SAE Alternate Refrigerant Cooperative Research Program And Industry Impact

ARCRP

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Introduction

- Provide Overview of ARCRP
- Consumer needs for mobile A/C systems
  - The Environmental Impact
- The Impact of refrigerants on
  - Manufacturers
  - Consumers
  - Environment

ARCRP Overview

Project Objective

- Provide a directly comparative engineering evaluation of the existing R134a systems and other refrigerant technologies

Organization

- Three core groups (USA, JAMA, VDA) interfaced with vehicle and A/C system manufacturers
- SAE ARCRP Expert Team Determined System Components and Monitored The Research
  - Hans Fernqvist, Volvo
  - William Hill, GM
  - Steve Lepper, Ford
  - Juergen Wertenbach, DC
- **Test Facility**
  - University of Illinois (U of I) chosen to perform the testing
    - ★ Research Quality Test lab
    - ★ Selected after careful review of available labs by Expert Team

Phase I Systems Tested

R134a baseline

- Components
  - Variable displacement compressor-externally controlled
  - Plate/fin [laminated] evaporator-single tank
  - Micro-channel [“parallel flow”] condenser

R744 System (carbon dioxide)

- Components-2001 prototype
  - Variable displacement compressor- externally controlled [33 cc]
  - Micro-channel [parallel flow] evaporator [58 mm thick]
  - Micro-channel [parallel flow] condenser
  - Electronically controlled expansion device
  - Internal [Suction line] heat exchanger [tube-in-tube]
- Components-2002 prototype
  - Variable displacement compressor- externally controlled [31 cc]
  - Micro-channel [parallel flow] evaporator [38 mm thick]
  - Micro-channel [parallel flow] condenser
  - Electronically controlled expansion device
  - Internal [Suction line] heat exchanger [micro-channel]
  - Separate oil separator
  - Laboratory grade accumulator with independent liquid/oil flow control

Phase I Systems Tested

Enhanced R134a System

- Components
  - Variable displacement compressor, externally controlled
  - Micro-channel [parallel flow] evaporator [50 mm thick]
  - Micro-channel [parallel flow] sub-cooled condenser w/Integrated R/D
  - Electronically controlled expansion device, mimic TXV-not optimized

R290 System-proposed Secondary Loop

- Components
  - Variable displacement compressor [Set for fixed displacement]
  - Laminated evaporator/chiller (refrigerant to secondary fluid)
  - Micro-channel [parallel flow] condenser
  - Orifice tube-manual valve [Two stage]
  - Low side accumulator [sight glass]
  - Suction line heat exchanger [tube-in-tube]
  - Plate/fin Cooling core [Secondary fluid to air]
  - Secondary fluid circulating pump [10 GPM, variable flow]

Phase I Summary Results
COP at EQUAL capacity

Evaporator	35ºC x 45%	35ºC x 45%	25ºC x 80%+	25ºC x 80%+	15ºC x 80%	15ºC x 80%
Condenser	35ºC	35ºC	25ºC	25ºC	15ºC	15ºC
Speed	900	2500	900	2500	900	2500
Baseline R134a	3.4	1.9	3.8	2.8	4.4	3.8
Enhanced R134a	3.9	2.7	4.2	3.8	5.7	4.5
2001 CO2	3.1	2.6	3.5	3.6	5.6	4.5
Secondary Loop R290	2.5	2.0	2.7	2.8	4.0	3.5
2002 CO2	3.4	2.7	4.1	4.1	6.0	5.4

*Controlled capacity
+10ºC control setting

Phase II Systems Tested

- **R134a and R152a with the same system components**
  - **Neither was optimized due to strategy to test both with the same hardware and controls**
- **R744 with 2003 prototype components**
  - **Third prototype level of hardware and optimized controls**
  - **Also evaluated low cost CO_2 system components (compressor and refrigerant management)**
    - ★**Reduced COP [Coefficient of performance]**
    - ★**Lower energy efficiency**

Phase II Summary Results COP at EQUAL capacity

R152a

Table 2 Phase II Summary Results: Selected COP

Evaporator	35ºC x 40%	35ºC x 40%	35ºC x 40%	25ºC x 80%	25ºC x 80%	25ºC x 80%	15ºC x 80%	15ºC x 80%	15ºC x 80%
Condenser	35ºC	35ºC	35ºC	25ºC	25ºC	25ºC	15ºC	15ºC	15ºC
Speed [RPM]	**900**	**2500**	**4000**	**900**	**2500**	**4000**	**900**	**2500**	**4000**
R134a	3.17	1.89	1.43	3.76*	3.03*	2.53*	5.22*	2.64*	1.71*
R152a	3.36	2.35*	2.05*	3.61*	3.09*	2.54*	4.96*	2.80*	1.78*
SPEED [RPM]	**990**	**2750**	**4400**	**990**	**2750**	**4400**	**990**	**2750**	**4400**
2003 CO2	2.84	2.20*	2.04*	3.65*	3.16*	2.66*	5.48*	3.03*	1.78*
CO2 w/TXV	2.75	2.02*	1.96*	3.43*	3.08*	2.60*	4.52*	2.73*	1.94*
CO2 w/OTB	2.70	2.06*	1.86*	3.43*	3.06*	2.57*	4.89*	2.60*	1.87*
CO2 w/DPV	2.76	2.18*	1.91*	3.43*	3.15*	2.67*	5.17*	2.85*	2.10*

***Controlled compressor capacity
+**OTB**=Fixed **O**rifice **T**ube with a **B**y-pass
++**TXV**= **T**hermal mechanical **E**xpansion **V**alve
+++**DPV**=**D**elta **P**ressure Expansion **V**alve

COP is accurate to ±3% at loads greater than 1500W.
COP is accurate to ±9% at loads less than 1500W.

ARCRP Phase I & II R744 Results (Carbon Dioxide)

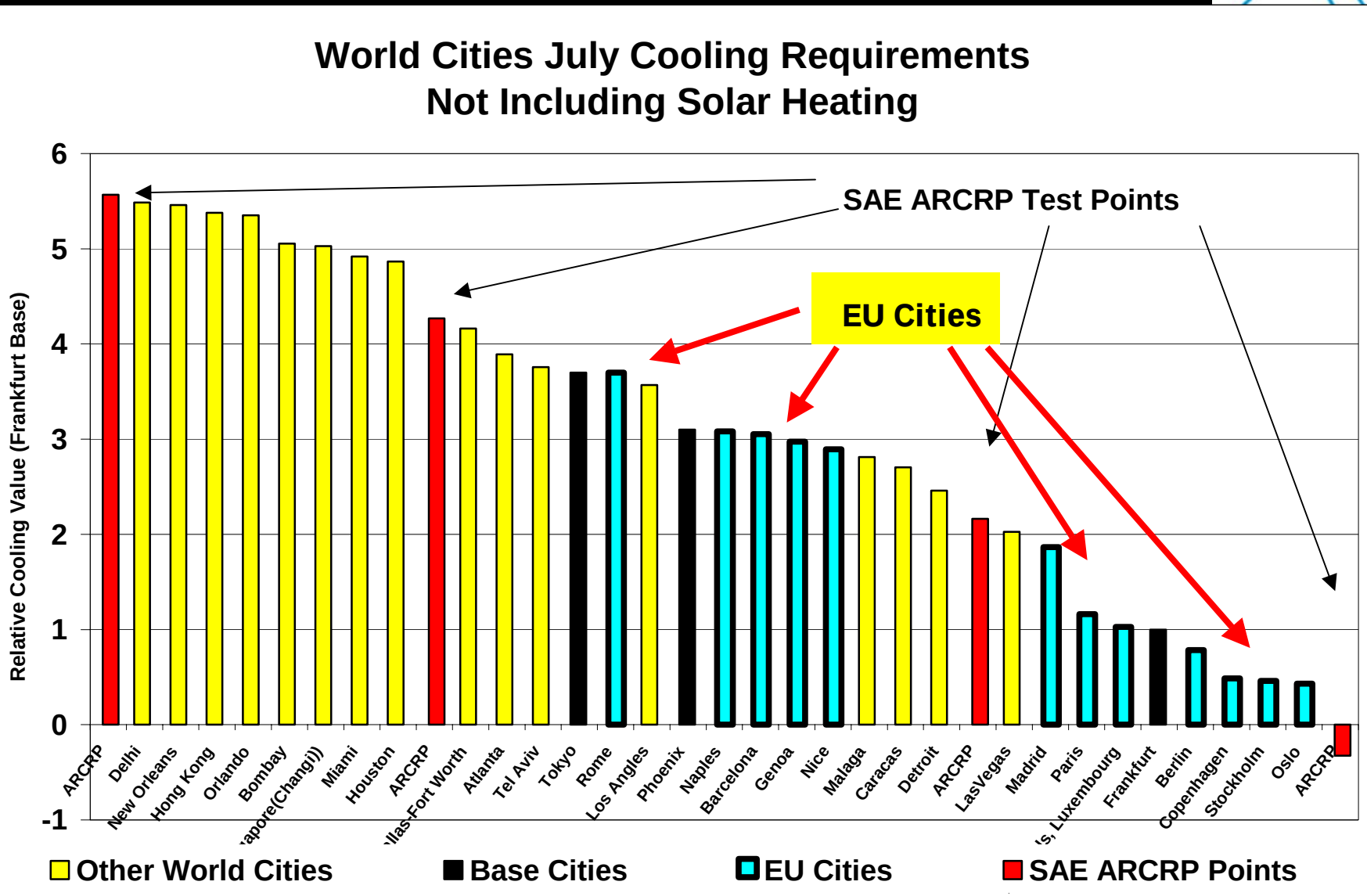
- **R744 system with experimental heat exchangers and optimized refrigerant management**
  - **R744 provides better efficiency (COP) at mild and mid temperatures [at 25 C and below] as compared to enhanced HFC-134a**
  - **Less efficient than HFC-134a at high temperatures**
- **Low cost refrigerant controls were less efficient than optimized refrigerant management**

ARCRP Phase I & II R134a Results

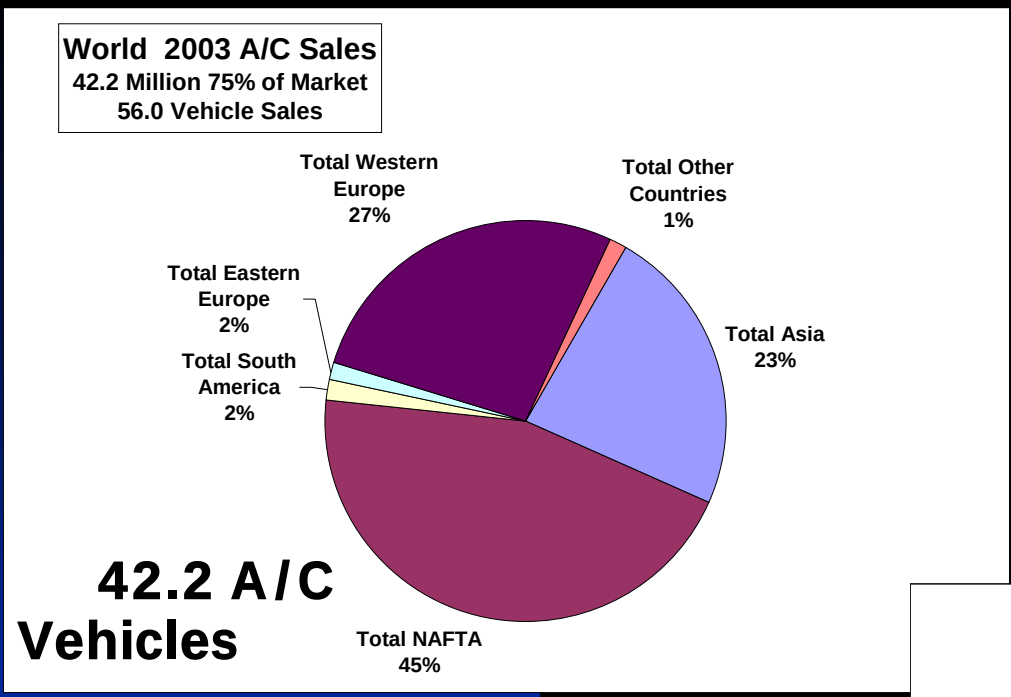
- R134a baseline had current production heat exchangers and refrigerant management
- Enhanced system had improved evaporator and compressor technology
  - Enhanced R134a system had 20 – 40% improvement in COP as compared to baseline
- Optimized refrigerant management technology could allow further improvements to R134a system energy efficiency
  - ⋆ **System improvements up to 30% have been demonstrated by SAE I-MAC program across the ambient range**

R290 System Phase I
(Secondary Loop)

- Simple, basic system assembled from current automotive components
  - No enhancement of components
  - No system optimization
- Secondary loop
  - Flammable refrigerant system in engine compartment only
  - Non-flammable liquid coolant provides cooling to passenger area
- COP Performance comparable to baseline R-134a system


World Cities July Cooling Requirements
Not Including Solar Heating
Relative Cooling Value (Frankfurt Base)
6
5
4
3
2
1
0
-1
SAE ARCRP Test Points
EU Cities
ARCRP
Delhi
New Orleans
Hong Kong
Orlando
Bombay
Miami
Houston
ARCRP
Atlanta
Tel Aviv
Tokyo
Rome
Los Angles
Phoenix
Naples
Barcelona
Genoa
Nice
Malaga
Caracas
Detroit
ARCRP
LasVegas
Madrid
Paris
Frankfurt
Berlin
Copenhagen
Stockholm
Oslo
ARCRP
Other World Cities
Base Cities
EU Cities
SAE ARCRP Points

2003 World A/C Sales



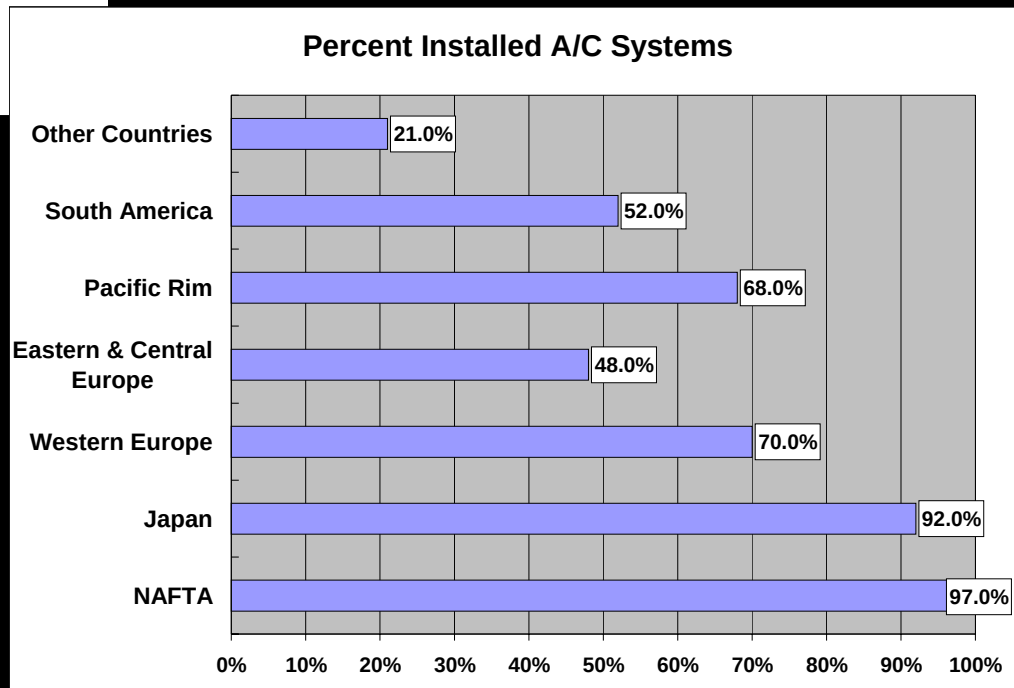
Potential ratio Based on Systems Sold in 2003

CO_2 Systems

-Europe - 12.2 million

R134a Systems

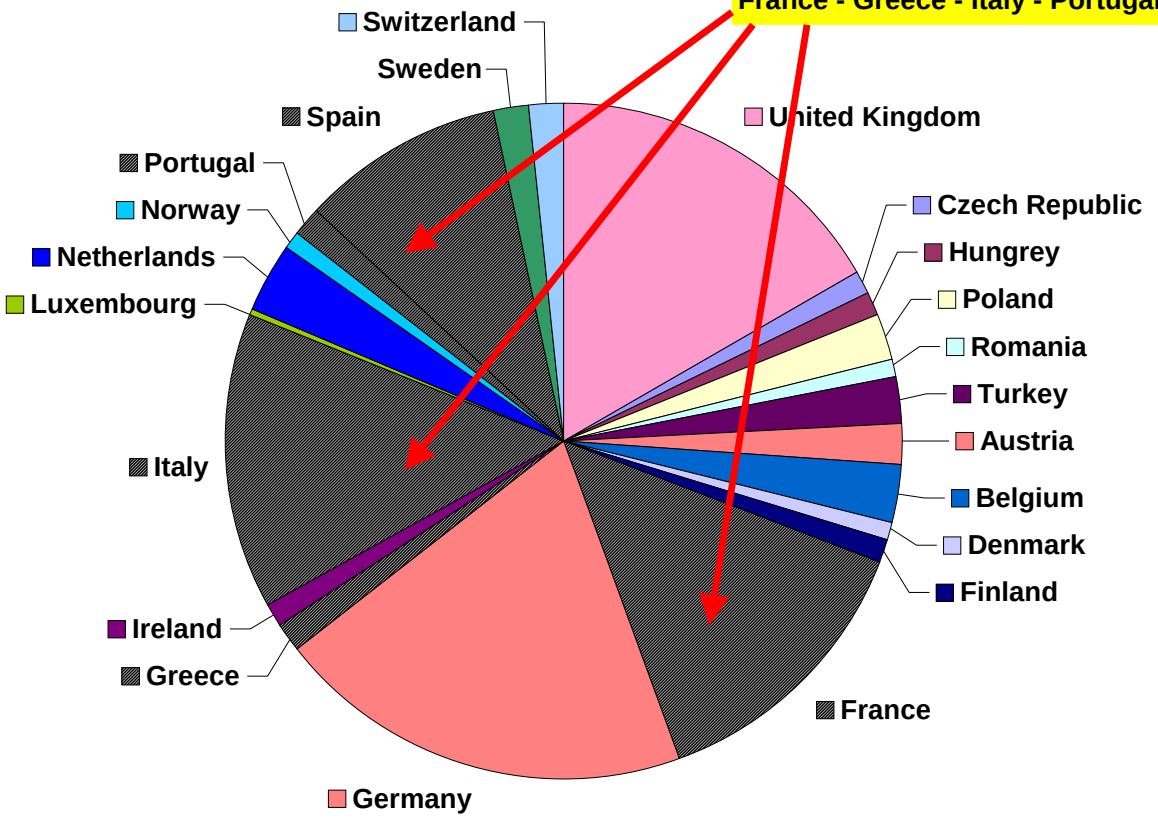
-Other World Market -30 million



Europe Vehicle Sales

17.6 million 2003 Sales EC

40% of 2003 Vehicle Sales In 5 European Countries Have Warm Regions: France - Greece - Italy - Portugal - Spain



40% of vehicles sold are in 5 countries having July avg. 82.9F (28C) and max. of 104.5F (40C)

Alternatives For Industry-Manufacturing

- **Manufacture Market Required Systems? [Common Product Line Export Vehicles]**
  - **R134a Systems for North America**
  - **R744 Systems for Europe**
  - **R134a System For Asia All Others**
- **Manufacture R744 For All Markets?**
  - **[Common Product Line Export Vehicles]**

Consumer Impact Due To An Alternate Refrigerants

- **Initial Cost**
- **Frequency of service**
- **Cost of service**
- **Safety**

Industry Design Direction ?

- System Design
  - Electronic vs. Mechanical Refrigerant Controls
  - Compressor Fixed vs. Variable
  - R744 and flammable refrigerants will require safety mitigation in U.S. market
- What Is The Best Cost and Environmentally Effective System?
  - Direct Emissions
    - ★System Leakage
    - ★Release During Service
  - Indirect Emissions
    - ★System Weight
    - ★System energy consumption
    - ★Vehicle Fuel Economy For All Cooling Demands

Alternate Refrigerants

- All alternate refrigerants can provide cold air from MAC systems
- Questions to consider:
  - Do they meet consumer needs:
    - ★Cooling performance during all weather conditions?
    - ★Fuel economy?
  - Are they cost and environmentally effective?
  - Are they safe for the consumer and service technician?

Global Refrigerant

- **Chemical companies have recently developed new refrigerants**

Can industry establish consensus on a single best world refrigerant?