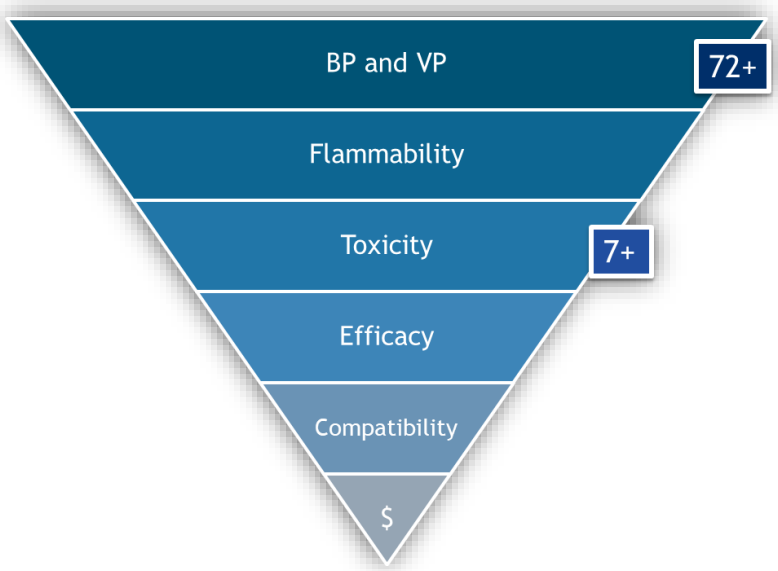
- Minimum ignition energy evaluation
- Modeling underway for candidate screening

Next Steps:

- Compatibility and performance evaluations

Additive Selection
✓ BP
✓ VP
✓ Non-ozone depleting
✓ Low GWP
✓ Non-toxic
✓ Efficacy
○ IP
○ Compatibility
○ Performance
○ Cost

Progress: Candidate Selection



Additive Screening

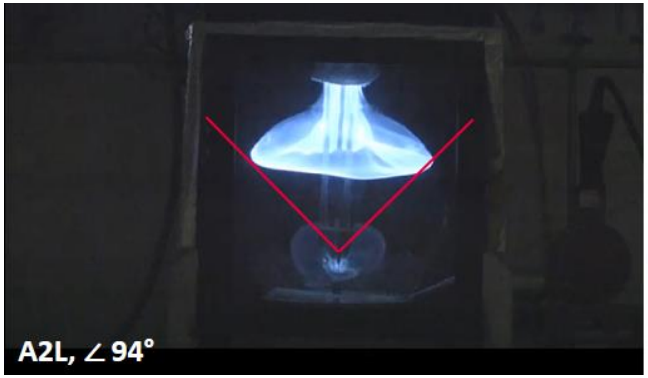
- ✓ BP
- ✓ VP
- ✓ Non-ozone depleting
- ✓ Low GWP
- ✓ Non-toxic
- ○ Efficacy
- ○ IP
- ○ Compatibility
- ○ Performance
- ○ Cost

Progress: Flammability Limit Testing

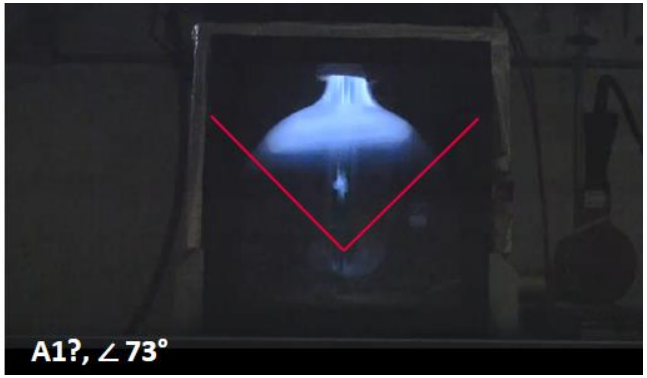
Lower Flammability Limit

Can we increase the concentration required for flammability?

No additive



With additive



Additive Screening

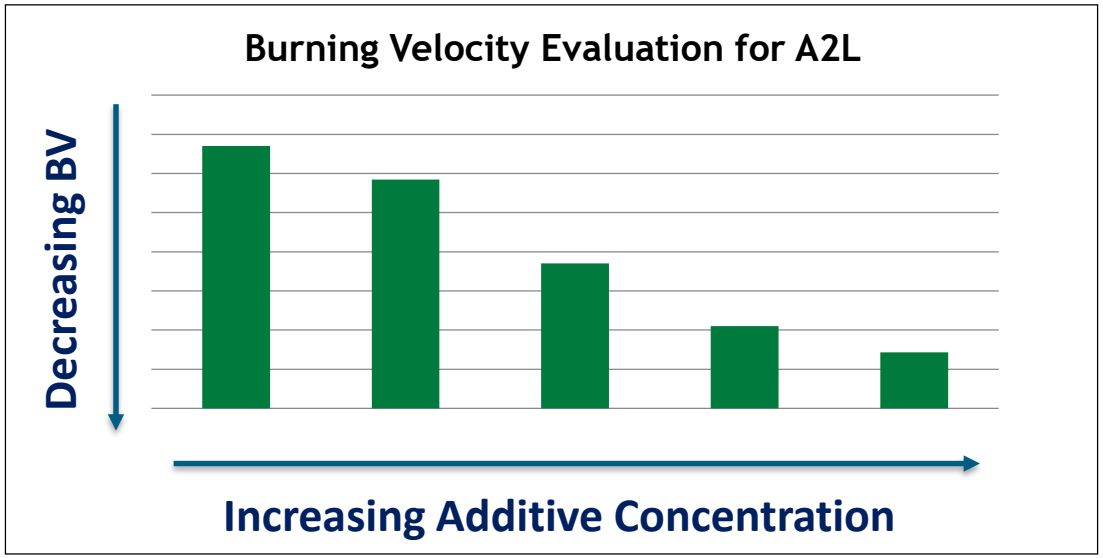
- ✓ BP
- ✓ VP
- ✓ Non-ozone depleting
- ✓ Low GWP
- ✓ Non-toxic
- ✓ **Efficacy**
- ○ IP
- ○ Compatibility
- ○ Performance
- ○ Cost

Decrease in flame angle in presence of additive

Progress: Burning Velocity Testing

Reduce Burning Velocity

Can we slow down flame propagation?



Additive Screening

- ✓ BP
- ✓ VP
- ✓ Non-ozone depleting
- ✓ Low GWP
- ✓ Non-toxic
- ✓ **Efficacy**
- ○ IP
- ○ Compatibility
- ○ Performance
- ○ Cost

Decrease in burning velocity in presence of additive

Stakeholder Engagement

Current Project Stage: Mid

Stakeholder Engagement:

- All major equipment manufacturers
- Regulatory agencies including state, federal and international
- Trade organizations

Field Trial with Partner:

- Planned for late stage of project

Pursuing stakeholder feedback across value-chain with focus on understanding design challenges, opportunities, timelines and regulatory environment

Remaining Project Work

Immediate Future:

- Flammability testing with additional candidates
- Minimum ignition energy evaluation
- Modeling to support candidate screening

Advanced Future and Challenges

- Intellectual Property
- Compatibility screening
- Performance evaluations
- Field trial with partner

Additive Screening

- ✓ BP
- ✓ VP
- ✓ Non-ozone depleting
- ✓ Low GWP
- ✓ Non-toxic
- ✓ Efficacy
- ○ **IP**
- ○ **Compatibility**
- ○ **Performance**
- ○ **Cost**

Thank You

Arkema Inc.
Jessica DeMott, Research Scientist
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REFERENCE SLIDES

Project Budget

Project Budget:
BP 1 - $351,682, BP 2 - $406,797, Total - $758,479
Variances: None
Cost to Date: $164,986 (22%)
Additional Funding: None

Budget Period	Total	Spent	Federal	Cost Share	
1	$351,682	$164,986	$271,976	$79,706	22.66%
2	$406,797	$0	$325,967	$80,830	19.87%
Total	$758,479	$164,986	$597,943	$160,536	21.27%

Budget History

May 15th – FY 2018 (past)		FY 2019 (current)		FY 2020 – May 15th (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$48,739	$14,284	$331,893	$92,366	$217,310	$53,887

Project Plan and Schedule