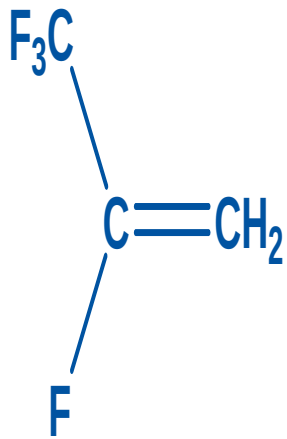
# SAE CRP1234
## Risk Assessment and Performance Evaluation of HFO-1234yf

HFO-1234yf

$CF_3CF=CH_2$




*Presentation to VDA Winter Meeting*

*13FEB08*

*William Hill [Chairperson of CRP1234]*

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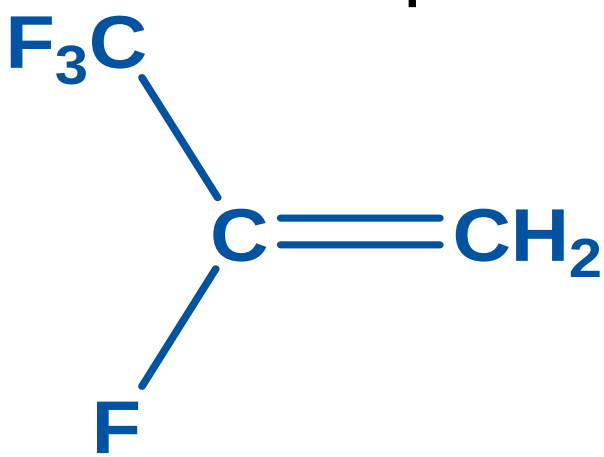
Honeywell

# Agenda

- What is HFO-1234yf?
- Why is it a good candidate for Mobile Air Conditioning?
- SAE CRP1234 Overview
  - Risk Assessment
    - Boundary Conditions
    - Flammability Metrics
    - Flammability Testing
    - Fault Tree Analysis
  - Performance evaluation
  - Conclusions
- Next Steps

# What is HFO-1234yf?

- **HFO-Hydro-Fluoro-Olefin**
  - **2,2,2,3 Tetrafluoropropene**
  - **Major component of Refrigerant "H" blend**
  - **Mild flammability**
    - **Flame limits (ASTM E681) & minimum ignition energy (ASTM E582) significantly better than R-152a**
    - **Distribution of the Refrigerant inside the vehicle during leakage is different as compared to R-152a**
    - **Potential to use in a direct expansion A/C system**



# CRP1234 Scope

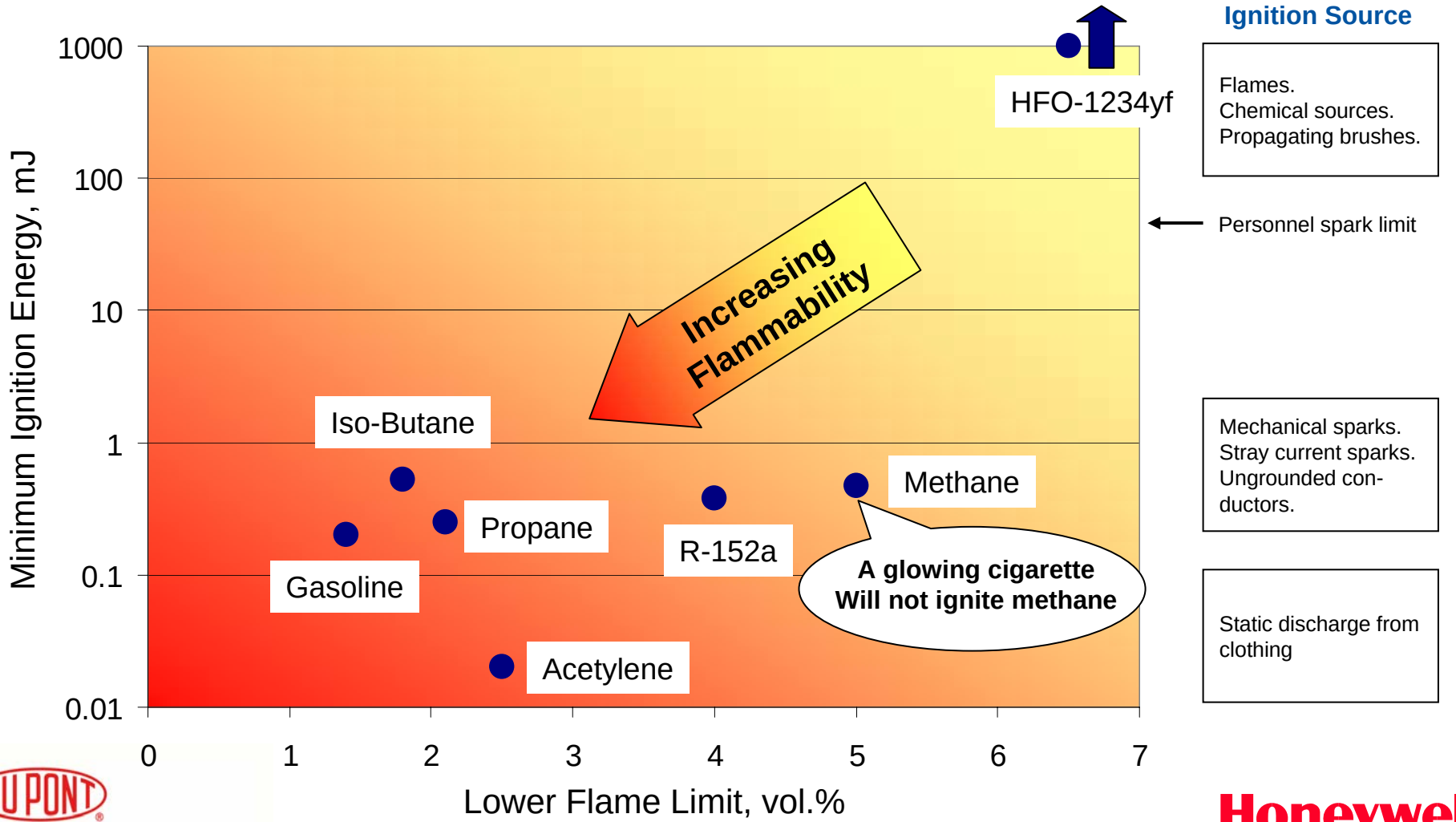
- **Risk Assessment**
  - **Built on framework from previous risk assessments (CRP150-1, EPA)**
    - **Performed by independent toxicologist from Gradient Corporation**
  - **Inputs – Two major components**
    - **Toxicity assessment**
    - **Flammability assessment**
      - » **CFD modeling [DuPont and Honeywell]**
      - » **Actual vehicle test in passenger compartment and engine compartment performed by Independent Lab-Exponent Failure Analysis Associates**
  - **Output – Fault Tree Analysis to determine risk probability**
- **Performance Assessment**
  - **Utilize existing framework from CRP150-3**
  - **Single evaporator direct expansion system**
    - **New TXV, increased suction line diameter**
    - **IHX evaluation**
- **Effort included OEM's together with DuPont and Honeywell**
  - **Toyota, Volvo, Renault, PSA, Hyundai, GM, Ford, Fiat**

# Toxicity Inputs



| Test | HFO-1234yf | R-134a | |
|---|---|---|---|
| • Acute Animal Lethality | No deaths 400,000 ppm | No deaths 359,700 ppm | ✓ |
| • Cardiac sensitization | NOEL > 120,000 ppm | NOEL 50,000 ppm<br>LOEL 75,000 ppm | ✓ |
| • 13 week inhalation | NOEL 50,000 ppm | NOEL 50,000 ppm | ✓ |
| • Developmental (Rat) | NOAEL 50,000 ppm | NOAEL 50,000 ppm | ✓ |
| • Genetic toxicity | Not Mutagenic | Not Mutagenic | ✓ |
| • 13 week genomic (carcinogenicity) | Not active (50,000 ppm) | Baseline (50,000 ppm) | ✓ |
| • Environmental Tox | NOEL > 100 mg/L (Pass) | NOEL > 100 mg/L (Pass) | ✓ |

# HFO-1234yf Flammability Inputs

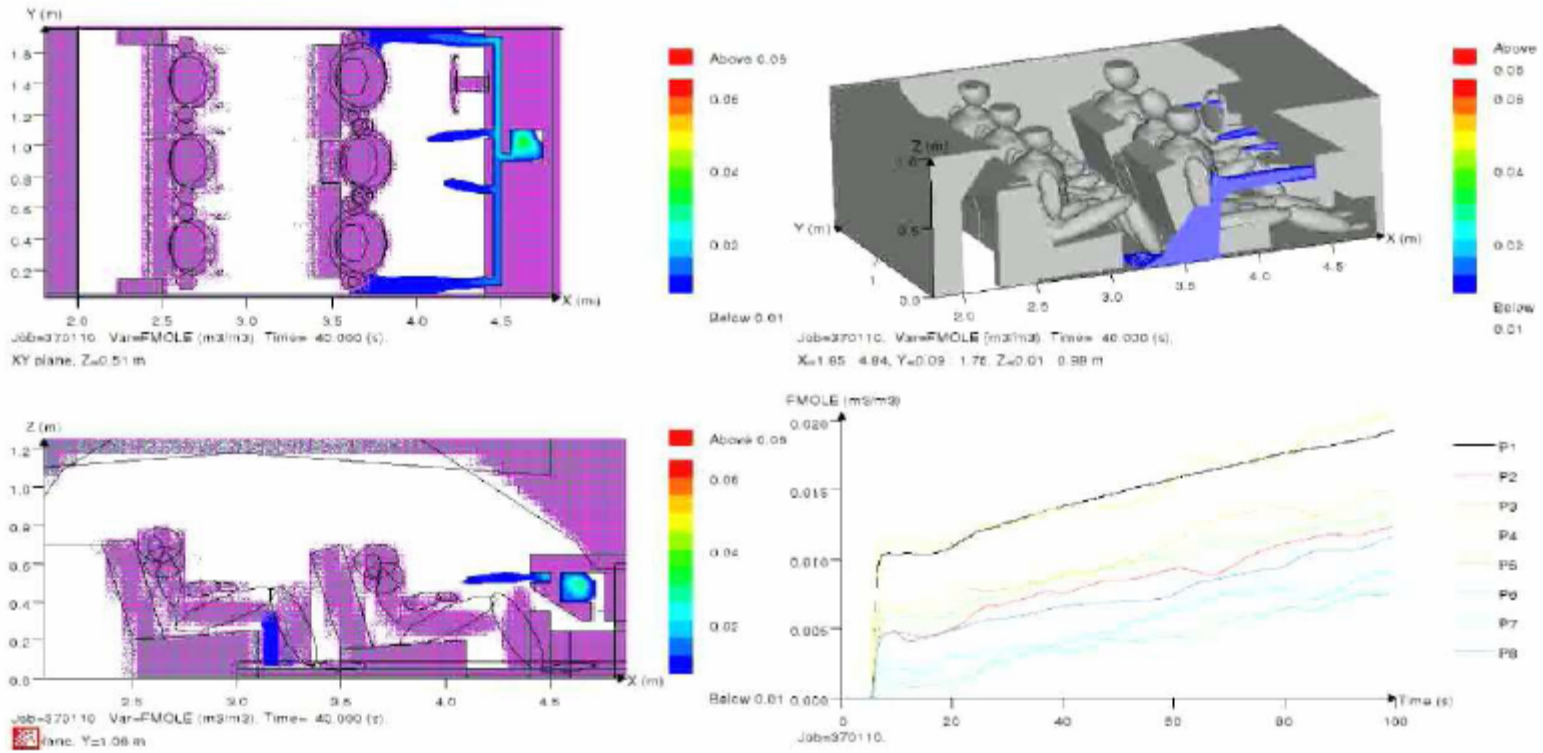


# CFD Modeling HFO-1234yf Leak

- DuPont Developed Computational Fluid Dynamics model based on US Army study conducted for EPA [Ford Crown Victoria] on R-152a and CRP150
- Simulated leakage into the vehicle interior using worst case car design (largest ratio of refrigerant charge to passenger compartment size) and highest leak flow rate in passenger compartment
  - Internal volume = 3.1 $m^3$ , 691 g refrigerant charge, 6 passengers
  - 30 l/s airflow, RECIRC/Vent Mode, Constant leak rate [1.14 g/s]
- Honeywell simulated Opel Astra
  - Results similar to DuPont results
- Results confirmed with lab testing and mockup testing
- Did not model engine compartment leak, but did actual test of hose rupture on hot surface underhood

# CFD Model – Vehicle Layout

## 0.5 mm, 100% Recirc – 40 seconds



# Passenger Compartment Vehicle Concentration testing

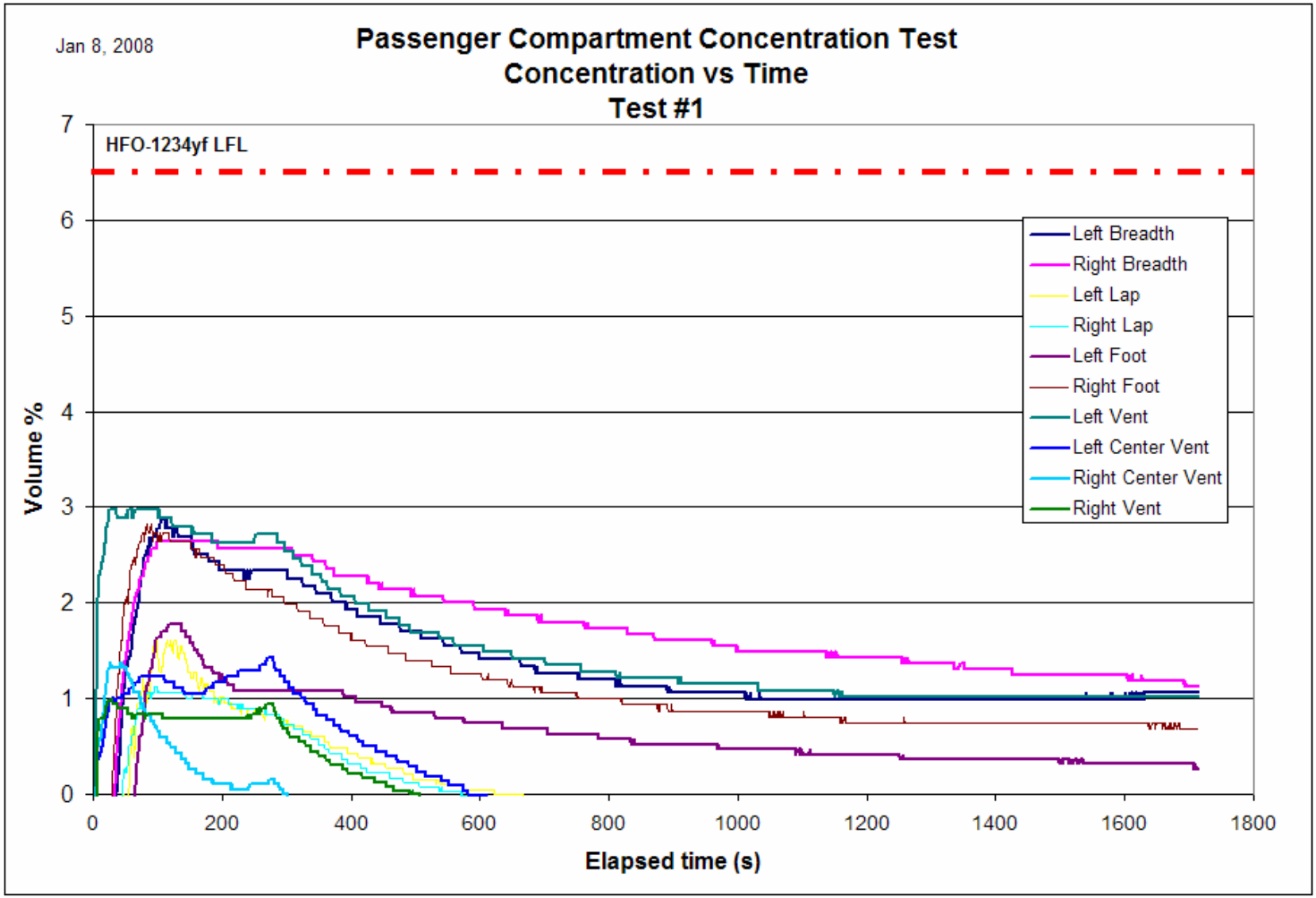
- **Actual vehicle testing confirms maximum HFO-1234yf concentration level in the passenger compartment is below LFL [6.5%] with leakage rate of 2.3 g/s [higher than CFD]**

- **CFD and laboratory results compare well to concentration measurements in the vehicle testing**


Figure 5 Passenger compartment mannequins and sensors

# Passenger Compartment Concentration Results





# Passenger Compartment Vehicle Ignition Test

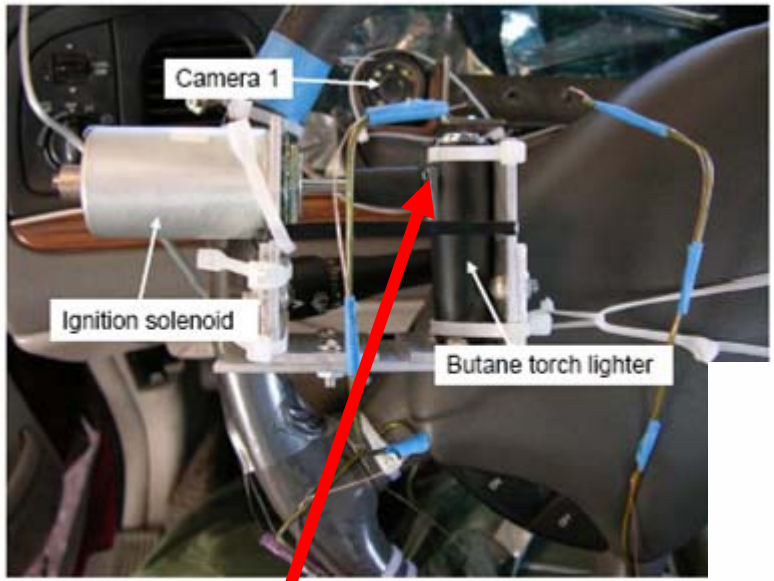



Figure 12 Close-up view of butane torch lighter assembly

**Ignition source: butane lighter**

## No Ignition!

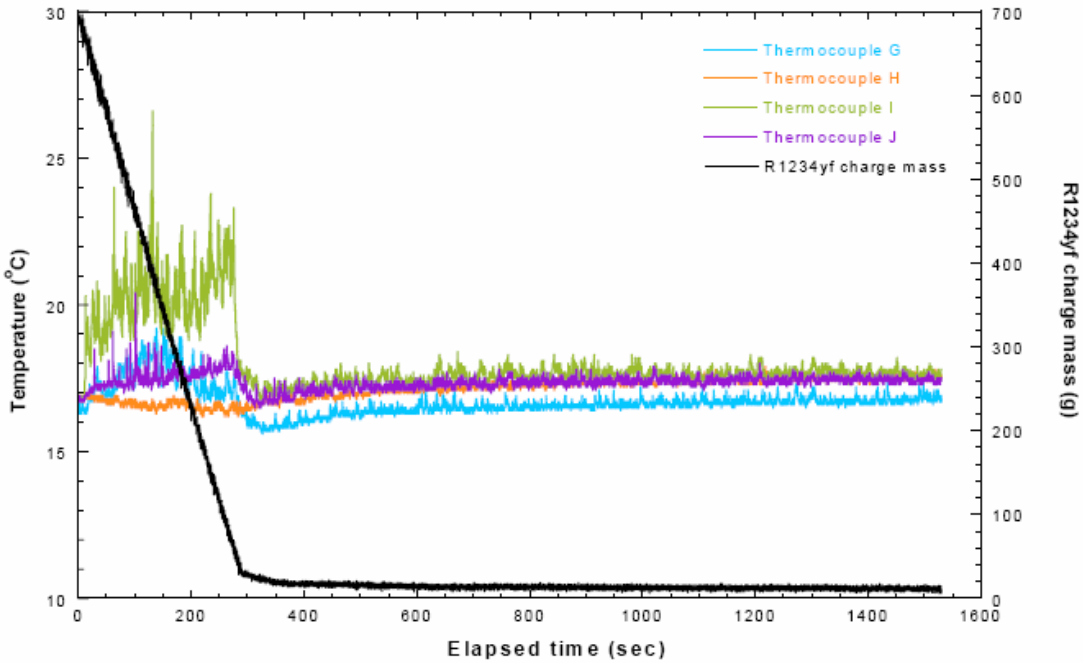
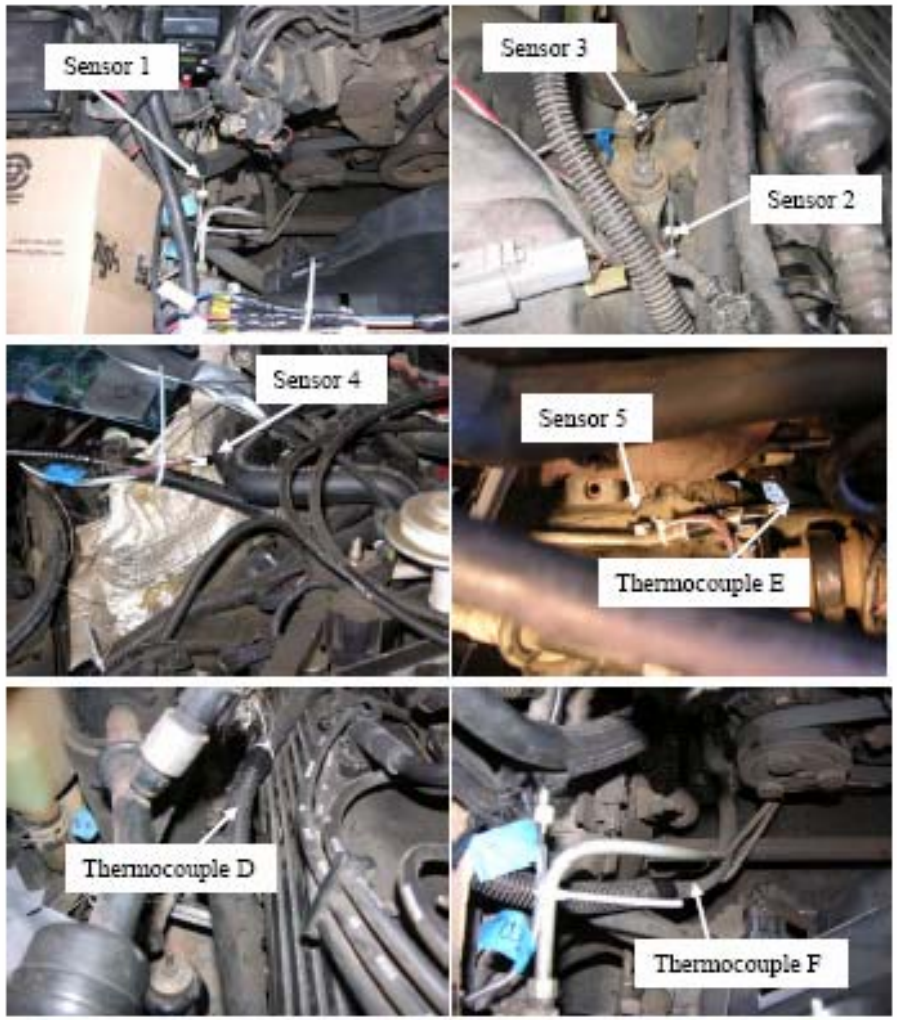



Figure 23 Passenger compartment ignition test (PCI Test 1) Temperature and R1234yf discharge mass versus elapsed time

# Engine Compartment Vehicle Concentration Testing



- Underhood simulation of compressor pressure relief valve opening
  - Leakage rate of 14.5 g/s
- Concentration tests repeated well – 3 tests
- Results just over LFL [6.5%]



# Engine Compartment Concentration Results



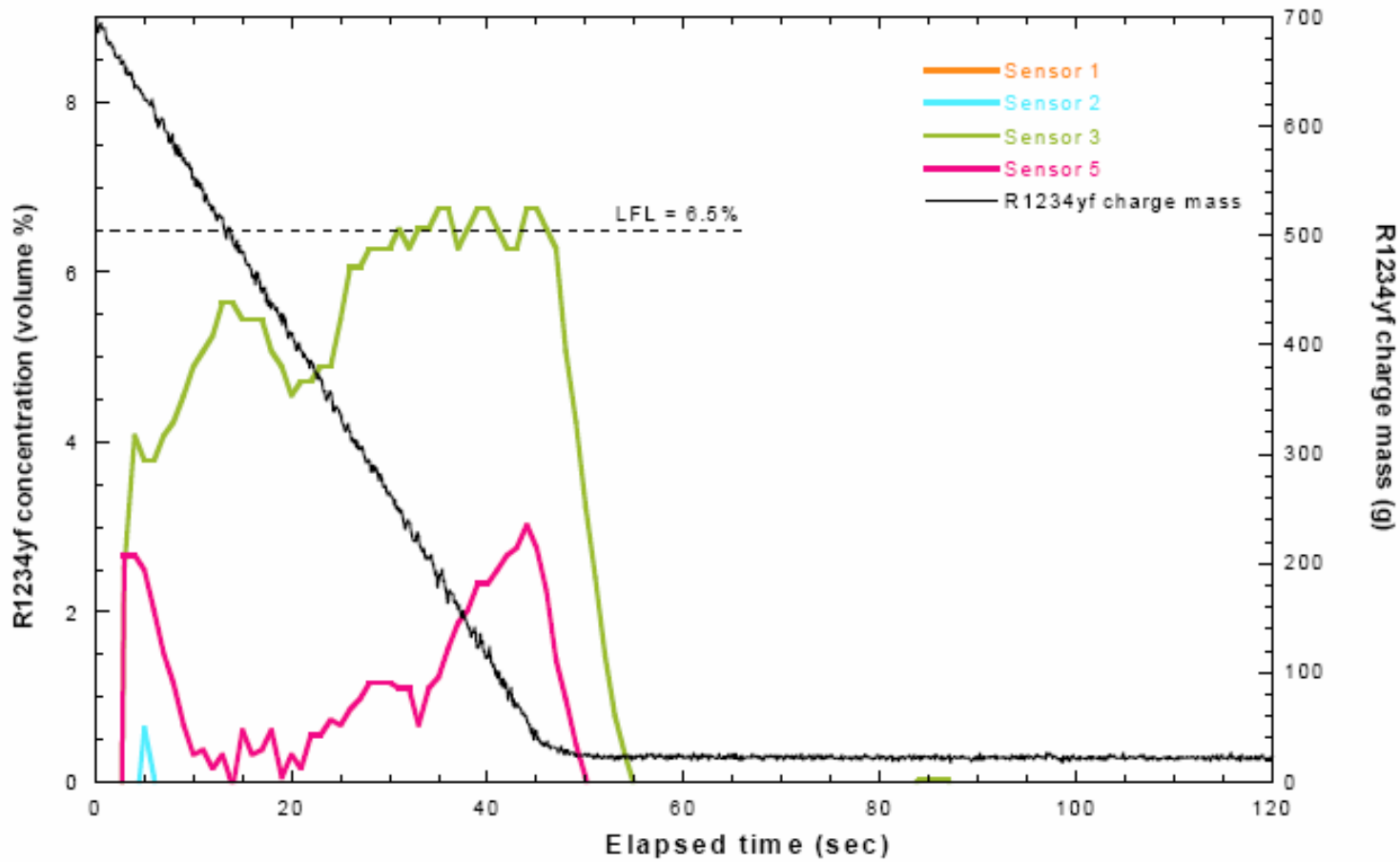



Figure 29 Engine compartment concentration test (ECC Test 2) – R1234yf concentration and discharge mass versus elapsed time

# Engine Compartment Ignition Test

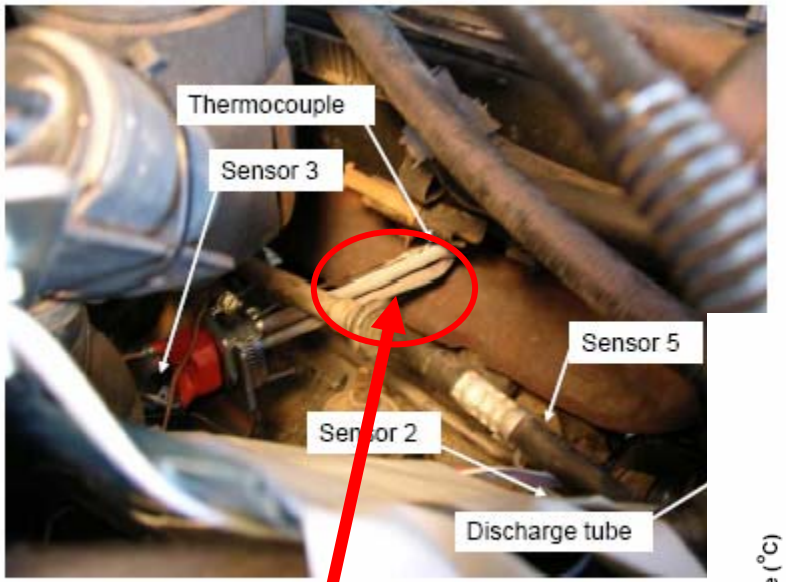



Figure 13 Heating element ignition source in engine compartment

**Ignition source: heating element at 600-750°C**

## No Ignition!

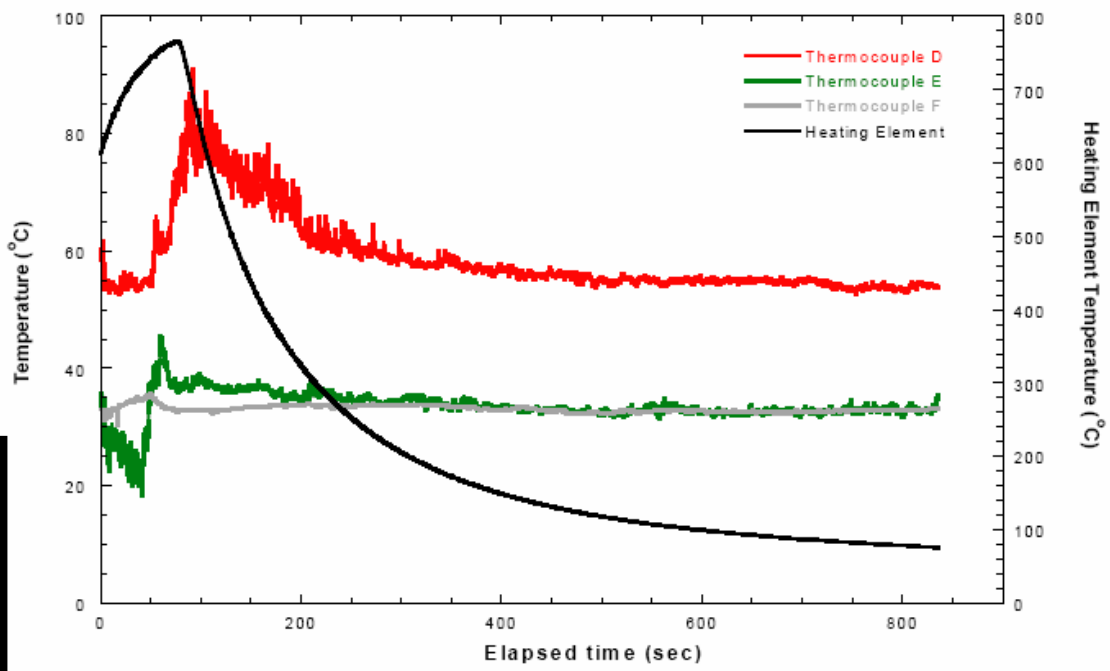



Figure 32 Engine compartment ignition test (ECI Test 1) – Thermocouple and heating element temperature versus elapsed time

# HFO-1234yf FTA Scenarios Outputs

- Risk of potentially adverse exposure associated with a small/medium/large leak into passenger compartment
- Risk of potentially adverse exposure associated with a leak due to vehicle collision
- Risk of potentially adverse exposure associated with a leak during vehicle repair
- Risk of fires due to refrigerant release under these conditions
  - with a small/medium/large leak into passenger compartment
  - with a leak in engine compartment
  - with a leak during vehicle repair by professional service technicians
  - with a leak during vehicle repair by DIYers

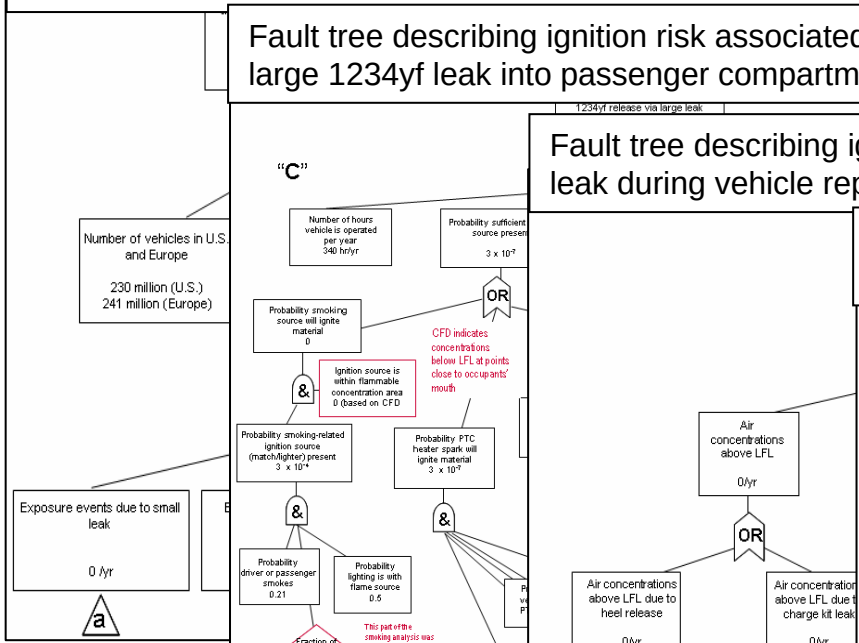
# FTA Examples

Aggregate risk of potentially adverse exposure due to 1234yf release

Fault tree describing ignition risk associated with a large 1234yf leak into passenger compartment

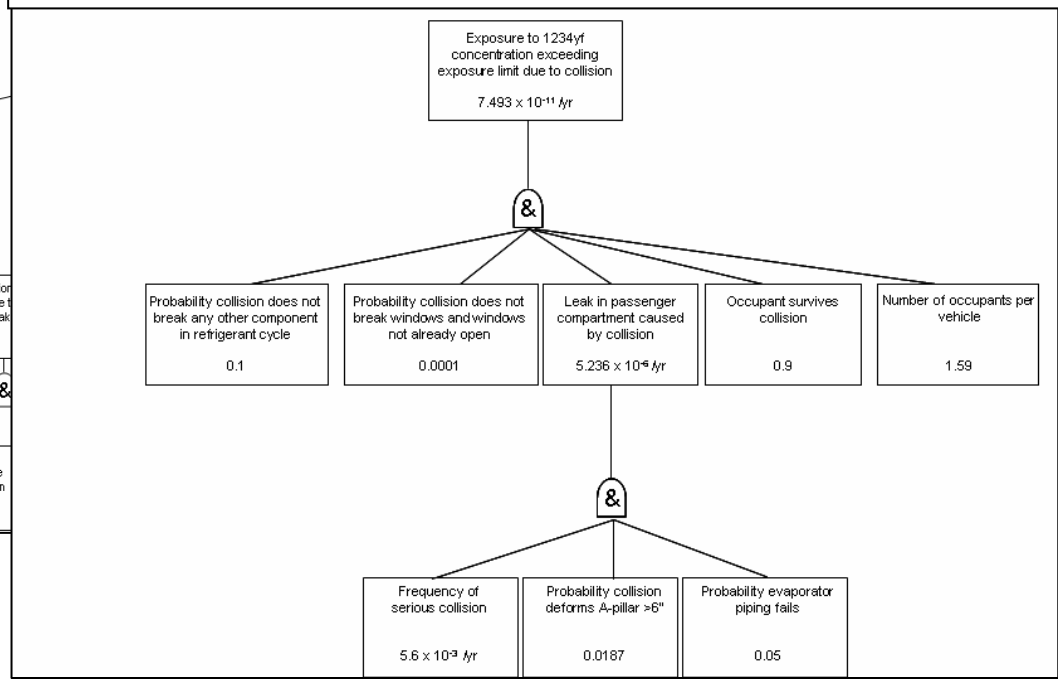
Fault tree describing ignition risk associated with a 1234yf leak during vehicle repair by DIYers

Fault tree describing risk of potentially adverse exposure associated with a 1234yf leak due to vehicle collision









# FTA Conclusions

- DuPont/Honeywell HFO-1234yf, offers equivalent or lower toxicity compared to R-134a or R-12 in terms of both human health effects and ecological effects.
- Risk assessment of HFO-1234yf indicates less risk than the baseline R-12 refrigerant
- Annual risk per driver of an exposure above the ASHRAE acute exposure limit adjusted to distinguish between stress-inducing and non-stress-inducing situations would be $1 \times 10^{-10}$ [Risk per year]
- Annual risk of an HFO-1234yf release leading to an ignition event and an injury would be $4.5 \times 10^{-11}$ [Risk per year]

- The estimated level of health risk associated with use of HFO-1234yf as a refrigerant is substantially less than the level of risk tolerated by the general public as part of every day life and less than the risk inherent in many commonly accepted activities [see next page]

# Typical Everyday Risks



**Table 26. Risks of Injury or Fatality from Various Events Compared to Risks Associated with Leaks of HFO-1234yf**

| Risk | Risk per year | Citation |
|---|---|---|
| Risk of stroke | $2.7 \times 10^{-3}$ | Rhys Williams, 2001 |
| Fatal accident in the home | $1.1 \times 10^{-4}$ | Wilson and Crouch, 1987 |
| Fatal accident while climbing mountains (if mountaineer) | $6 \times 10^{-4}$ | Wilson and Crouch, 1987 |
| Risk of being injured as a pedestrian | $2.1 \times 10^{-5}$ | NSC, 2004 |
| Fatal injury at work (all occupations) | $3.6 \times 10^{-5}$ | NSC, 2004 |
| Injury from lightning strike | $1 \times 10^{-6}$ | NWS, undated** |
| Risk of being fatally injured in an elevator ride | $2 \times 10^{-7}$ | McCann and Zalesky, 2006 |
| **Risk of exposure to HFO-1234yf above health based limits resulting from a collision** | **$1 \times 10^{-10}$** | CRP1234 Analysis |
| **Risk of being injured by an HFO-1234yf ignition resulting from a collision** | **$4.5 \times 10^{-11}$** | CRP1234 Analysis |

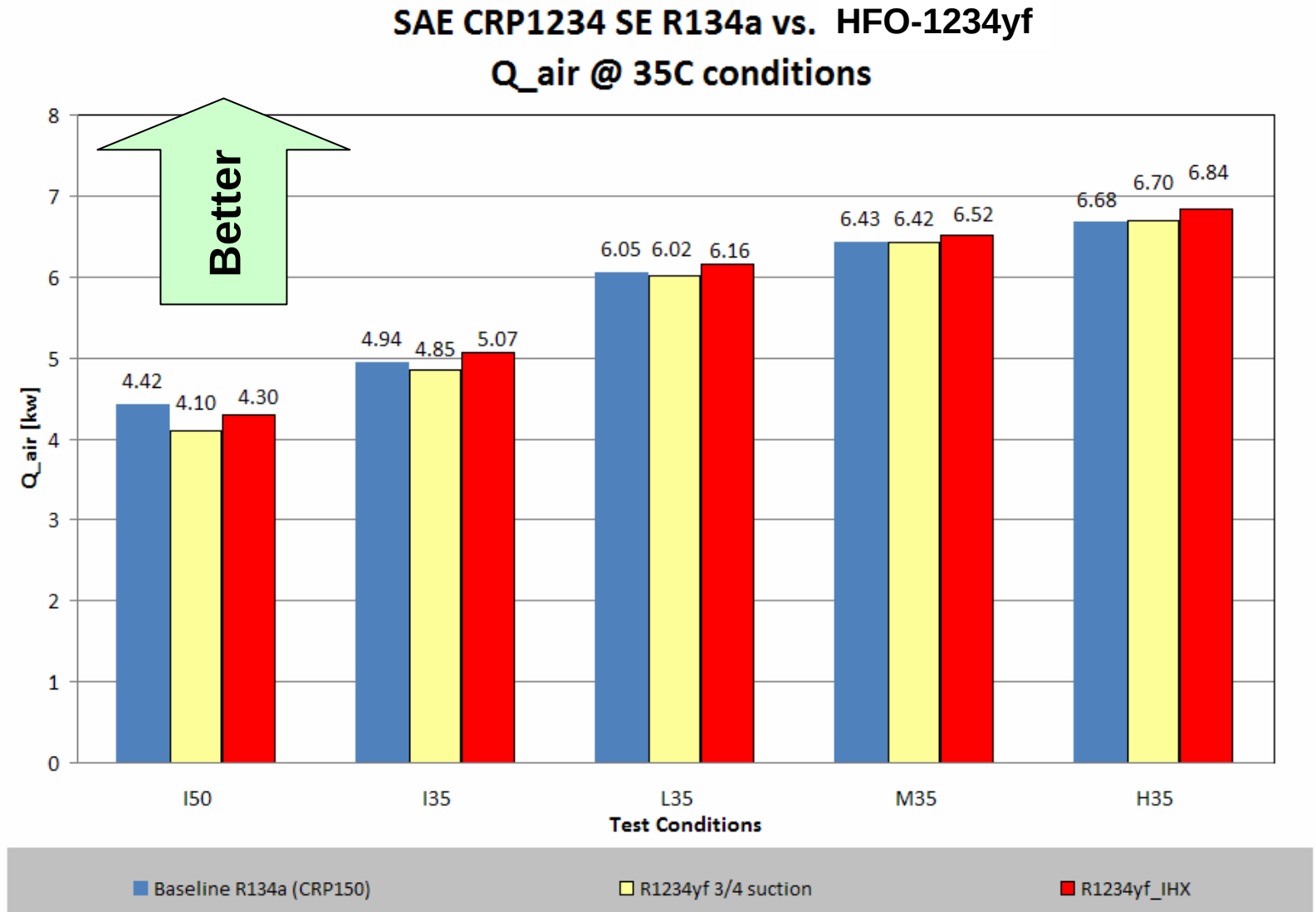
*Risk cited is 1 in 10,000 over the next century
# Injury sufficiently serious to require hospital visit. Based on number of injuries per year divided by total U.S. adult population.
§ Total number of injuries requiring hospital visit per year divided by the total U.S. population.
** Total number of documented injuries from lightning strikes per year, divided by total U.S. population.
& FTA risk multiplied by the number of estimated drivers in the U.S..

# Bench Test System Performance [Capacity and COP]

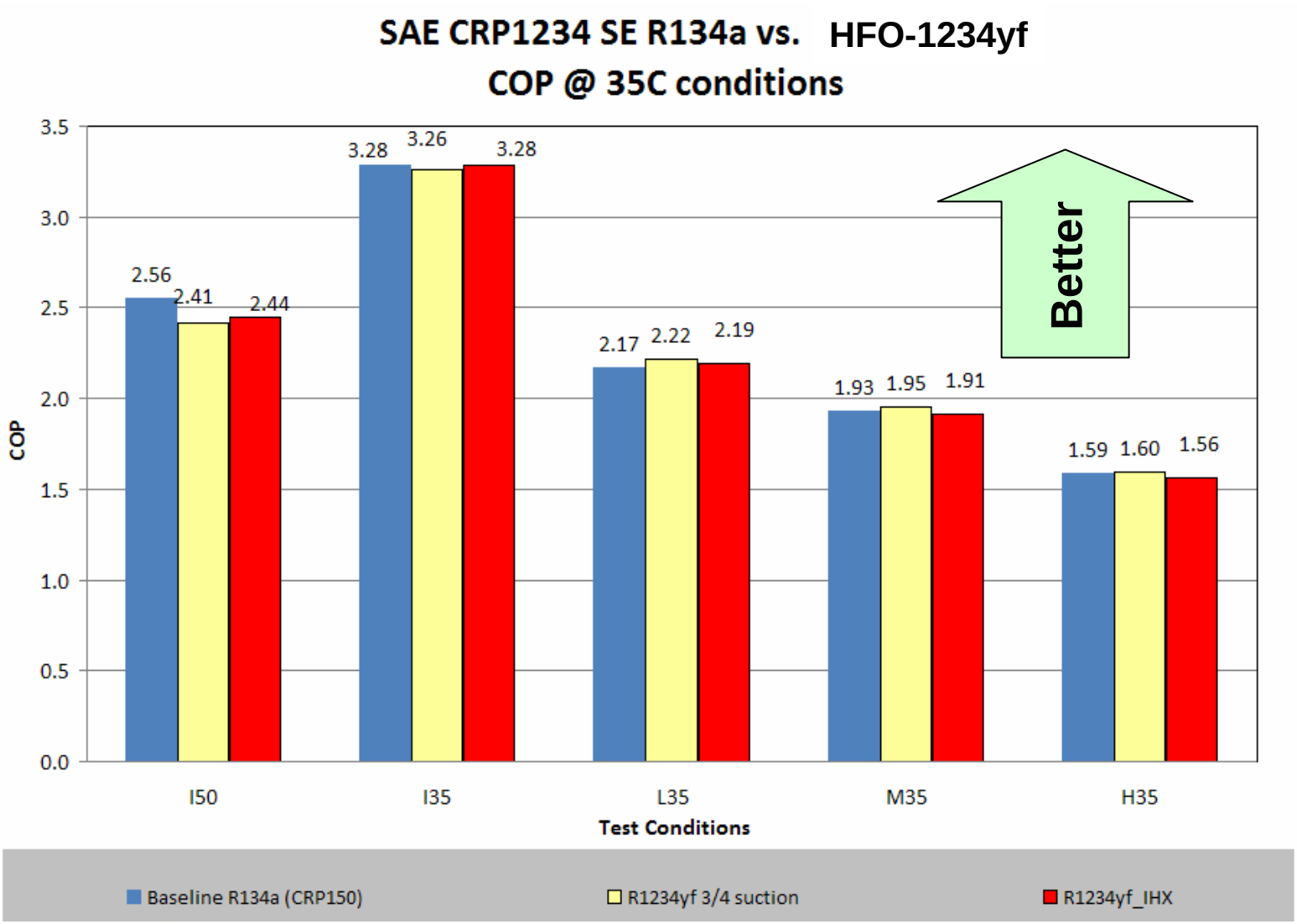


- **Cadillac CTS system by Denso**
  - **Baseline from CRP150**
  - **Tests run at Independent Lab - Creative Thermal Solutions**
- **Results**
  - **Capacity [Controlled capacity at lower loads at 3ºC and 10ºC]**
  - **COP**
  - **Life cycle according to GREEN-MAC-LCCP© Model**

# Capacity

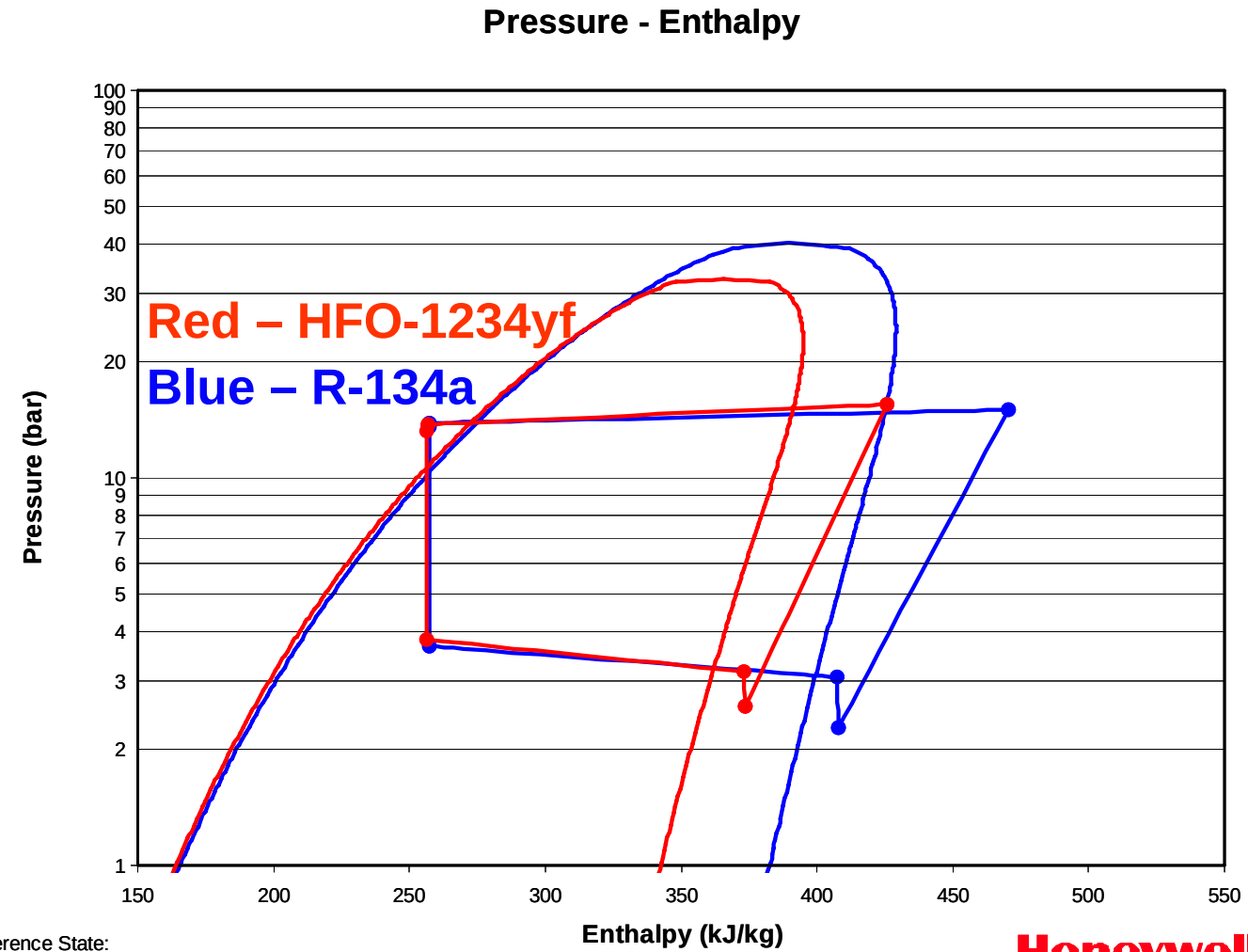

SAE CRP1234 SE R134a vs. HFO-1234yf
Q_air @ 35C conditions
Better
Q_air [kw]
0
1
2
3
4
5
6
7
8
4.42
4.10
4.30
4.94
4.85
5.07
6.05
6.02
6.16
6.43
6.42
6.52
6.68
6.70
6.84
I50
I35
L35
M35
H35
Test Conditions
Baseline R134a (CRP150)
R1234yf 3/4 suction
R1234yf_IHX

# COP


SAE CRP1234 SE R134a vs. HFO-1234yf
COP @ 35C conditions
COP
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
2.56
2.41
2.44
3.28
3.26
3.28
2.17
2.22
2.19
1.93
1.95
1.91
1.59
1.60
1.56
Better
I50
I35
L35
M35
H35
Test Conditions
Baseline R134a (CRP150)
R1234yf 3/4 suction
R1234yf_IHX

# SAE CRP HFO-1234yf Test Results – SAE M35 condition- R-134a vs. HFO-1234yf






Reference State:
h = 200 kJ/kg, s = 1.00 kJ/kg-K
sat. liq at 0 ºC

## Experimental Data

$COP_{R134a}$ = 101%

$Capacity_{R134a}$ = 100%

$Vol.\ Disp_{R134a}$ = 100%

$Massflow_{R134a}$ = 120%

$Charge_{R134a}$ = 95%

Honeywell

R134a-5/8” suction, HFO-1234yf-3/4” suction

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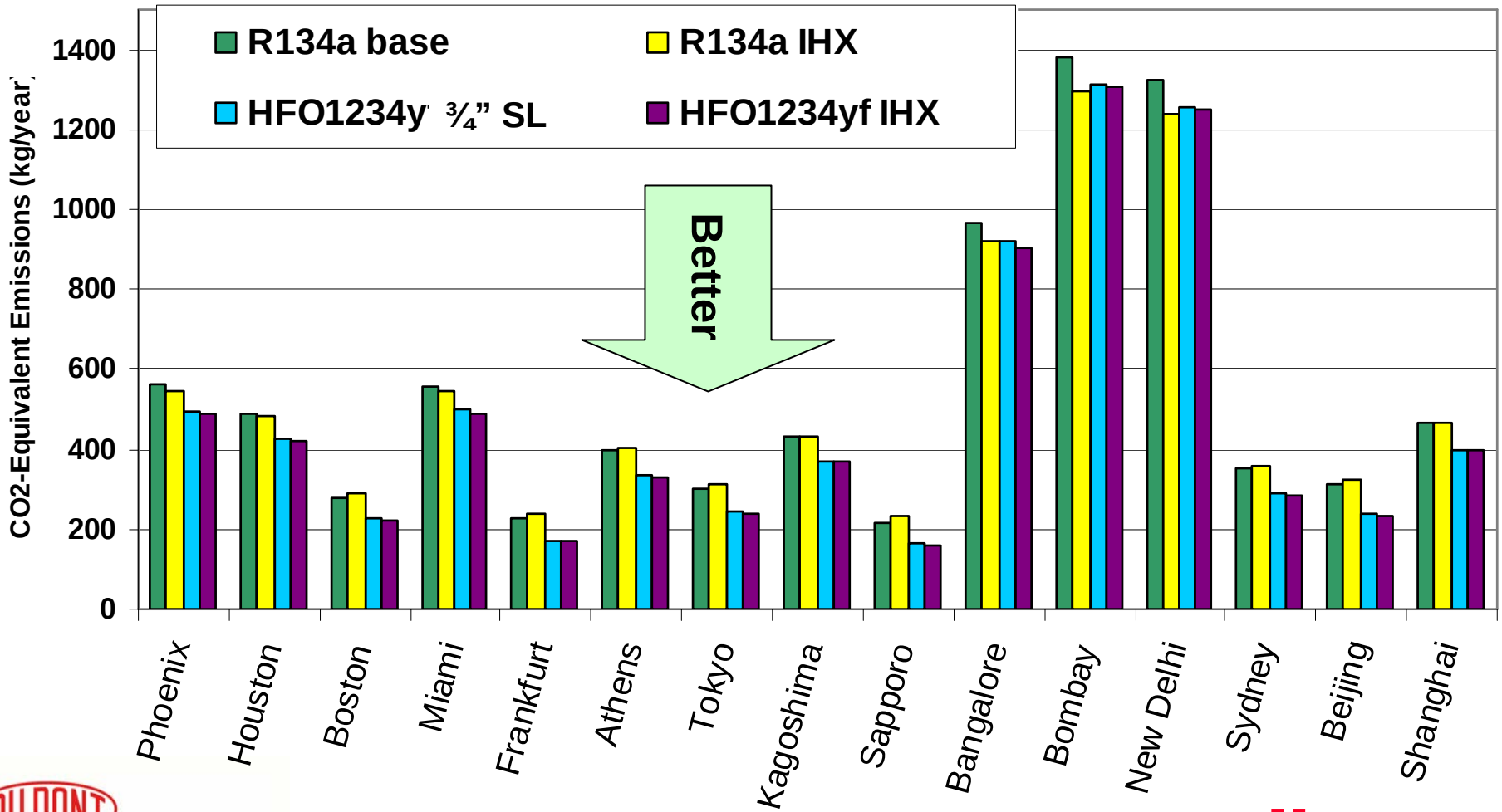
Honeywell

# Life Cycle

## LCCP $CO_2$-Equivalent Emissions per Year




Based on GREEN-MAC-LCCP Version 2

# CRP1234 Conclusions

- Initial Flammability tests have been conducted in the real world vehicle testing without indications of significant risk
- Risk Assessment has been completed and results are favorable for HFO-1234yf
- Initial Performance very similar to R-134a
  - COP and Capacity with only TXV change and suction line increase are within +/-5%
  - Addition of Internal Heat Exchanger provides modest additional improvement
  - Increased superheat provides improvements in capacity and COP
- Potential exists for direct substitution of HFO-1234yf in R-134a mobile A/C systems and potential retrofit
- Life Cycle results show that HFO-1234yf has improved performance as compared to R-134a
  - With further efficiency improvements, indirect contribution can be reduced further

# HFO-1234yf – Next Steps



- Additional flammability tests
- Material compatibility testing
- Sealing Permeation testing
- Support for SNAP/REACH approval

- Joint development going forward
  - SAE CRP1234-1?
  - Individual?
  - Alliances?

# HFO-1234yf Future Development Plan