New Refrigerants Evaluation Results

JAMA-JAPIA Consortium

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Contents

The Purpose of the New Refrigerants Evaluation

PURPOSE

STEP-1:

1. Is a simple ‘Drop-in’ possible?

2. If not possible, evaluate the influence.

STEP-2:

1. Confirmation of a vehicle marketability.

2. Long-term toxic evaluation.

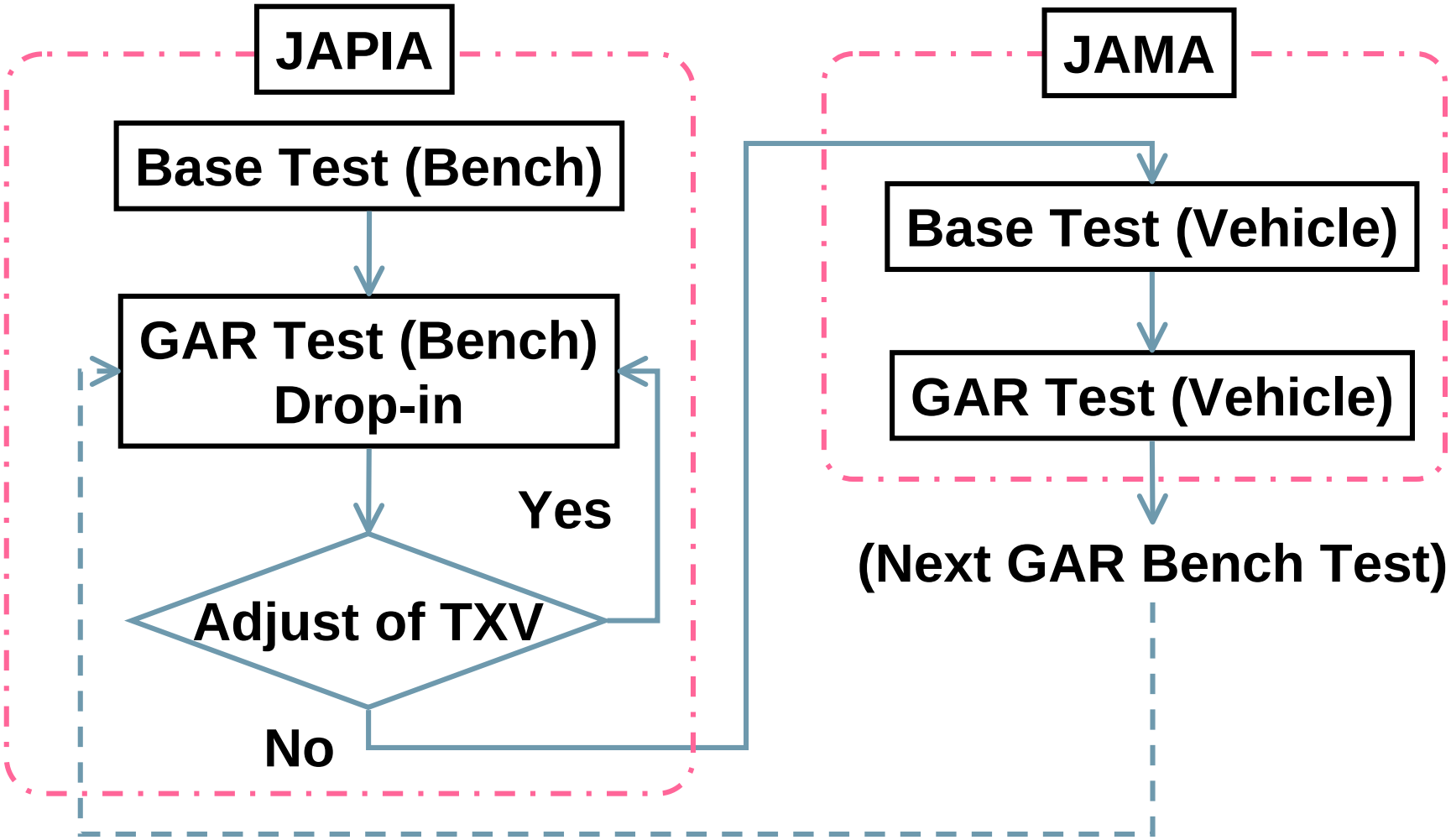
Framework of the New Refrigerants Evaluation

Items	Ref. Suppliers	Suppliers (JAPIA)	OEM's (JAMA)	STEP-1	STEP-2
The Feasibility of the Refrigerant	◎			•Thermal Stability	•Toxicity •Cost
System Bench Test		◎		•Materials Compatibility •Cooling Capacity •COP	•System Durability and Reliability
Vehicle Test		○	◎	•Cooling Performance •A/C Power Consumption	•Vehicle Durability •Cooling Capability •NV

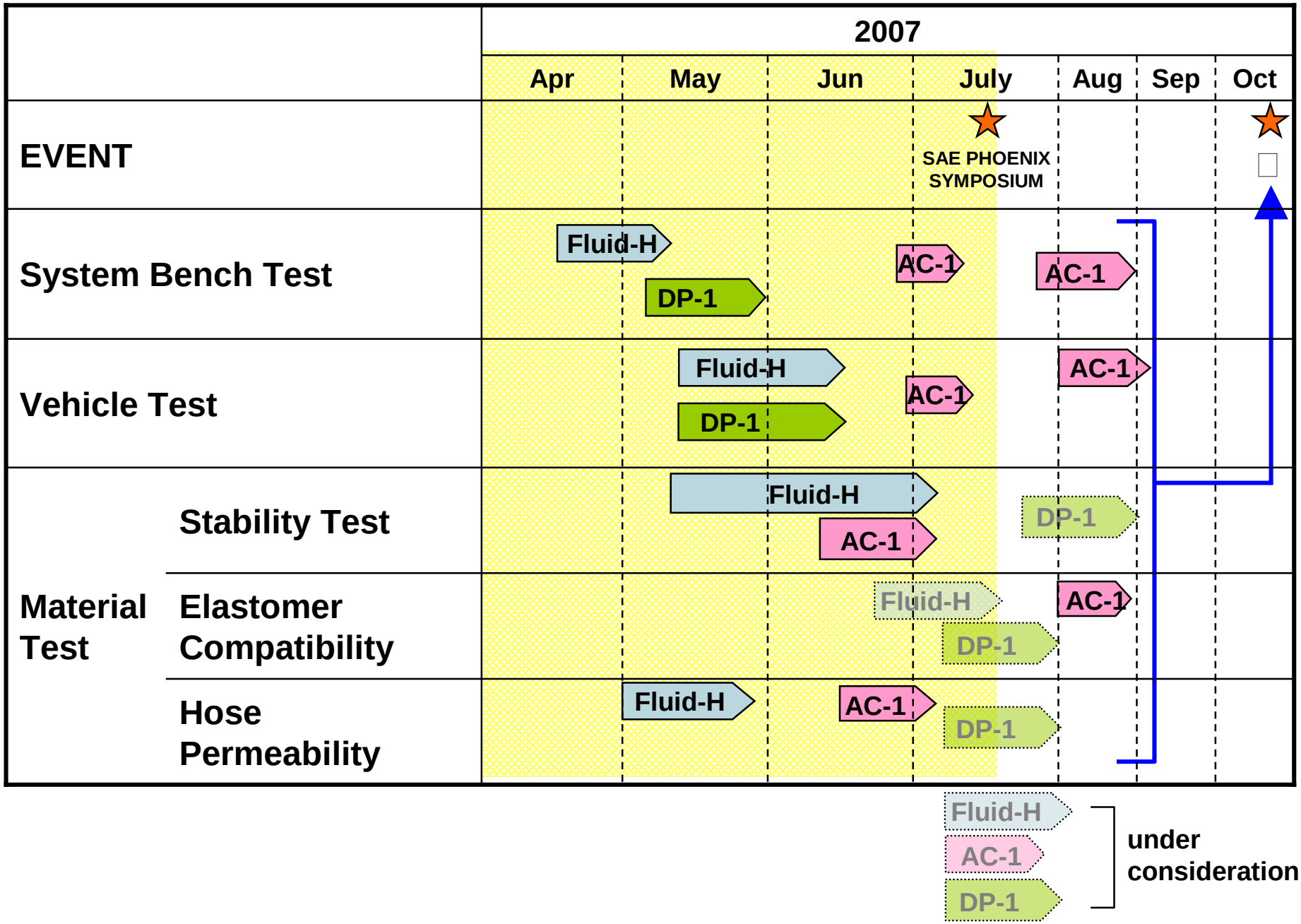
◎ Main ○ Support

Refrigerant Suppliers : DuPont(DP-1), INEOS-Fluor(AC-1), Honeywell(Fluid-H)
JAPIA : 7 Tire1 suppliers
JAMA : 13 OEM's

Evaluation Flow (STEP-1)



Evaluation Schedule (STEP-1)



Test Vehicles

Vehicles		Engine	Type	Transmission
Toyota GS430		4.3L	SEDAN	A/T
Nissan Sylphy		1.5-2.0L	SEDAN	A/T
Mitsubishi Outlander		2.4L	SUV	CVT
Nissan Tiida		1.5-1.8L	H/B	A/T
Mazda Axela		1.5-2.0L	H/B	M/T
Suzuki Every		0.6L	K-Car	A/T
Honda Zest		0.6L	K-Car	A/T

A/C System Specifications

Vehicle		GS430	Sylphy	Out lander	Tiida	Axela	Every	Zest
Com-pressor	TYPE	Variable piston	Variable piston	Fixed scroll	Fixed rotary	Fixed rotary	Fixed rotary	Fixed scroll
	Capacity (cm^3)	160	105	90	80	120	63.4	53.9
Con-denser	Size (Wmmx HmmxDmm □	660x 363.8x16	615x 343x16	623x x407x16	607x 340.8x16	560.5x 382.3x16.5	420x 320x16	405x 356.9x16
	Fin pitch	3.55mm	2.8mm	3.196mm	2.8mm	2.8mm	2.8mm	2.6mm
Evapo-rator	Size (Wmmx HmmxDmm □	211x 293.1x38	198x 192x40	254x 205x38	207.8x 225x39	230x 185x55	199.4x 200x38	181.1x 221x38
	Fin pitch	3.0mm	3.1mm	2.6mm	3.1mm	3.4mm	3.0mm	3.2mm
Expan-sion valve	Capacity	1.5ton (Modified)	2ton (Serial)	1.5ton (Modified)	F-H 1.5ton DP-1 1.0ton (Modified)	1.5ton (Modified)	1.0ton (Modified)	F-H 2.0ton DP-1 1.0ton (Modified)

System Bench Test Conditions (GAR Common Spec)

Series of measurement	Compressor speed	Air temperature upstream of condenser	Air velocity upstream of condenser	Set point air downstream from evaporator	Evaporator air amount	Conditions evaporator entry	Remarks
	min-1	℃	m/s	℃	kg/min		
1	900	60	1.5	3	Max air flow	45℃/25%	
2	900	45	1.5				
3	1800		2				
4	2500		3				
5	4000		4				
6	1800	45	2	3	56%		
7	900	60	1.5	3	Max air flow	35℃/25%	
8	900	45	1.5				
9	1800		2				
10	2500		3				
11	4000		4				
12	1800	45	2	3	56%		
13	900	50	1.5	3	Max air flow	35℃/40%	
14	900	35	1.5				
15	1800		2				
16	2500		3				
17	4000		4				
18	1800	35	2	3	56%		
20	900	40	1.5	3/10	72%	25℃/50%	
22	900	25	1.5				
24	1800		2				
26	2500		3				
28	4000		4				
30	1800	25	2	3/10	44%		
32	900	30	1.5	3/10	72%	15℃/80%	
34	900	15	1.5				
36	1800		2				
38	2500		3				
40	4000		4				
42	1800	15	2	3/10	44%		

45 ºC Evaporator entry is few cases. Besides, this condition is severe for some bench facilities.

60 ºC Condenser entry is severe at some bench facilities. Omit this test condition.

35 ºC /25% humidity is severe at some bench. Use 40% instead of 25%.

Set point 10 adapts only external variable compressor.
Internal type is impossible.
Fix type uses variable thermo switch but it's not major. And it seems not crucial to compare different refrigerants for fix type compressor.

9kg/min is large for air volume of a small car.
Max air volume uses test data.
Medium air flow depends on each ratio

Vehicle Test Conditions (GAR Common Spec)

Test Condition

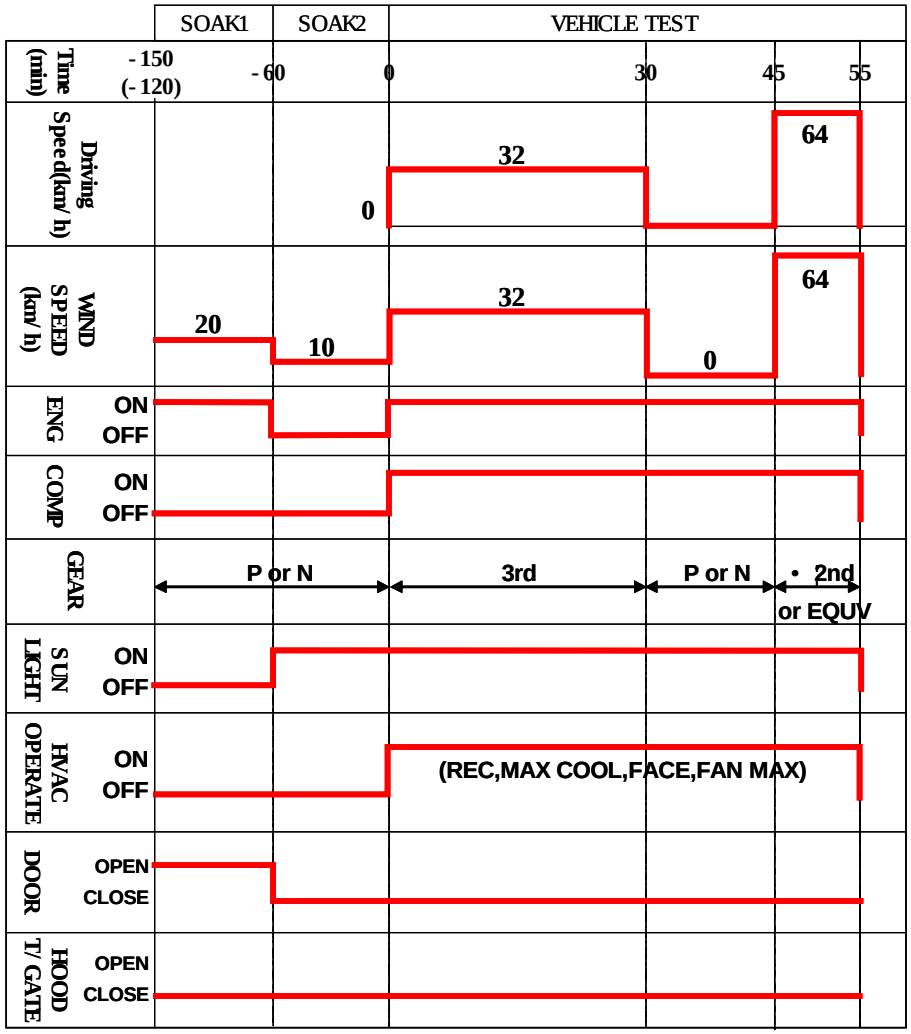
Chamber temperature : 40ºC
Relative humidity : 40%
Solar load : 1,000 W/m²

Blower Setting and Air Distribution:

Automatic and Manual HVAC Control:

Cooling : max
Blower : max
Grill outlet : “face level” open
Recirculation : 100%

Driving cycle



Based on Common Spec Book for evaluating Global Alternative Refrigerants (GAR) V2.0

Material Test Conditions

Stability Test

- Procedure : ANSI/ASHRAE97-1999 Sealed Glass Tube Method to Test the Chemical Stability of Materials for Use Within Refrigerant Systems
- Test condition

Temperature	ºC	175 , 200
Moisture	PPM	<10 , 1000 , (10000)
Test period		2 week
* Oil		PAG , POE
* Refrigetant		R134a , Fluid H , AC-1
Oil:Ref. (Rate)		1 : 1
Catalyst		Al , Cu , Fe

* Oil : The kind of the evaluated oil

PAG
PAG1:Serial PAG for MACs
PAG2:PAG (without extreme pressure additive ,oiliness additive)

POE
POE1:Serial POE for HV AC
POE2:Serial POE for Stationary AC
POE3: POE Honeywell recommendation Additive

Permeation Test

- Procedure: *JRAIA standard JRA2021
- Test condition : Temp. : 80ºC , Ref. charge amount: 0.6g/mL
  (Permeation was calculated with the difference between the residual mass of 24hour point and that of 96 hour point.)
- Samples: Yokohama (use 2 types of discharge/suction lines)

* JRAIA : THE JAPAN REFRIGERATION AND AIR CONDITIONING INDUSTRY ASSOCIATION

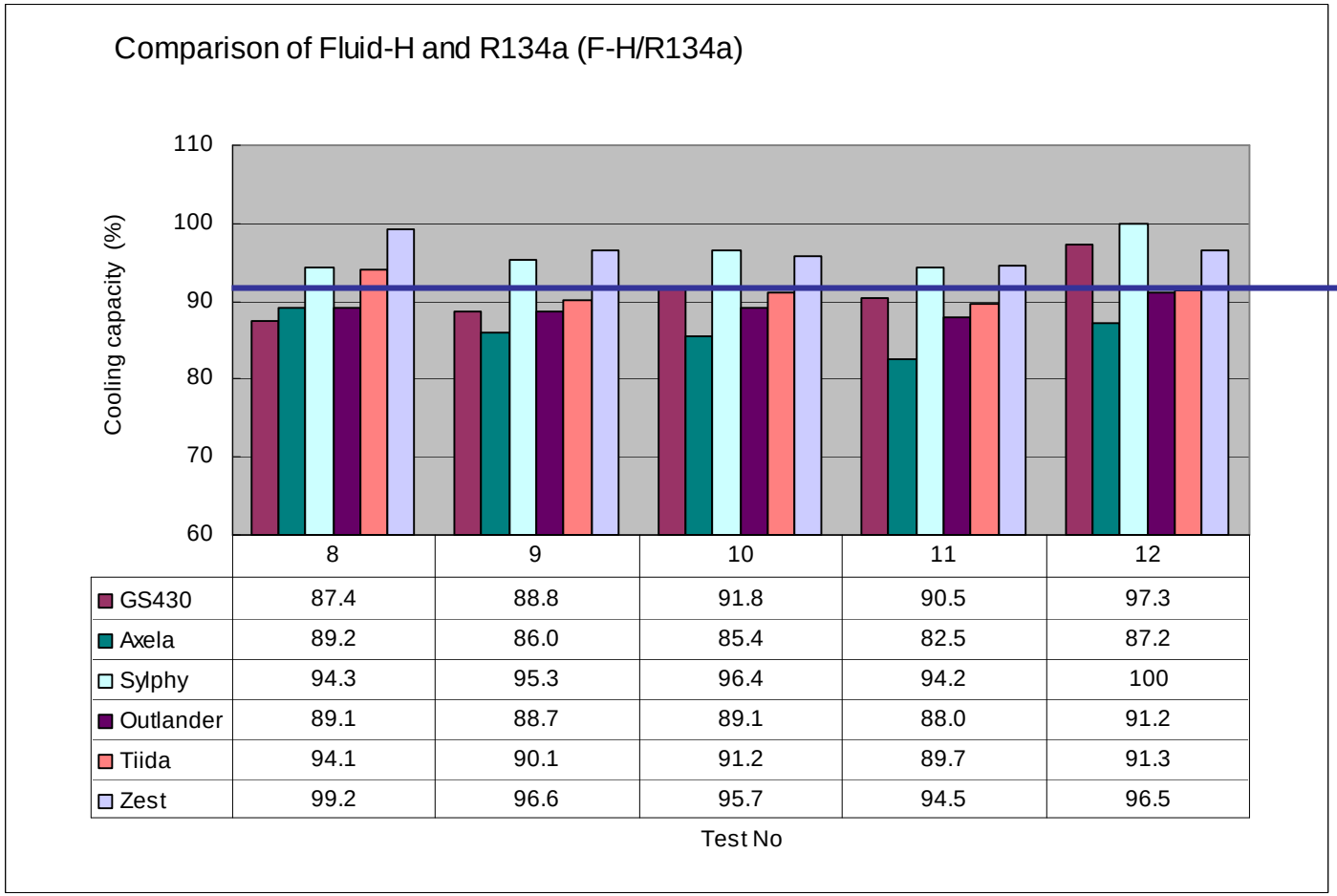
* Refrigetant: DP1 evaluation is under consideration.

Honeywell Fluid-H Evaluation Results

System Bench Test Results

Cooling Capacity

Condenser 45ºC
Evaporator 35ºC/40%



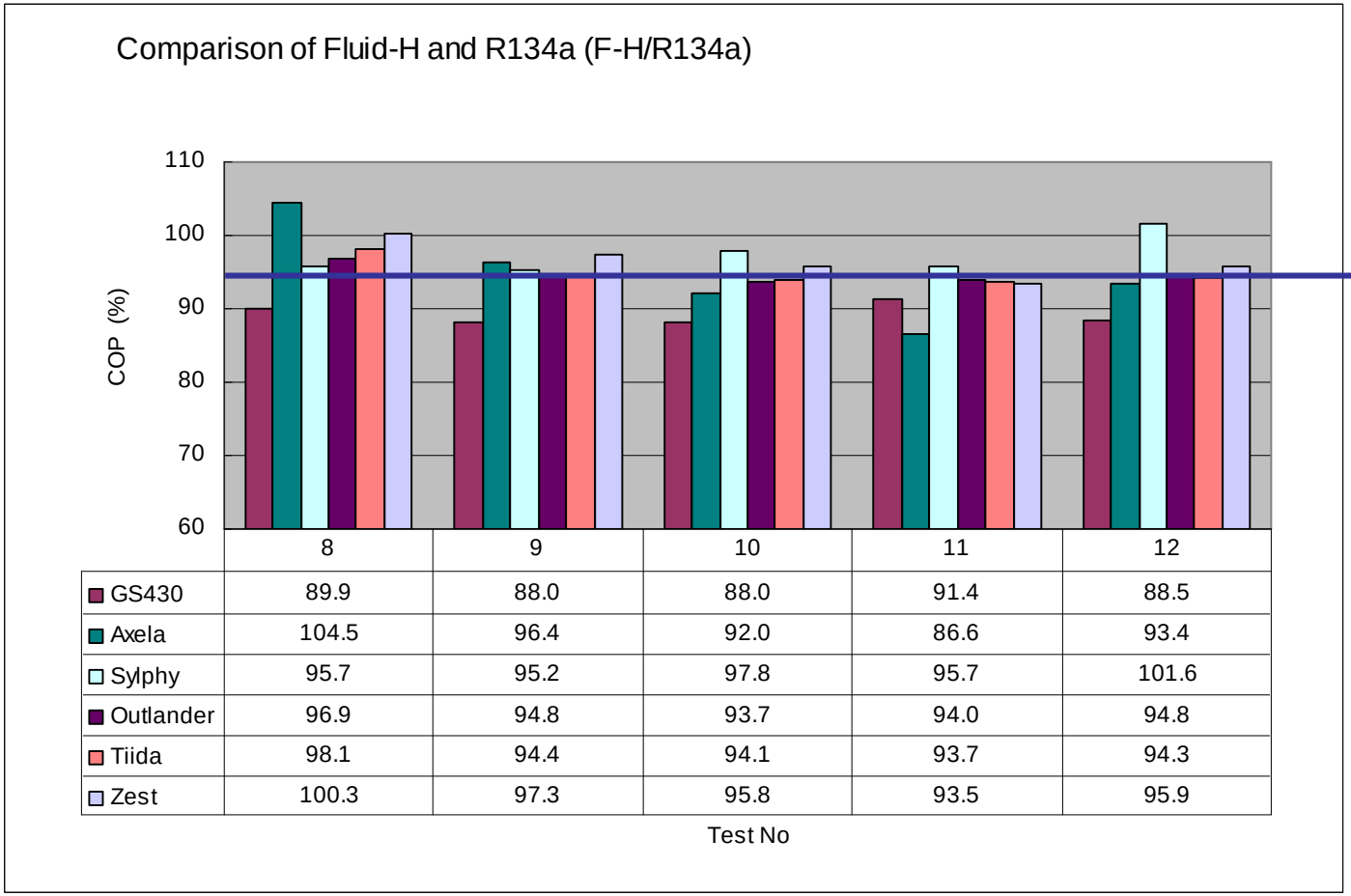
	8	9	10	11	12
GS430	87.4	88.8	91.8	90.5	97.3
Axela	89.2	86.0	85.4	82.5	87.2
Sylphy	94.3	95.3	96.4	94.2	100
Outlander	89.1	88.7	89.1	88.0	91.2
Tiida	94.1	90.1	91.2	89.7	91.3
Zest	99.2	96.6	95.7	94.5	96.5

Average
91.7%
Max-Min cut
(91.8%)

System Bench Test Results

COP

Condenser 45ºC
Evaporator 35ºC/40%



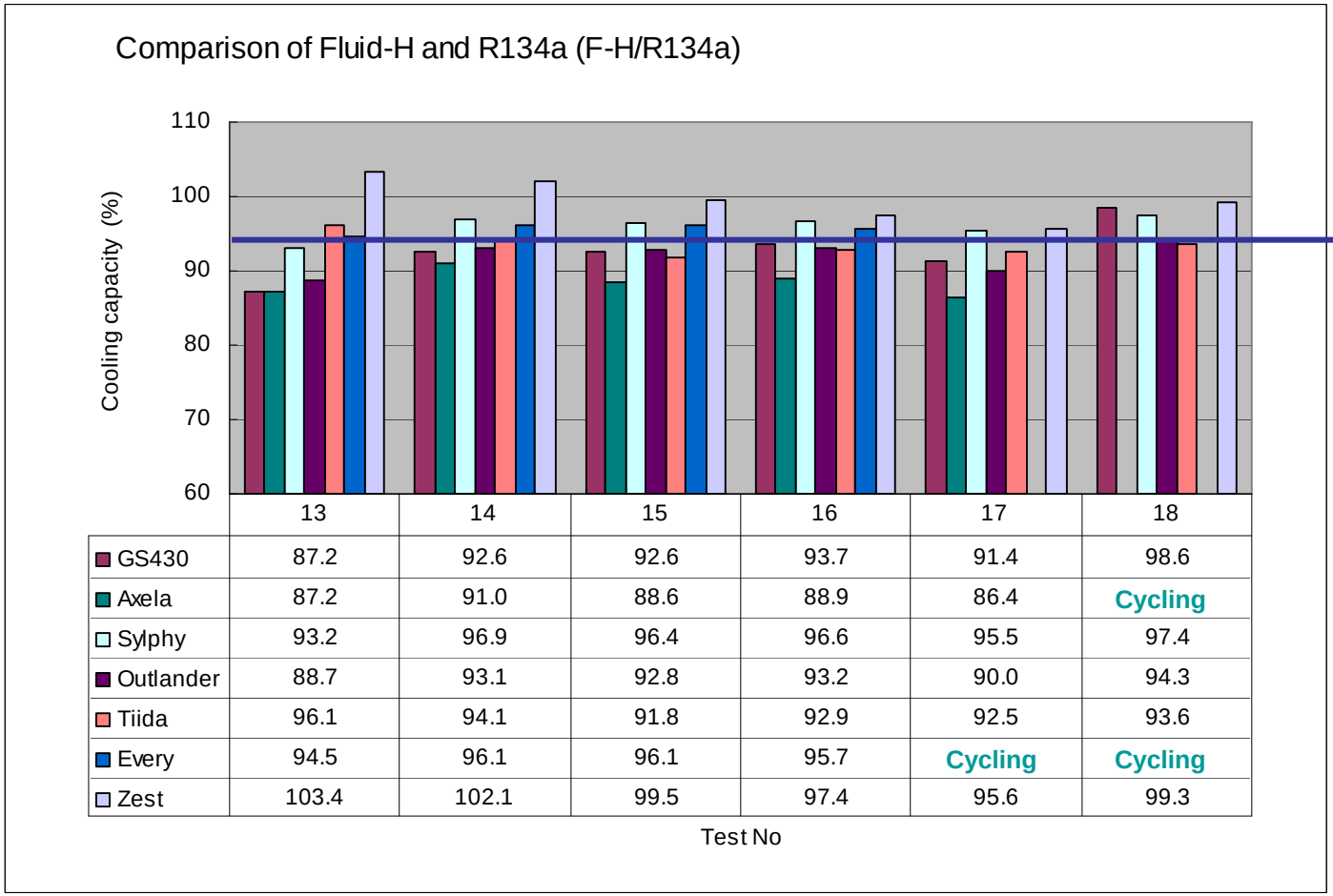
	8	9	10	11	12
GS430	89.9	88.0	88.0	91.4	88.5
Axela	104.5	96.4	92.0	86.6	93.4
Sylphy	95.7	95.2	97.8	95.7	101.6
Outlander	96.9	94.8	93.7	94.0	94.8
Tiida	98.1	94.4	94.1	93.7	94.3
Zest	100.3	97.3	95.8	93.5	95.9

Average
94.5%
Max-Min cut
(94.9%)

System Bench Test Results

Cooling Capacity

Condenser 35, 50ºC
Evaporator 35ºC/40%

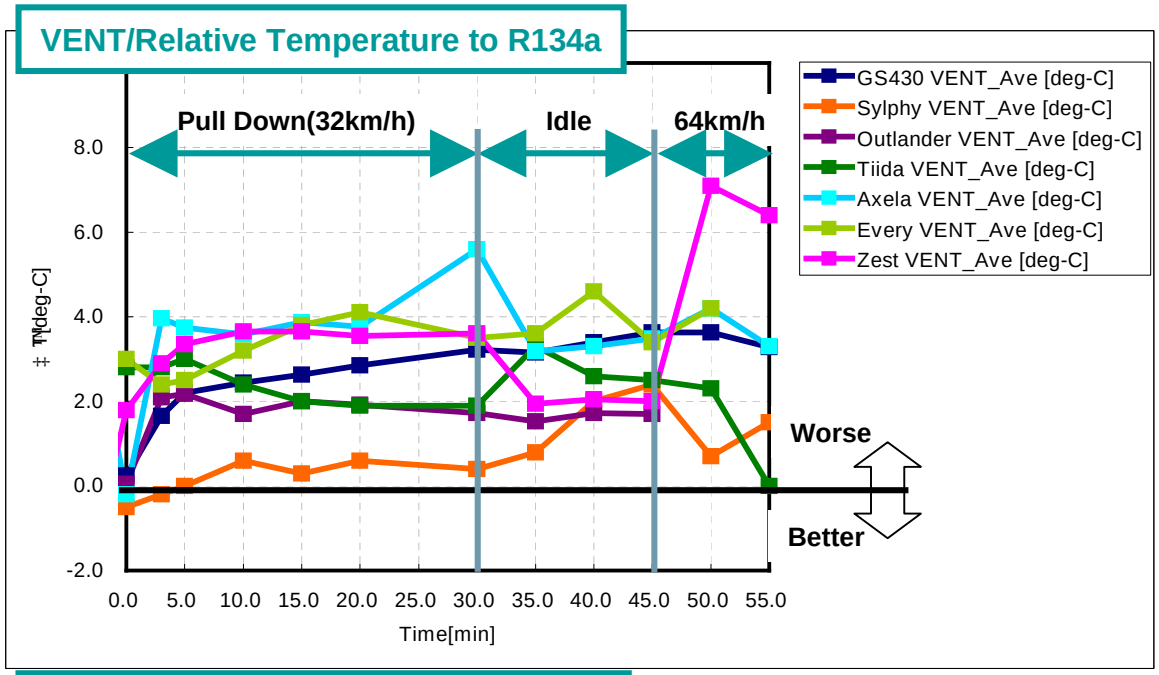


	13	14	15	16	17	18
GS430	87.2	92.6	92.6	93.7	91.4	98.6
Axela	87.2	91.0	88.6	88.9	86.4	**Cycling**
Sylphy	93.2	96.9	96.4	96.6	95.5	97.4
Outlander	88.7	93.1	92.8	93.2	90.0	94.3
Tiida	96.1	94.1	91.8	92.9	92.5	93.6
Every	94.5	96.1	96.1	95.7	**Cycling**	**Cycling**
Zest	103.4	102.1	99.5	97.4	95.6	99.3

Average
94.1%
Max-Min cut
(94.0%)

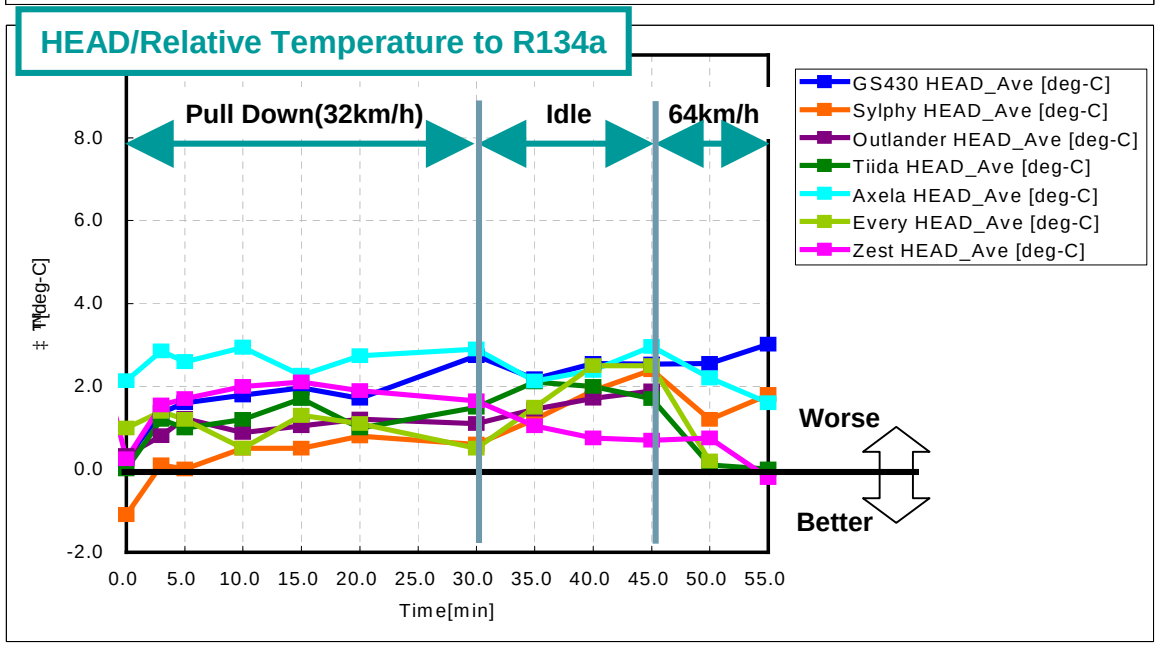
Cycling:
one refrigerant system had on – off cycling. Another didn't have cycling.

Vehicle Test Results (Fluid-H)



ΔT [ºC]

Time (min)	10	30	45	55
GS430	2.5	3.2	3.6	3.3
Sylphy	0.6	0.4	2.4	1.5
Outlander	1.7	1.7	1.7	
Tiida	2.4	1.9	2.5	0.0
Axela	3.6	5.6	3.5	3.3
Every	3.2	3.5	3.4	
Zest	3.7	3.6	2.0	6.4
Average	2.5	2.9	2.7	2.9



ΔT [ºC]

Time (min)	10	30	45	55
GS430	1.8	2.7	2.5	3.0
Sylphy	0.5	0.6	2.4	1.8
Outlander	0.9	1.1	1.9	
Tiida	1.2	1.5	1.7	0.0
Axela	2.9	2.9	3.0	1.6
Every	0.5	0.5	2.5	
Zest	2.0	1.7	0.7	-0.2
Average	1.4	1.6	1.9	1.2

Material Evaluation Results

Stability

Proposed Spec
<3.3

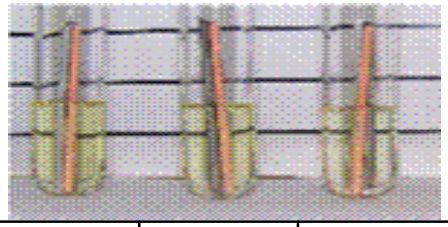
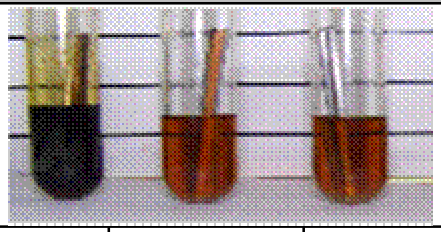
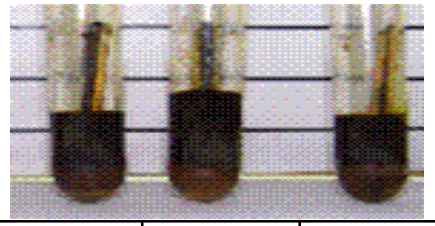
Ref.		R134a				Fluid-H				
Oil		PAG1	PAG2	POE1	POE2	PAG1	PAG2	POE1	POE2	POE3
Condition		175deg-C/14days								
Low Moisture	ppm	<10								
Total Acid Number	mgKOH/g	0.03	0.00	0.00	0.00	18.4	1.41	6.64	7.11	5.21
Low Moisture	ppm	1000								
Total Acid Number	mgKOH/g	0.82	0.00	0.01	0.10	2.82	1.65	6.05	6.78	6.13
High Moisture	ppm	10000								
Total Acid Number	mgKOH/g	1.75	0.00	21.3	21.4	3.92	2.81	22.4	24.3	19.9
Condition		200deg-C/14days								
Low Moisture	ppm	<10								
Total Acid Number	mgKOH/g	1.28	0.00	0.00	0.00	14.6	13.5	9.72	9.34	6.83
Low Moisture	ppm	1000								
Total Acid Number	mgKOH/g	1.15	0.54	0.1	0.21	14.9	14.2	9.92	8.92	6.38
High Moisture	ppm	10000								
Total Acid Number	mgKOH/g	2.19	0.87	21.4	22.3	18.2	12.3	17.2	17.1	21.5

Material Evaluation Results

Stability

Oil:PAG1(Serial PAG for MACs)
Temperature: 175 , 200 ºC

* Not Co . :Not Contain

Refrigetant		R134a			Fluid-H		
Moisture	ppm	<10	1000	10000	<10	1000	10000
Temperature	ºC	175					
Oil appearance photograph							
Oil appearance		Maize	Maize	Maize	Black	Dark Brown	Dark Brown
Sludge		*Not Co.	Not Co.	Not Co.	Contain	Not Co.	Contain
Total Acid Number (mgkoh/g)		0.03	0.82	1.75	18.4	2.82	3.92
Temperature	ºC	200					
Oil appearance photograph							
Oil appearance		Yellow	Yellow	Yellow	Black	Black	Black
Sludge		Not Co.	Not Co.	Not Co.	Contain	Contain	Contain
Total Acid Number (mgkoh/g)		1.28	1.15	2.19	14.6	14.9	18.2

Material Evaluation Results

Permeation

[g/year]

HOSE L=400mm	Discharge Inner coating(1)	Discharge Inner coating(2)	Suction Inner coating
	Inner coat : 6-Nylon Inner rubber : IIR Outer rubber : Cl-IIR	Inner coat : 6-Nylon Inner rubber : IIR Outer rubber : EPDM	Inner coat : 6-Nylon Inner rubber : IIR Outer rubber : Cl-IIR
HFC134a	40.8	46.4	78.3
Fluid-H	49.3	59.1	129.9

(at 80 □)

Inner diameter		
Discharge inner coating (1)	(ACH 77 11)	11.2mm
Discharge inner coating (2)	(ANESIS 11)	11.2mm
Suction inner coating	(ACH 87 15)	15.2mm
Suction without coating	(ANESIS 15)	15.1mm

Summary Honeywell Fluid-H Evaluation Results

Under high load and the present conditions that TXV is adjusted only,

- **Cooling capacity : Fluid-H is inferior to R134a by 8%.**
- **COP : Fluid-H is inferior to R134a by 5%.**
- **Material : Fluid-H is insufficient in thermal stability.**

It is very difficult that we use Fluid-H as 'Drop-in' refrigerant for MAC.

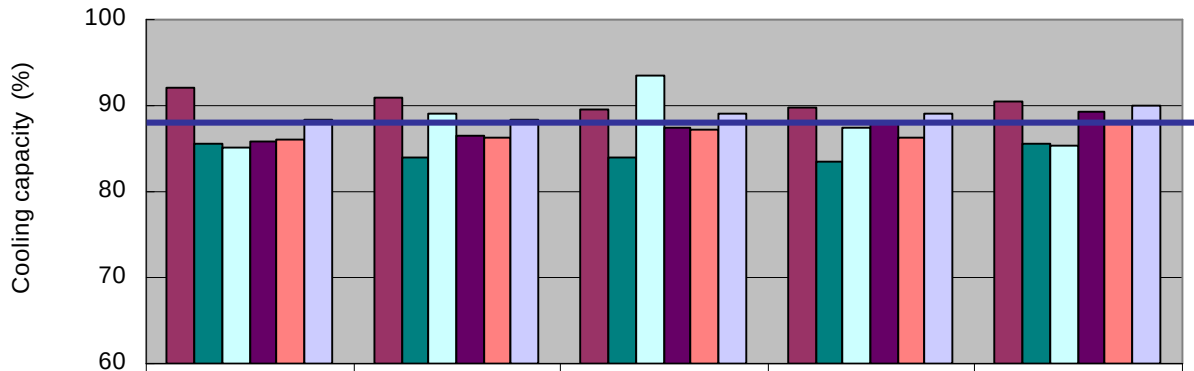
DuPont DP-1 Evaluation Results

System Bench Test Results

Cooling Capacity

Condenser 45ºC
Evaporator 35ºC/40%

Comparison of DP-1 and R134a (DP-1/R134a)



	8	9	10	11	12
GS430	92.1	90.9	89.6	89.8	90.6
Axela	85.6	83.8	84.0	83.4	85.6
Sylphy	85.1	89.0	93.5	87.5	85.4
Outlander	85.8	86.6	87.4	87.9	89.2
Tiida	86.0	86.4	87.1	86.3	88.0
Zest	88.3	88.4	89.1	89.0	90.0

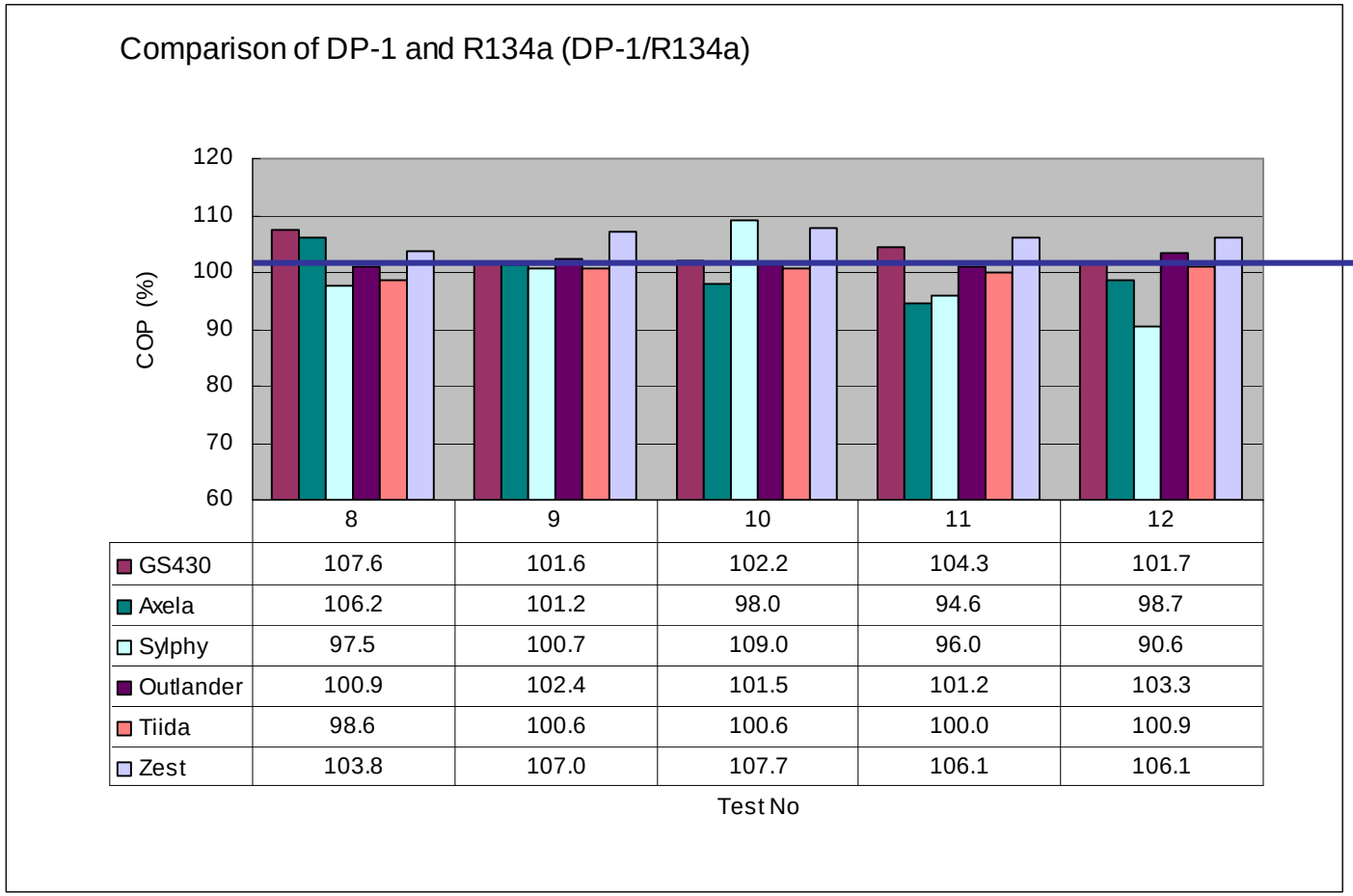
Test No

Average
87.7%
Max-Min cut
(87.6%)

System Bench Test Results

COP

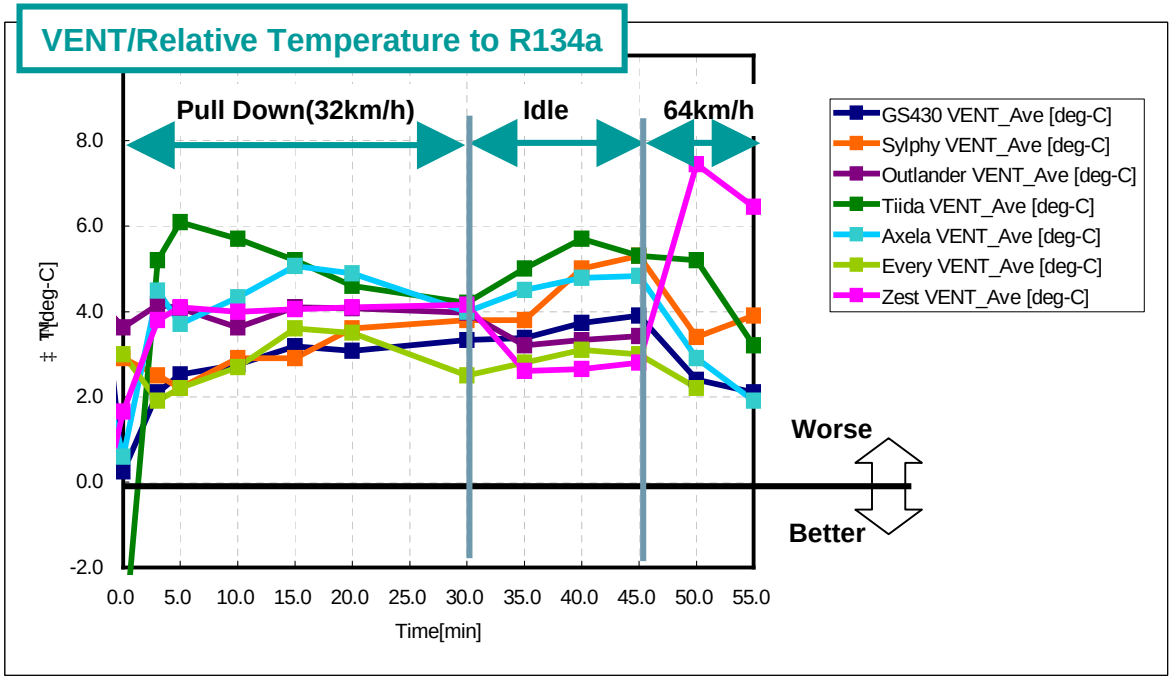
Condenser 45ºC
Evaporator 35ºC/40%



	8	9	10	11	12
GS430	107.6	101.6	102.2	104.3	101.7
Axela	106.2	101.2	98.0	94.6	98.7
Sylphy	97.5	100.7	109.0	96.0	90.6
Outlander	100.9	102.4	101.5	101.2	103.3
Tiida	98.6	100.6	100.6	100.0	100.9
Zest	103.8	107.0	107.7	106.1	106.1

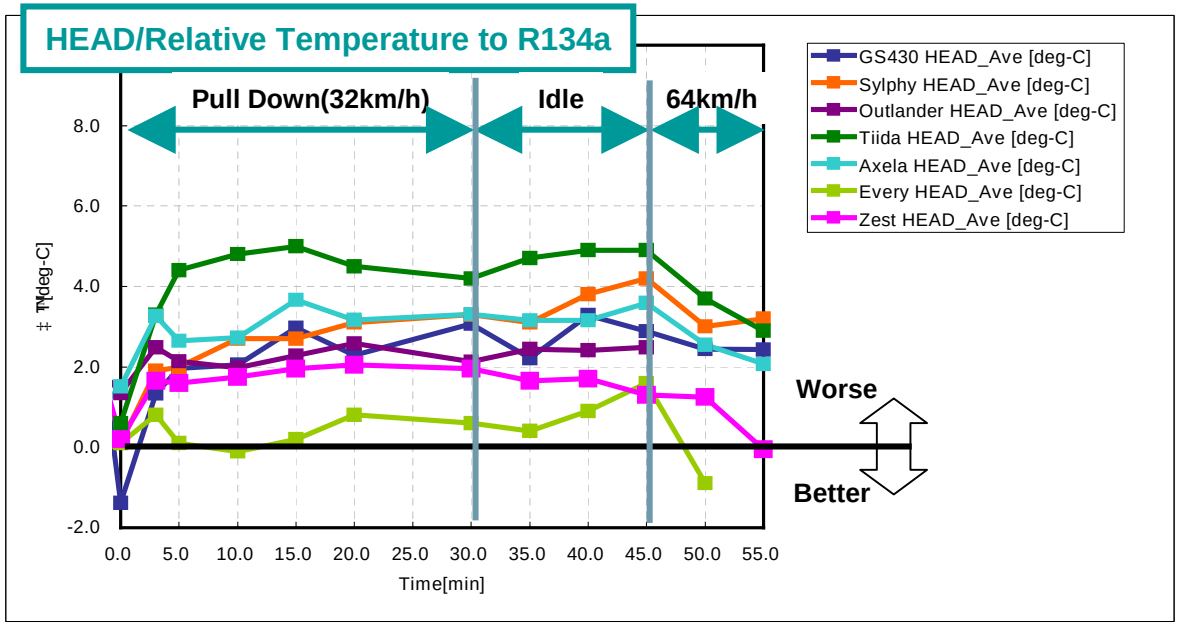
Average
101.7%
Max-Min cut
(101.7%)

Vehicle Test Results (DP-1)



ΔT [ºC]

Time (min)	10	30	45	55
GS430	2.8	3.3	3.9	2.1
Sylphy	2.9	3.8	5.3	3.9
Outlander	3.6	4.0	3.4	
Tiida	5.7	4.2	5.3	3.2
Axela	4.3	4.0	4.8	1.9
Every	2.7	2.5	3.0	
Zest	4.0	4.2	2.8	6.5
Average	3.7	3.7	4.1	3.5



ΔT [ºC]

Time (min)	10	30	45	55
GS430	2.1	3.1	2.9	2.4
Sylphy	2.7	3.3	4.2	3.2
Outlander	2.0	2.1	2.5	
Tiida	4.8	4.2	4.9	2.9
Axela	2.7	3.3	3.6	2.1
Every	-0.1	0.6	1.6	
Zest	1.8	2.0	1.3	-0.1
Average	2.3	2.6	3.0	2.1

Summary DuPont DP-1 Evaluation Results

Under high load and the present conditions that TXV is adjusted only,

- **Cooling capacity : DP-1 is inferior to R134a by 12%.**
- **COP : DP-1 is superior to R134a by 2%.**
- **Material : DP-1 evaluation is under consideration**

Cooling capacity deterioration is not negligible, but it is worth to continue to evaluate. Material compatibility evaluation is under consideration.

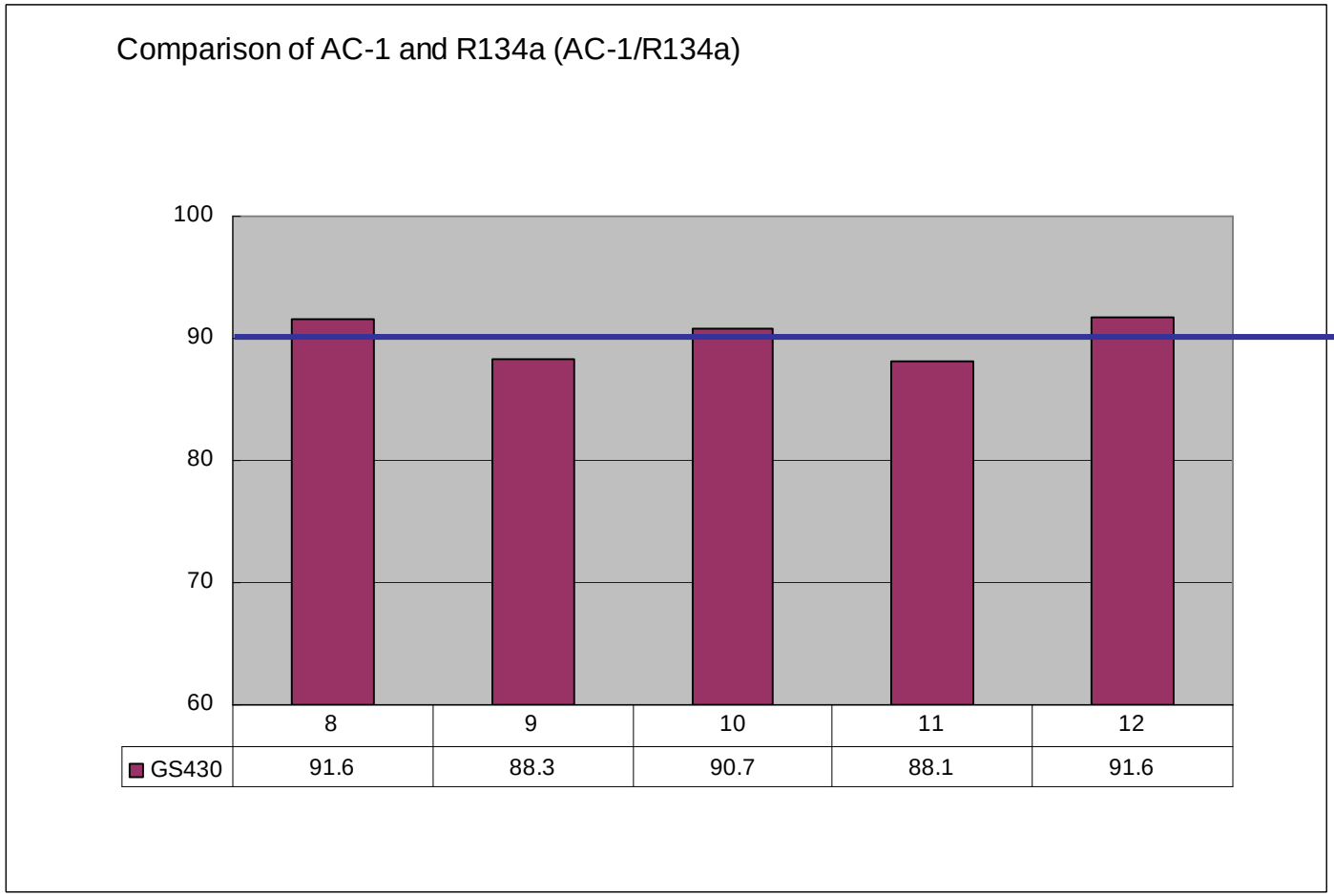
INEOS-Fluor AC-1 Evaluation Results

System Bench Test Results

Reference

Condenser 45ºC
Evaporator 35ºC 40%

Cooling Capacity



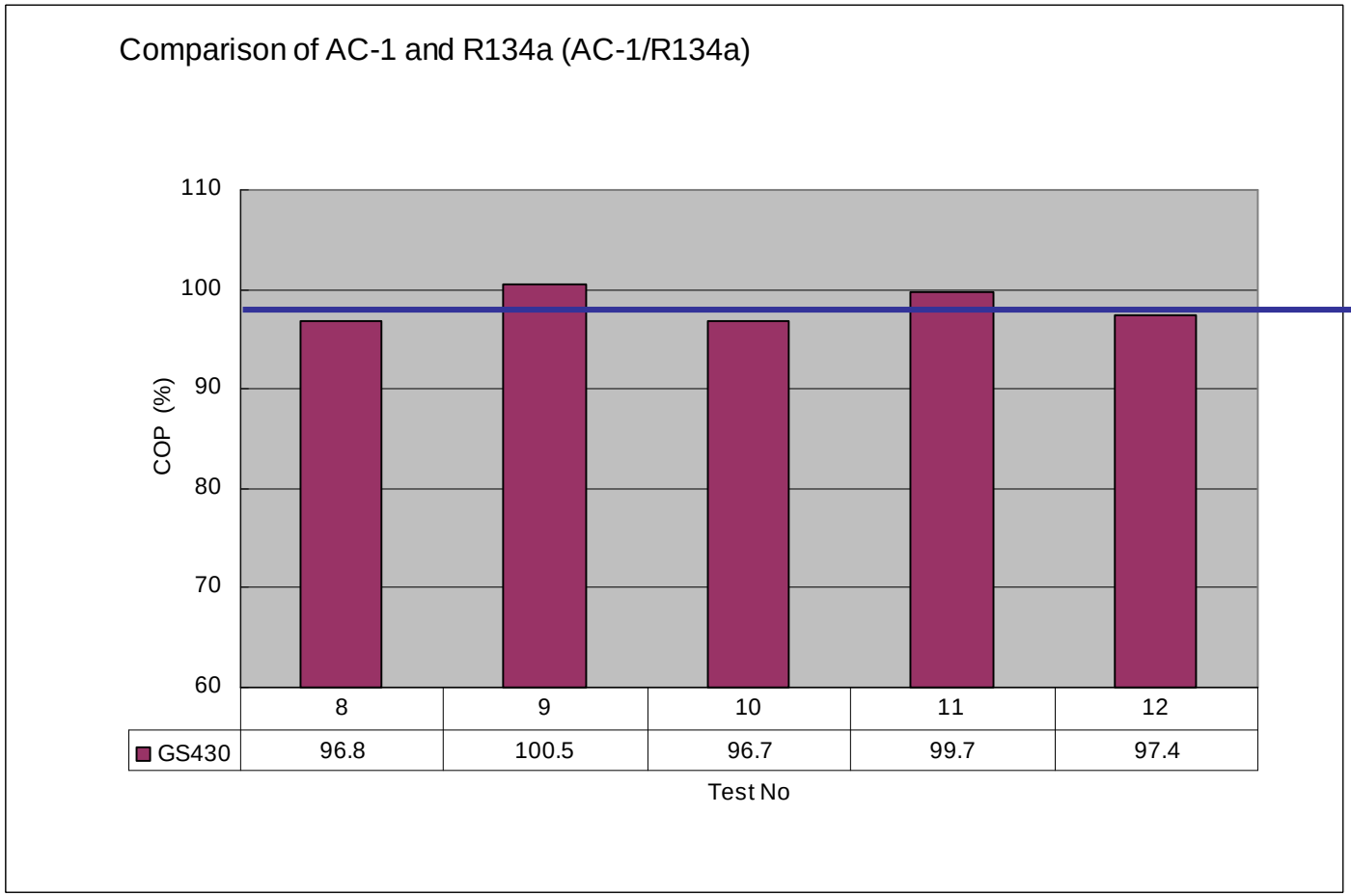
Average
90.1%
Max-Min cut
(90.2%)

System Bench Test Results

Reference

Condenser 45,50ºC
Evaporator 35ºC 40%

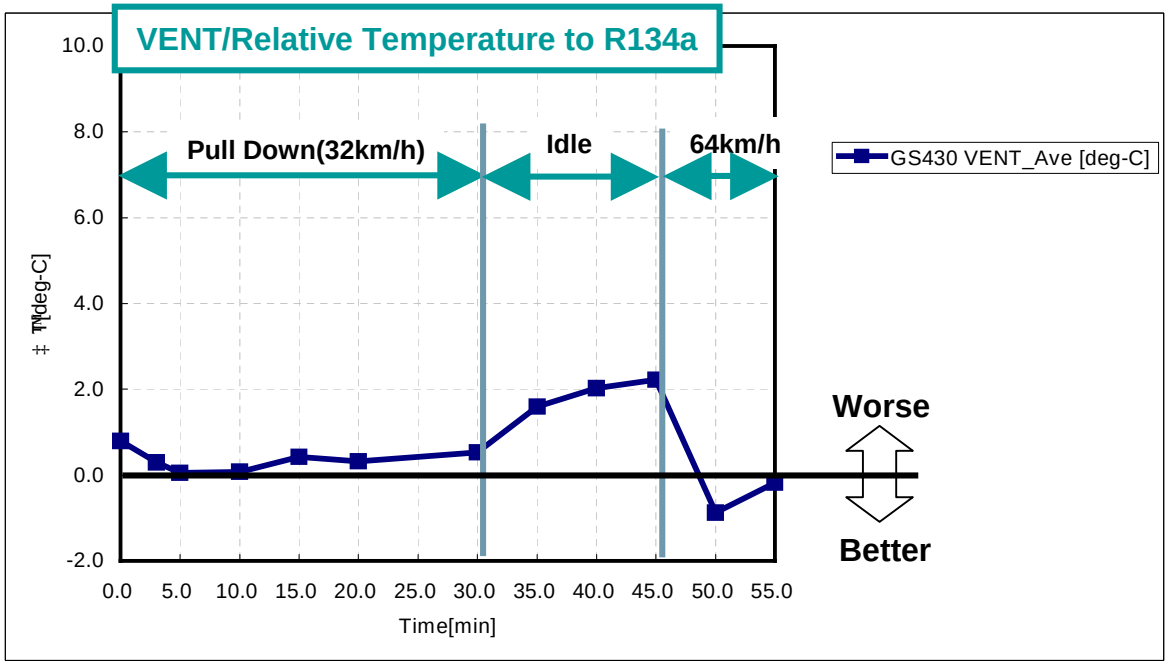
COP



Average
98.2%
Max-Min cut
(98.0%)

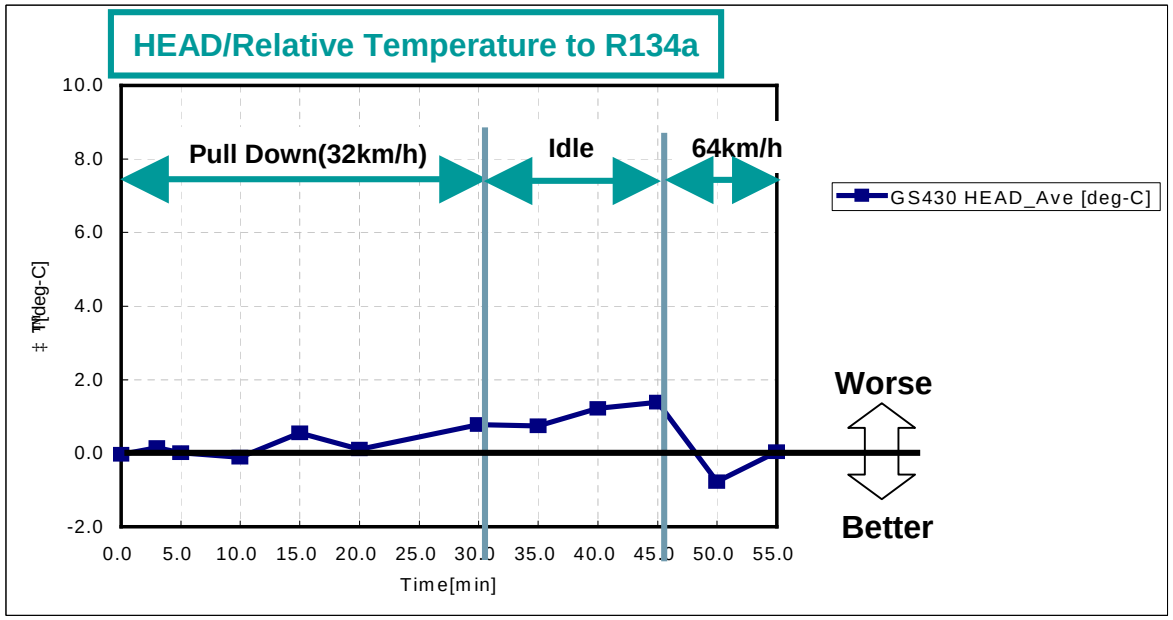
Vehicle Test Results (AC-1)

Reference



ΔT [ºC]

Time (min)	10	30	45	55
GS430	0.1	0.5	2.2	-0.2
Sylphy				
Outlander				
Tiida				
Axela				
Every				
Zest				
Average				



ΔT [ºC]

Time (min)	10	30	45	55
GS430	-0.1	0.8	1.4	0.0
Sylphy				
Outlander				
Tiida				
Axela				
Every				
Zest				
Average				

Material Evaluation Results

Stability

Proposed Spec
<3.3

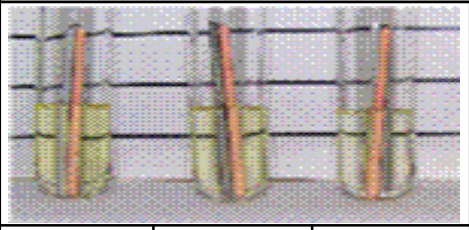
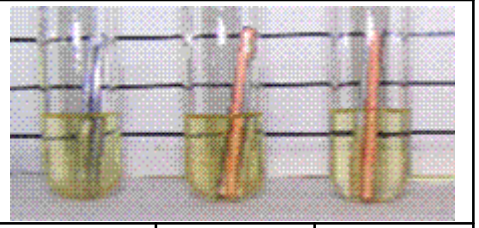
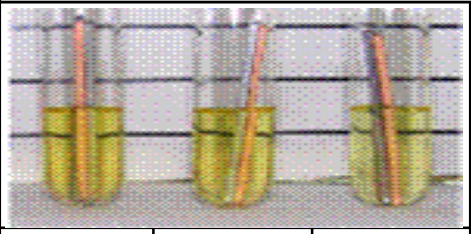
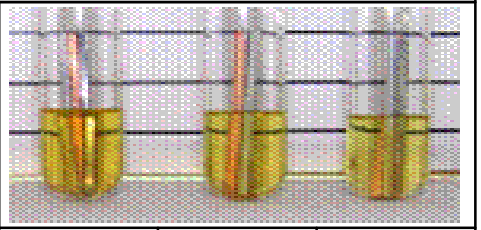
Ref.		R134a				AC-1			
Oil		PAG1	PAG2	POE1	POE2	PAG1	PAG2	POE1	POE2
Condition		175deg-C/14days							
Low Moisture	ppm	<10							
Total Acid Number	mgKOH/g	0.03	0.00	0.00	0.00	0.86	0.01	0.03	0.06
Low Moisture	ppm	1000							
Total Acid Number	mgKOH/g	0.82	0.00	0.01	0.10	2.04	0.05	0.55	0.81
High Moisture	ppm	10000							
Total Acid Number	mgKOH/g	1.75	0.00	21.3	21.4	2.12	0.12	21.1	21.4
Condition		200deg-C/14days							
Low Moisture	ppm	<10							
Total Acid Number	mgKOH/g	1.28	0.00	0.00	0.00	2.75	1.07	0.05	0.07
Low Moisture	ppm	1000							
Total Acid Number	mgKOH/g	1.15	0.54	0.1	0.21	2.90	1.02	1.41	1.95
High Moisture	ppm	10000							
Total Acid Number	mgKOH/g	2.19	0.87	21.4	22.3	3.20	1.45	20.8	22.1

Material Evaluation Results

Stability

Oil:PAG1(Serial PAG for MACs)
Temperature: 175 , 200 ºC

***** Not Co . :Not Contain

Refrigetant		R134a			AC-1		
Moisture	ppm	<10	1000	10000	<10	1000	10000
Temperature	ºC	175					
Oil appearance photograph							
Oil appearance		Maize	Maize	Maize	Maize	Maize	Maize
Sludge		*Not Co.	Not Co.	Not Co.	Not Co.	Not Co.	Not Co.
Total Acid Number (mgkoh/g)		0.03	0.82	1.75	0.86	2.04	2.12
Temperature	ºC	200					
Oil appearance photograph							
Oil appearance		Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
Sludge		Not Co.	Not Co.	Not Co.	Not Co.	Contain	Contain
Total Acid Number (mgkoh/g)		1.28	1.15	2.19	2.75	2.90	3.20

Material Evaluation Results

Permeation

[g/year]

HOSE L=400mm	Discharge Inner coating(1)	Discharge Inner coating(2)	Suction Inner coating
	Inner coat : 6-Nylon Inner rubber : IIR Outer rubber : Cl-IIR	Inner coat : 6-Nylon Inner rubber : IIR Outer rubber : EPDM	Inner coat : 6-Nylon Inner rubber : IIR Outer rubber : Cl-IIR
HFC134a	40.8	46.4	78.3
AC-1	40.8	49.3	108.9

(at 80 □)

Inner diameter		
Discharge inner coating (1)	(ACH 77 11)	11.2mm
Discharge inner coating (2)	(ANESIS 11)	11.2mm
Suction inner coating	(ACH 87 15)	15.2mm
Suction without coating	(ANESIS 15)	15.1mm

Summary INEOS-Fluor AC-1 Evaluation Results

Under high load and the present conditions that TXV is adjusted only,

- **Cooling capacity : AC-1 is inferior to R134a by 10%.**
- **COP : AC-1 is inferior to R134a by 2%.**
- **Material : AC-1 is very similar to R134a.**

Cooling capacity deterioration is not negligible, but it is worth to continue to evaluate. System bench tests and vehicle tests are under consideration.

Summary New Refrigerants Evaluation Results

- We are proceeding ‘STEP-1’ evaluation of 3 refrigerants.
- Under ‘Drop-in’ condition(TXV and amount of charge are adjusted), cooling capacity deterioration is not negligible, so we have to improve performance.
- Fluid-H is insufficient in thermal stability.
- AC-1 is very similar to R134a in material compatibility.
- We will complete ‘STEP-1’ evaluation at the end of September.

DP-1:Material Compatibility

(Thermal Stability, Hose Permeation)

AC-1:Performance Test (Bench Test, Vehicle Test)

LCCP Result from JAMA

X Koji Kikuchi NISSAN
Tohru Ikegami TOYOTA
Kiwamu Inui TOYOTA
Kenta Aoki NISSAN

Stella Papasavva GM
William Hill GM

SAE 8th Alternate Refrigerant Systems Symposium
17-19 July 2007

Content

Life Cycle Climate Performance

JAMA cooperated with SAE challenges to establish LCCP keeping it transparent, fair, utility and theoretically precise
in assessment of Total Global Warming up Impact due to MAC.
To exclude influence of particular benefit, technical misjudgement like only forcusing on GWP.

Today's contents

- **LCCP Methodology**
- **LCCP Results**
- **Summary**

LCCP Methodology

LCCP Methodology

What is LCCP standing for Life Cycle Climate Performance ?

Method to estimate equivalent CO2 emission of MAC system totally **from manufacturing to end of life of a vehicle**

LCCP [kg/vehicle life] = Direct Emission + Indirect Emission

Direct emission

Indirect emission

LCCP Methodology

Direct Emission [kg] =

Leakage during charge in plant + Annual regular leakage + Annual irregular leakage + Service + End of Life leakage

[1] [2]




(Total value) x GWP

[1] Accoding to investigation value of both SAE and JAMA, they are very similiar
[2] Derived from refrigerant recycle target of SAE

LCCP Methodology

Indirect Emission [kg]=

CO2 emission for **AC system operation** +

CO2 emission when **refrigerant is manufactured and tranported** [4] +

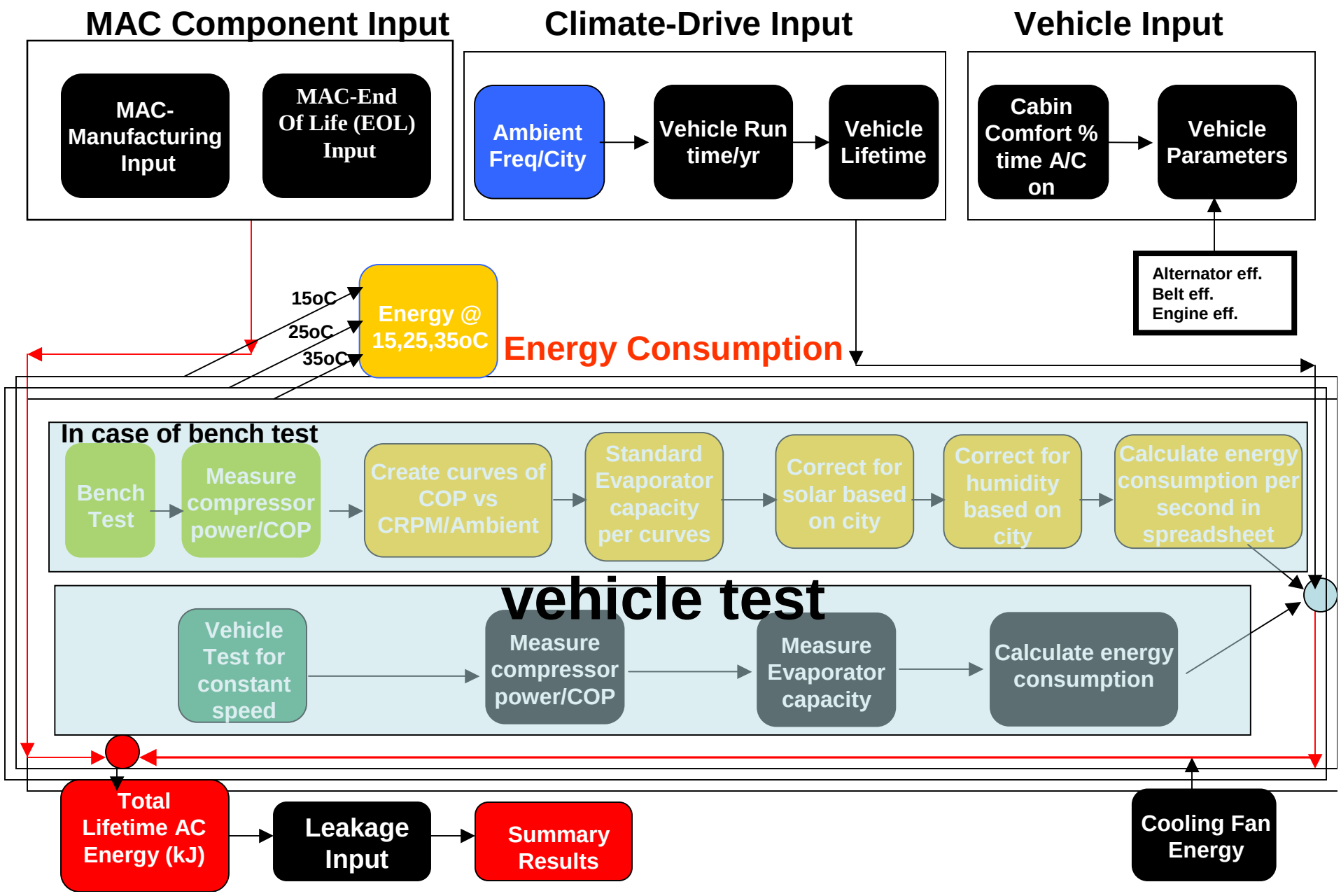
CO2 emission when **AC components is manufactured and tranported** [5] +

CO2 emission due to **weight of AC system** on the vehicle. [6] +

Equivalent CO2 emissions to **Recover/Recycle/Recharge refrigerant** [7]

[4] According to publication by Dupont and Archie McCulloch (for R134a) for emission during manufacturing refrigerant + GM's assumption for leakage during filling and transporting refrigerant.
[5] Accoding to research results from SAE
[6] Accoding to TNO report
[7] According to Dupont's publication

Energy Calculation Flow Chart



Vehicle Test

JAMA uses Vehicle Test Result to calculate "CO2 emission due to AC system operation" .

Agreed TEST Condition bet. JAMA&SAE

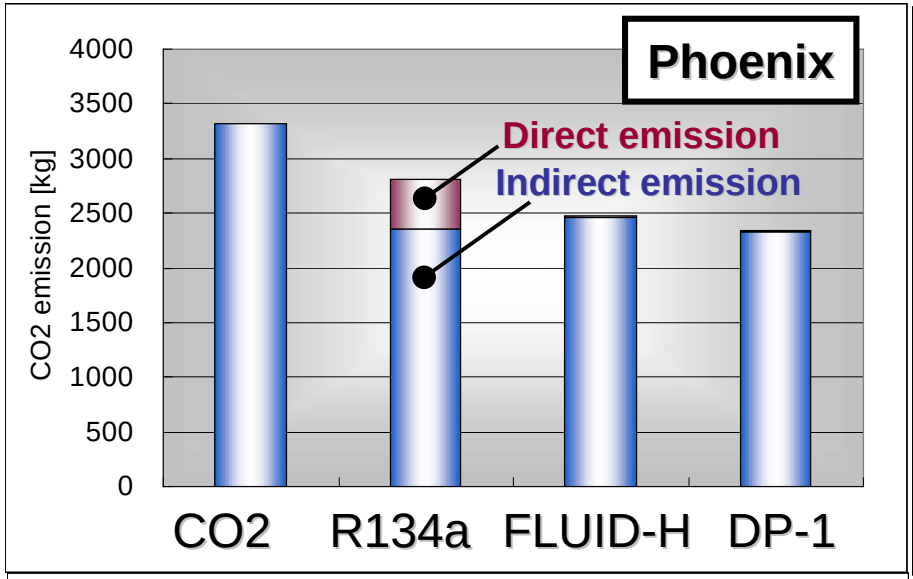
Agreed proposal: vehicle			
Ambient	35	25	15
RH%	50	50	80
Solar [W/m^2]	850*	500	100
Target temperature setting+	22	22	22
For manual AC:	FC	1/2 of heater controller	3/4 of heater controller
Air Intake	REC	OSA	OSA
Fan Speed	High	2nd	1st
Drive Schedule	Fixed speed Idle / 40km/hr / 100km/hr		
Air Output	VENT	VENT	VENT

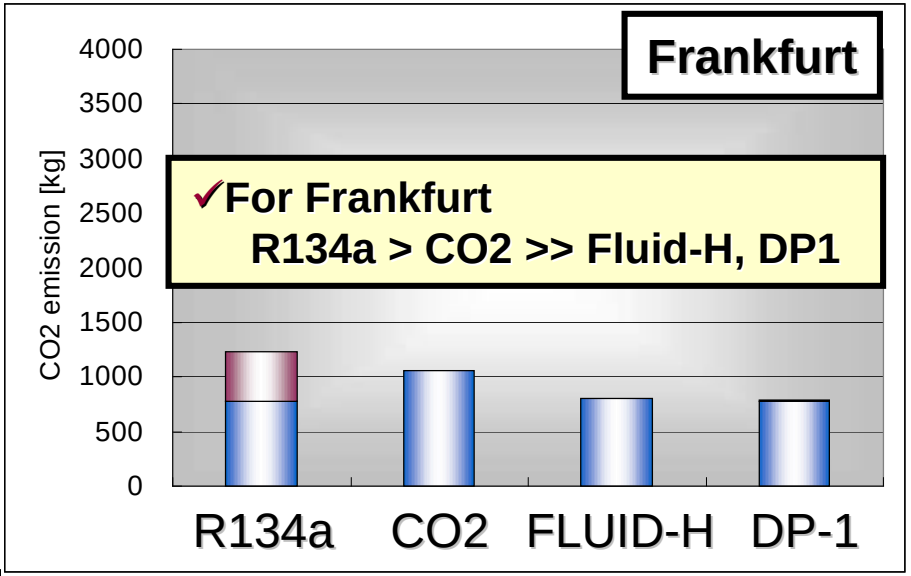
From these test results, we take into account
- ✓**Driving Schedule**
- ✓**Ambient Condition**
- ✓**AC Operation Time**

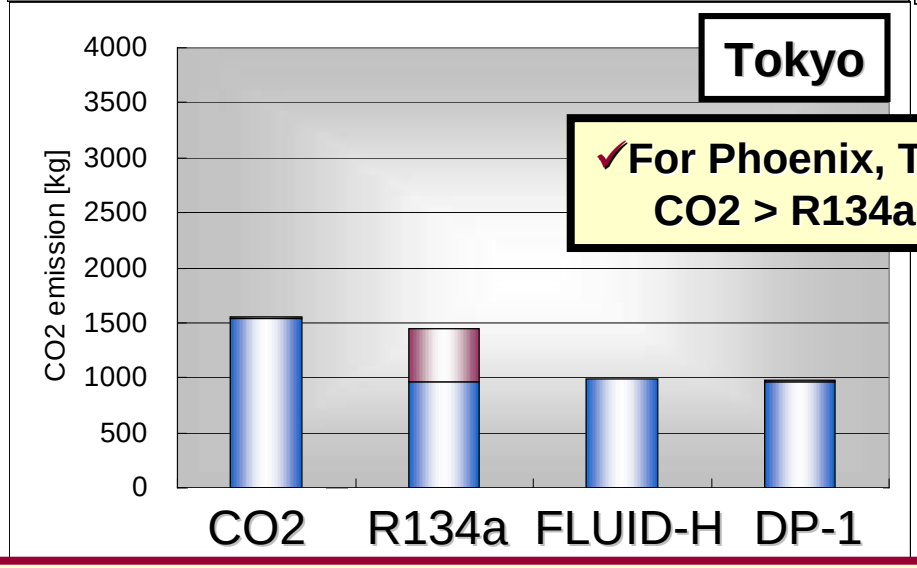
for each Cities (i.e. Phoenix, Frankfurt, Tokyo, etc)

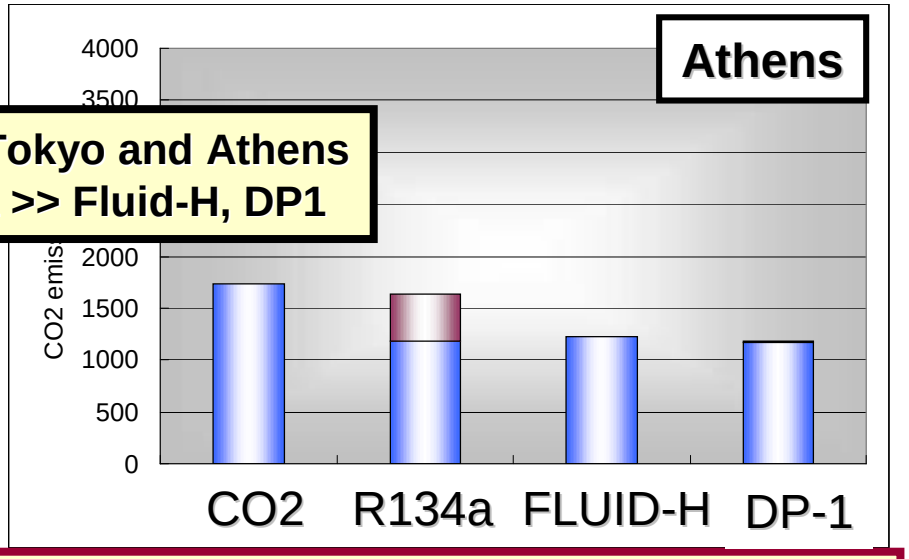
LCCP Results

Calculation Result - Compact Car - 1.5L Gasoline Engine





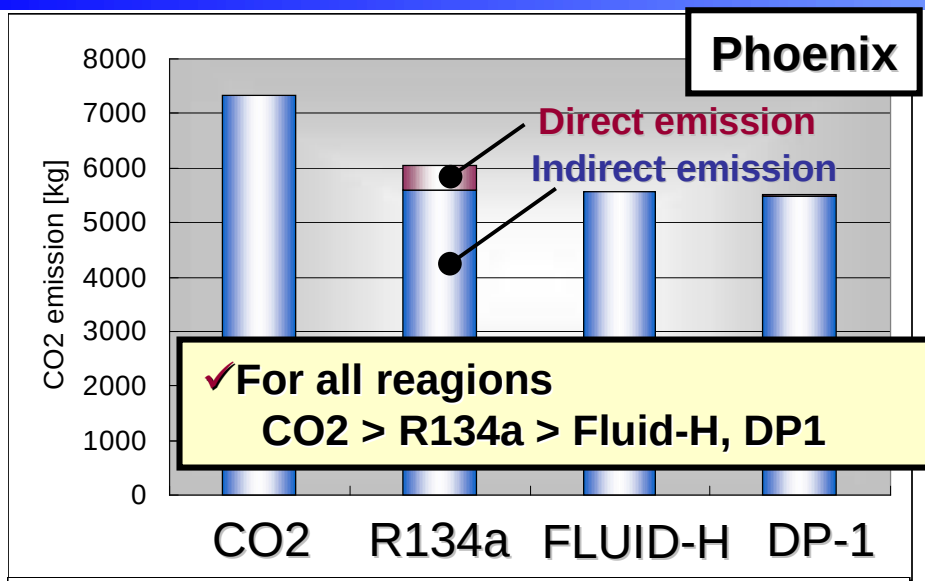


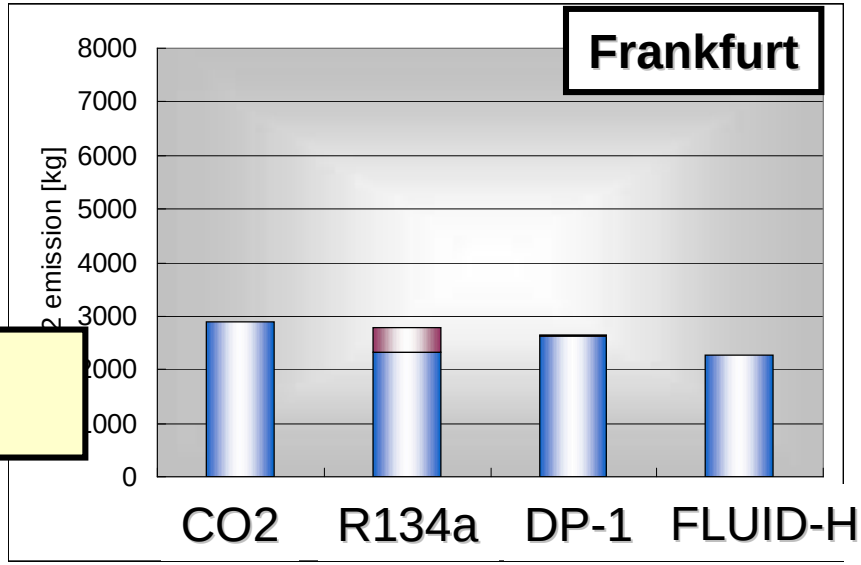


➢**LCCP resulted better environmental performance for Fluid-H and DP-1 as far as it's compared among R134a,CO2,Fluid-H and DP-1. Other will be evaluated later.**

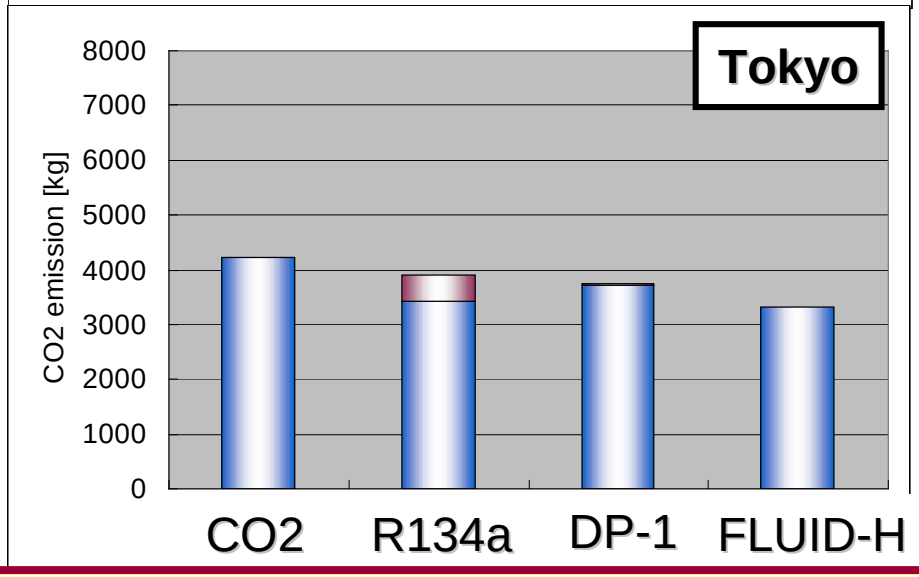
Calculation Result - Luxury car -

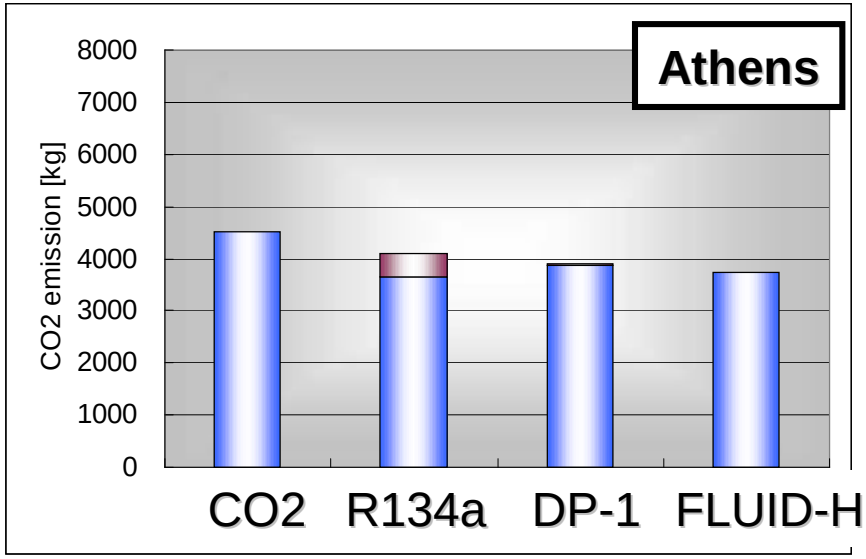
4.3L Gasoline Engine





✓**For all reagions**
CO2 > R134a > Fluid-H, DP1





➢**LCCP resulted better environmental performance for Fluid-H and DP-1 no matter what size of vehicles.**

Summary

Summary

1. LCCP Methodology

➢**LCCP** methodology is established to get it **transparent, fair, utility** and **theoretically precise** in assessment of Total Global Warming up due to MAC.

➢**LCCP** methodology is established by **global great cooperation** between SAE and JAMA.

➢**Alternative refrigerant system** should not be only considered about **GWP** but also **energy consumption like LCCP**.

2. LCCP Results

➢**LCCP** will be expected to find out the **global solution** like picking up better refrigerant, Fluid-H,DP-1 and so on.

JAMA

Toward the global solution !!

Thank you for your attention.

END