Society of Automotive Engineers

Improved Mobile Air Conditioning Cooperative Research Program

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IMAC Chair

Improved Mobile Air Conditioning (IMAC)

- Announced April 22, 2004
- A comprehensive program to address all aspects of lifetime vehicle air conditioner environmental performance
  - Develop and demonstrate improved vehicle air conditioners using HFC-134a refrigerant
  - Improve recovery and recycling of refrigerant during service and vehicle end-of-life disposal
- Participants include international automobile and air conditioner system manufacturers, component and equipment suppliers, refrigerant manufacturers, MAC service providers and the Environmental Protection Agency
- Over $1.7 million in cash and approximately $2.0 million in in-kind industry contributions

Current 28 Corporate Sponsors

- Arkema (Autofina)
- Audi
- Behr
- BMW
- DaimlerChrysler
- Delphi
- Denso
- DuPont
- Ford
- Fujikoki
- General Motors
- Goodyear
- Honeywell
- Ineous Fluor
- Japan Fluor Mfg Assoc
- Manuli
- Modine
- Nissan
- Parker Hannifin
- Sanden
- Schrader-Bridgeport
- Solvay
- TI Automotive
- Toyota
- Trelleborg
- Viking Plastics
- Visteon
- Volkswagen

Project Goals

IMAC Core

Team 1
50% Leakage
Reduction

Team 2
30% Efficiency
Improvement

Team 3
30% Load
Reduction

Team 4
Containment During
Service & Disposal

Demonstration Vehicles 2006

Project Organization

CORE GROUP

Tier One | **Tier Two** | **OEM** | **Industry**

SAE

- *Overall Project Management*
- *Financial Oversight*
- *Funding strategy*
- *Educate management*

TEAMS

Leakage	Efficiency	Vehicle Load	Service
Members: •Tier 1 suppliers •Tier 2 suppliers •OEM's •MACS and Members •EPA •Refrigerant Suppliers •Other	**Members:** •OEM's •Tier 1 suppliers •NREL •EPA •Universities •Other	**Members:** •OEM's •Tier 1 suppliers •NREL •Universities •Other	**Members:** •OEM's •Tier 1 suppliers •EPA •MACS and members •Other

- *Overall Technical Leadership*
- *LCA & Cost Benefit Analysis*
- *Sub-group Coordination*

OEM Advisors
- •GM
- •DCX
- •Nissan
- •Toyota
- •Audi

To advise in case of proprietary technologies

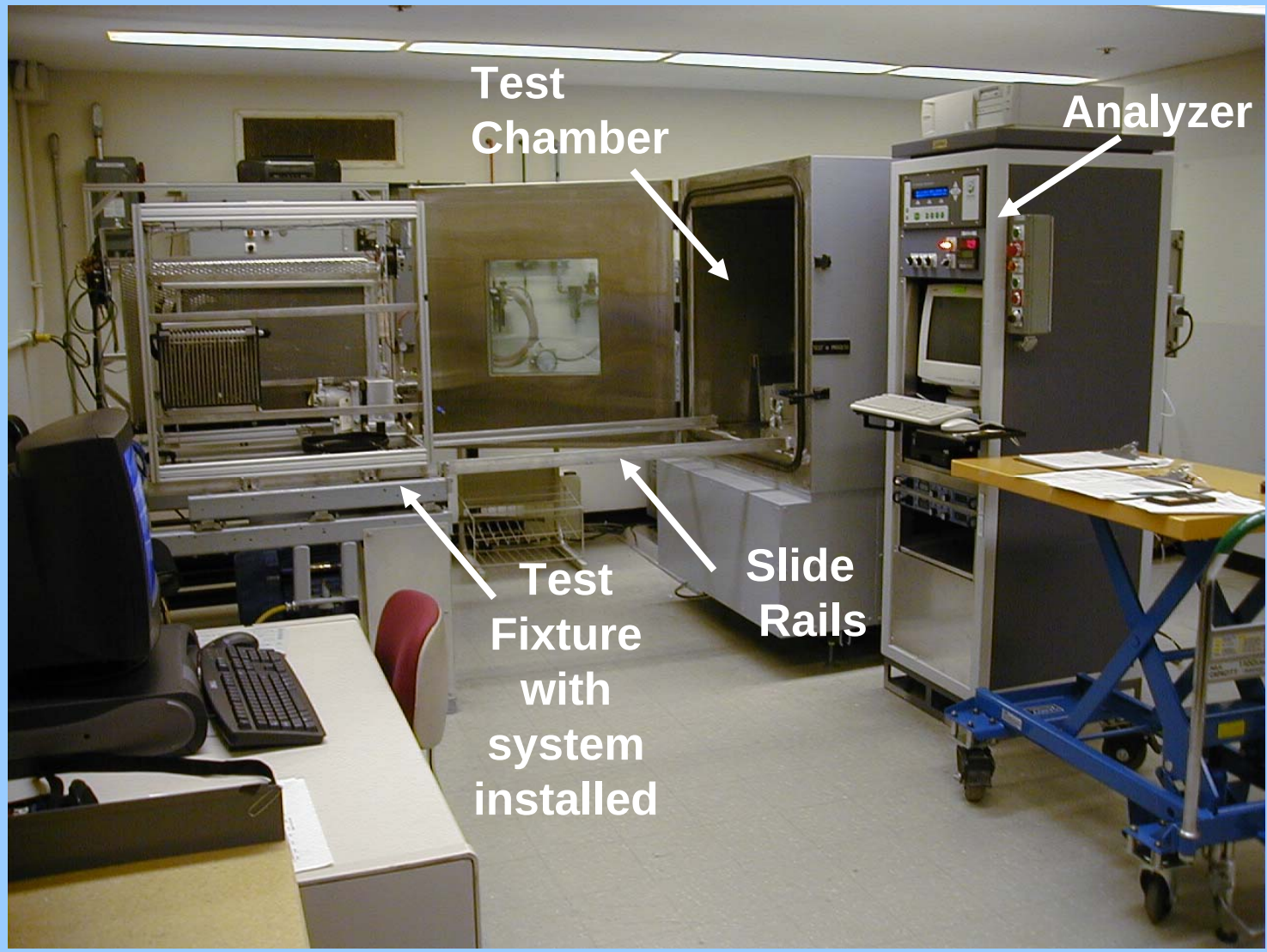
Team 1
Refrigerant Leakage Reduction

- **Goal:**
  - Reduce HFC-134a Mobile Air Conditioning System refrigerant direct emissions by 50 %

Team 1
Baseline Vehicles

- Identified 4 current production vehicles to baseline for refrigerant leakage rate
  - Dodge Caravan (dual system)
  - Ford F150
  - Toyota Camry
  - Pontiac Grand Prix
- Applied SAE J2727 to 4 baseline systems
- Conducted mini-shed tests at Delphi and Creative Thermal Solutions (CTS)

Mini-Shed Test Facility



Mini-Shed Emission Test Sequence

1. System Pre-Conditioning for 10 days @ 35ºC
2. Operate compressor for 30 minutes to distribute refrigerant and lubricant
3. Emission Test temperature cycle includes two dynamic operations per day to simulate morning and afternoon drives plus weekend non-use [120 h]
4. Emission Rate calculated Emissions = 2 x Thursday emissions + Thursday-Monday emissions

Team 1
Baseline Results

- Delphi submitted SAE Standard for mini-shed test at March 2006 SAE World Congress
- Delphi also submitted SAE Standard for reclaim procedure in order to determine actual system charge level
- Baseline annual leakage rates of 8 - 18 g/y
- SAE J2727 scores of 2.3 - 2.6
- Conclusion: Baseline leakage rates are low for typical vehicles with moderate J2727 scores

Team 1
Description of Technologies

- Improved crimps
- Improved fittings
- Compressor shaft seal and body seals
- Hose permeation
- Material integrity-tubing
- Reduced number of joints
- TXV
- Transducer/switches
- Service valves/caps
- Manufacturing/Assembly specifications
- Leakage Test Procedure
- Robust Manufacturing/Assembly Procedures

Team 2
System Efficiency

- **Goal:**
  - Improve system COP by 30% over the enhanced R134a system that was demonstrated in the SAE Phase 1 Alternative Refrigerant Cooperative Research Program (ARCRP)
  - Demonstrate equivalent performance

Team 2 Deliverables

- Demonstrate COP improvement on a System Test Stand
- Demonstrate equal performance in a Vehicle Tunnel
- SAE J Standard for Measurement of System COP using the System Test Stand Approach
- SAE J Standard for Annualized Climate Calculation of System Power Loss
- Relative Cost / Benefit Analysis:
  - Cost will be relative on a 1-10 scale
  - Benefit will be COP improvement over the enhanced R134a ARCRP system

Team 2 Technologies

- Compressor:
  - Improved piston compressors
  - Alternative technologies
- Heat Exchangers:
  - Improved Effectiveness evaporators and condensers
  - Internal heat exchangers
- Controls:
  - Optimized superheat controls
  - Optimized Sub-cooling controls
  - Optimized compressor controls
  - Flash gas removal
- Other items:
  - Optimized plumbing
  - Control of re-circulation

Team 2
Results to Date

- Condenser sub-cooling control study shows potential for 20-30% improved COP at low loads
- Evaporator superheat control study shows potential for 20% improved COP at low loads
- Improved efficiency compressor study shows potential for 15% improved COP
- SAE J2765 Test Standard for COP Measurement using the System Test Stand Method approved by SAE ICCC in April 2006
- SAE J2766 Recommended Practice for Annual Energy Simplified Calculation Method approved by SAE ICCC in April 2006

Team 3
Vehicle Load Reduction

- **Goal:**
  - Demonstrate vehicle level technologies that reduce the cooling load by 30%

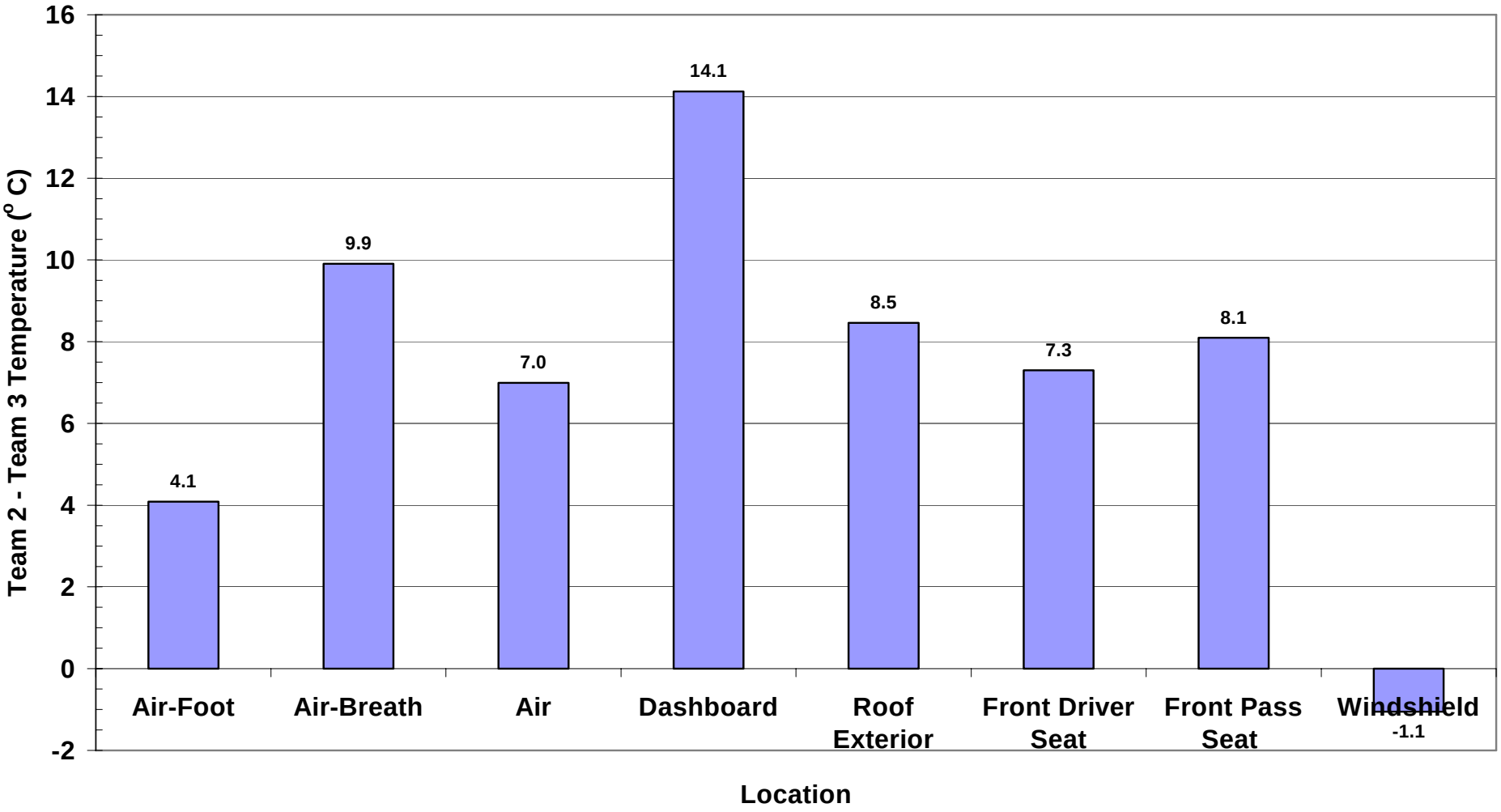
Team 3
Deliverables

- Procedure for evaluation of technology
- Evaluation of technologies in laboratory and in field through side-by-side outdoor vehicle soak testing
- Demonstration vehicle
- Ranking of approximate cost/benefits for various technologies
- Validate NREL model to estimate a technology's impact on soak temperature, time to comfort and power consumption

Team 3 Technologies

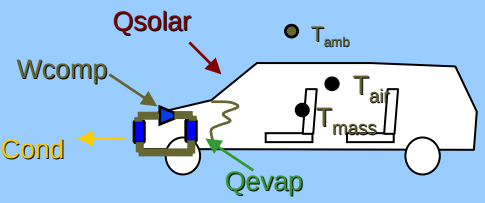
- Technologies
  - Power ventilation
  - Solar reflective glazing
  - Solar reflective paint
  - Lightweight insulation
  - Shades
  - Ventilated seats

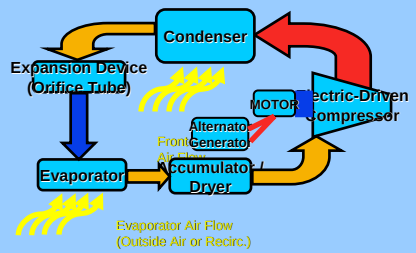
Combination Average Temperature Comparison



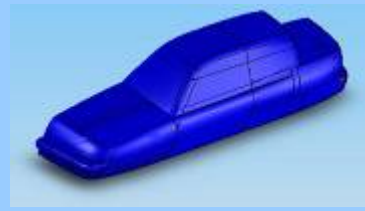
NREL Vehicle Model

Preliminary Model 3Q2005
Final Model 3Q2006



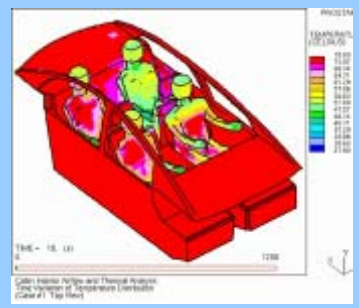


CAD



Solar Radiation → Glazing

Air Conditioning → Cabin Thermal/Fluid



Thermal Comfort → Vehicle

Vehicle → **Fuel Economy & Emissions**

Vehicle → **Cooling Capacity & A/C Power**

Thermal Comfort → **Occupant Thermal Comfort**

Team 4
Reduction in Refrigerant Loss During Servicing and EVL

- **Goals:**
  - Evaluate and Recommend Improvements for Service Tools, Equipment (New or Revised Standards) and Service Procedures
  - Identify, Quantify and Propose Remedies for Refrigerant Losses at Service, Vehicle End of Life
  - Quantify and Address Losses from One-Way Refrigerant Containers
  - Produce Educational Programs and Conduct Outreach to Reduce Refrigerant Emissions

Team 4
Leak Detection Results

1. **Leak detection tools, procedures**
   - **SAE J1627 standard developed for leak detection**
   - **Detection at 4 grams per joint/year (Current standard 14 grams)**
   - **Probe distance 3/8” (now ¼”)**
   - **‘Real world’ testing for standard**

Team 4
Recovery and Recharge

2. Service equipment, procedures
   - Testing has shown that current recovery equipment/procedures leaves refrigerant in system
   - SAE J2210 standard developed for equipment and recovery, recycling and recharging procedures

Reclaim Standards

Large potential impact on emissions...

Average System Charge	795 grams		With 20 million recoveries/y	With 25 million recoveries/y
	% Not Recovered	Grams	Annual Emissions [kg.]	Annual Emissions [kg.]
Refrigerant Not Recovered	30%	239	4,770,000	5,962,500
	25%	199	3,975,000	4,968,750
	20%	159	3,180,000	3,975,000
	15%	119	2,385,000	2,981,250
	10%	80	1,590,000	1,987,500
	5%	40	795,000	993,750

"…an estimated 20 to 25 million automotive A/C systems are serviced annually…"
Increasing Summer Profits with A/C Work, Larry Carley, Brake & Front End, 3/2005

Reducing refrigerant left in system at recovery could reduce emissions by millions of pounds at service annually

5 to 27 g/y Improvement

Team 4
Field Coupled Assemblies

3. Flexible coupled hose assemblies

- Conduct lab testing to evaluate field coupled assemblies for leakage
- Develop a cost-effective means of field evaluation of assemblies

Team 4
Emission Sources

4. **Analytical tool to evaluate service procedures**
   - **SAE Service Technology Group Activity**
     - **Focus on leak detection; diagnosis**

5. **Refrigerant mass balance**
   - **Data collection to identify and quantify the sources of all lifetime R-134a emissions**

Team 4
End of Vehicle Life

6. Vehicle end of life
   - Partnership with Automotive Recyclers Association
   - Raise awareness in this sector
   - Develop strategies to improve vehicle EOL refrigerant recovery

Vehicle Salvage

1.6 to 2.2 Million+ kg. at stake...

Average Remaining Charge:450 grams	
Vehicles Scrapped Annually in USA: 12 million	
Emissions if 30% have retained charge	Emissions if 40% have retained charge
1,634,400	2,179,200

Studies done in New Jersey and California suggest that 30% to 40% of vehicles arriving at end of life have an average refrigerant charge of one pound in system.

Better compliance and improved recovery techniques needed to reduce emissions.

7 to 10 g/y Improvement

Container Heels

3 Million pounds at stake...

Average Can Charge: 340 grams Cans sold annually in USA: 35 million	
Heel %	Emissions/y [kg]
1.3%	154,928
1.8%	214,515
1.9%	226,433
7.5%	893,813
10.0%	1,191,750

1 to 5 g/y Improvement

Average Cylinder Charge: 13.6 kg Cans sold annually in USA: 1.1 million	
Heel %	Emissions/y [kg]
4.3%	644,226
12.0%	1,797,840
26.0%	3,895,320

Less than 1 g/y Improvement

If heel is reclaimed, these losses can be eliminated!

Summary of Service Impact

- **Summary of Fleet impact in grams/yr refrigerant release**

[A/C Vehicles US fleet (221,575,336)]

	High	Low
Small can heel	**5.4** 10%	**1.1** 2%
– 35 Million cans		
13.6 kg. Container	**0.6**	**0.1**
– 1.1 Million containers		
12 Million Salvage	**9.8** 40%	**7.4** 30%
– 1 pound recovery on 40 and 30% of salvage vehicles		
Service Recovery	**26.8** 70%	**4.5** 95%
– Refrigerant recovery at service efficiency 70 – 95% of charge removal		
Total Release gr/yr per operational A/C fleet	**42.6**	**13.1**

Conclusions

- Industry participation in the IMAC program has been substantial
- IMAC is on track to meet its research goals
- New vehicle performance is good but can still improve
- The service and recycling sectors are critical to refrigerant containment
- Cooperative industry-government programs such as IMAC can produce results
- R-134a provides a competitive combination of customer benefits and environmental performance
- Responsible use of R-134a will preserve its viability in the marketplace