GREEN-MAC-LCCP©

Global Refrigerants Energy & ENvironmental – Mobile Air Conditioning - Life Cycle Climate Performance

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GM

Outline

- Life Cycle Analysis Concept
- GREEN-MAC-LCCP© Model
  - Refrigerant System Assumptions
  - Vehicle Assumptions
  - Climate-Drive Assumptions
  - Environmental Assumptions
  - How to Use the Model?
  - Energy Calculation Flow Chart
- Model Outputs
- Conclusions

BACKGROUND

- Many companies have done complete life cycle (LCCP) and partial life cycle (TEWI) analysis in the recent past to evaluate the environmental impact of alternative refrigerants
- Assumptions and methodology can have a large impact on the conclusions, as it was indicated in the results presented by such studies
- JAMA and SAE have worked together to develop a common approach
- A new SAE J-standard will be proposed for estimating the Life Cycle Climate Performance (LCCP) of Alternative Refrigerants, considering energy consumption and Greenhouse Gas (GHG) Emissions

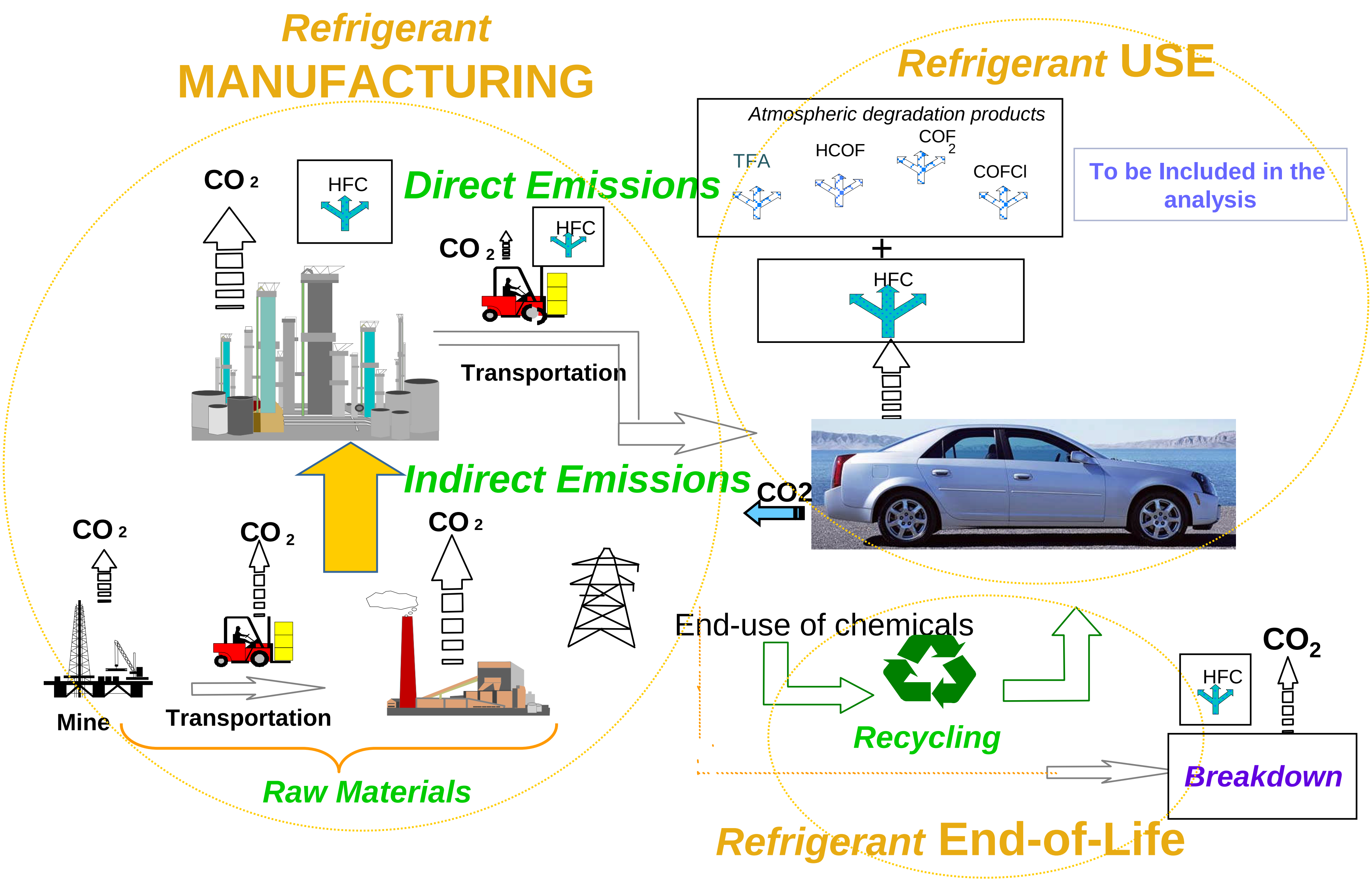
GREEN-MAC-LCCP© Model

- GM has developed the GREEN-MAC-LCCP© life cycle analysis model, based on input data that have been harmonized with OEMs worldwide

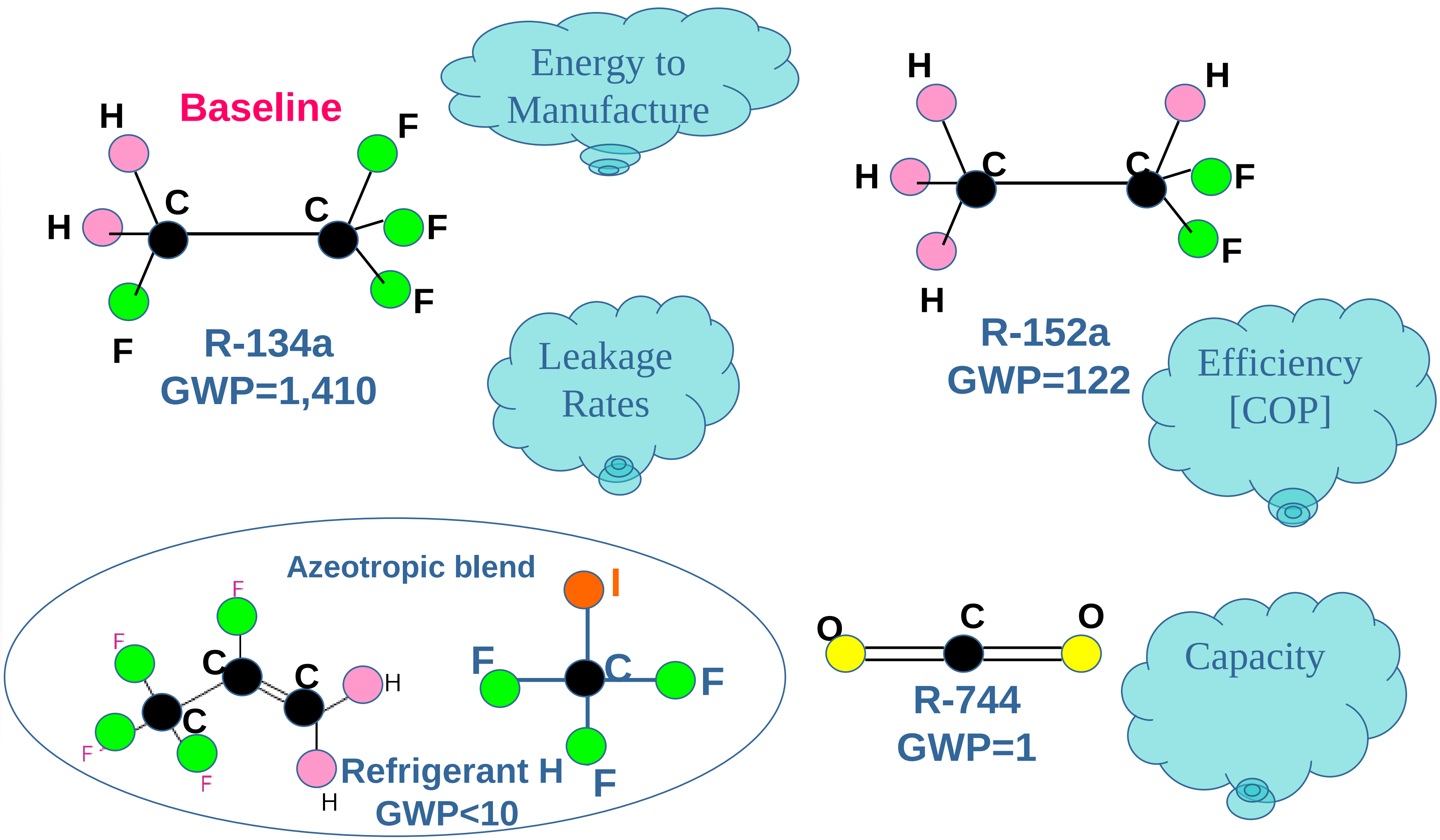
- The goal of the model is to provide guidance to HVAC engineers and policy makers in choosing among proposed Global Alternative Refrigerants [GAR]

- The model can estimate the Greenhouse Gas (GHGs) emissions of any proposed alternative refrigerant based on the Direct and Indirect emissions of the A/C system on a life time basis and on an annual basis

Life Cycle Greenhouse Gas Emissions of Refrigerants



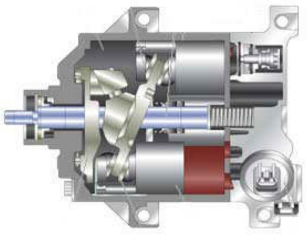
Alternative Refrigerants



Additional Refrigerants include *AC-1, DP-1 and Solvay's* but their chemical structures are proprietary

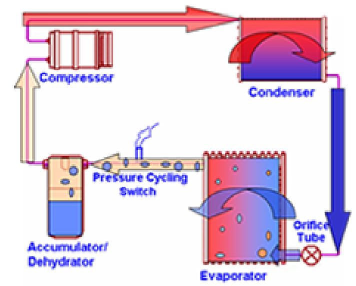
GREEN-MAC-LCCP©
Model Framework

Direct Emissions	Indirect Emissions
Regular Emissions	Energy Consumption of AC System and Engine Cooling Fan
Irregular Emissions	Energy Consumption to Make Components
Service Emissions	Energy Consumption to Make Refrigerant
End-of-Life Emissions	Energy to Transport Each Component
Leakage from Refrigerant Production and Transportation	Energy for the End-of-Life Recycling and Recovery



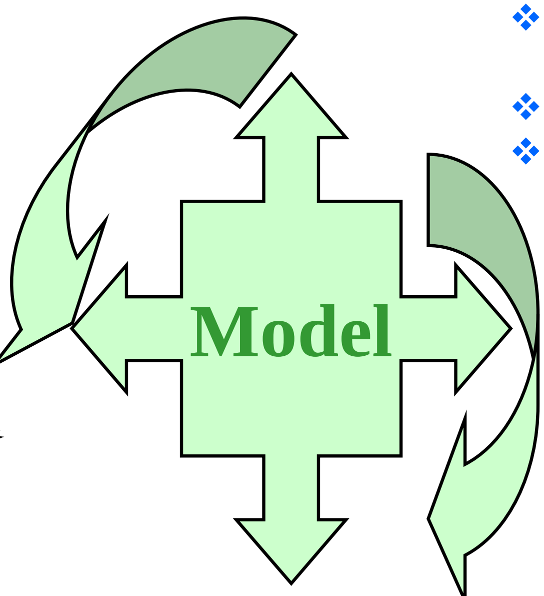
GREEN-MAC-LCCP©

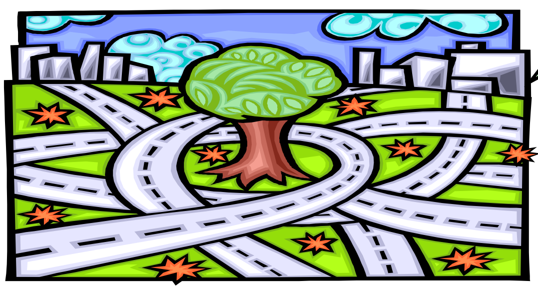
Input-Assumptions



- **Vehicle Assumptions**
  - Car Size
    - Compact [current]
    - Midsize [current]
    - SUV [current]
  - Engine type
    - L4 [current]
    - V6 [current]
    - V8 [current]

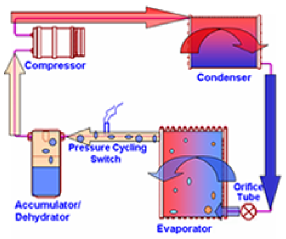
- **Refrigerant System Assumptions:**
  - Leakages
  - System Mass
  - Temperature at Evaporator Outlet
  - COP, Qe (from Bench or Vehicle tests)
  - Condenser/Gas Cooler Air Inlet air at idle conditions
  - Front End Air Flow
  - Engine Cooling Fan





- **Vehicle Usage & Climate Assumptions:**
  - Distance based on region
  - % Drive Time in Ambient during 6AM - 24PM Different for Each City
  - Cabin Comfort -% Time with A/C ON
  - Driving cycle based on region

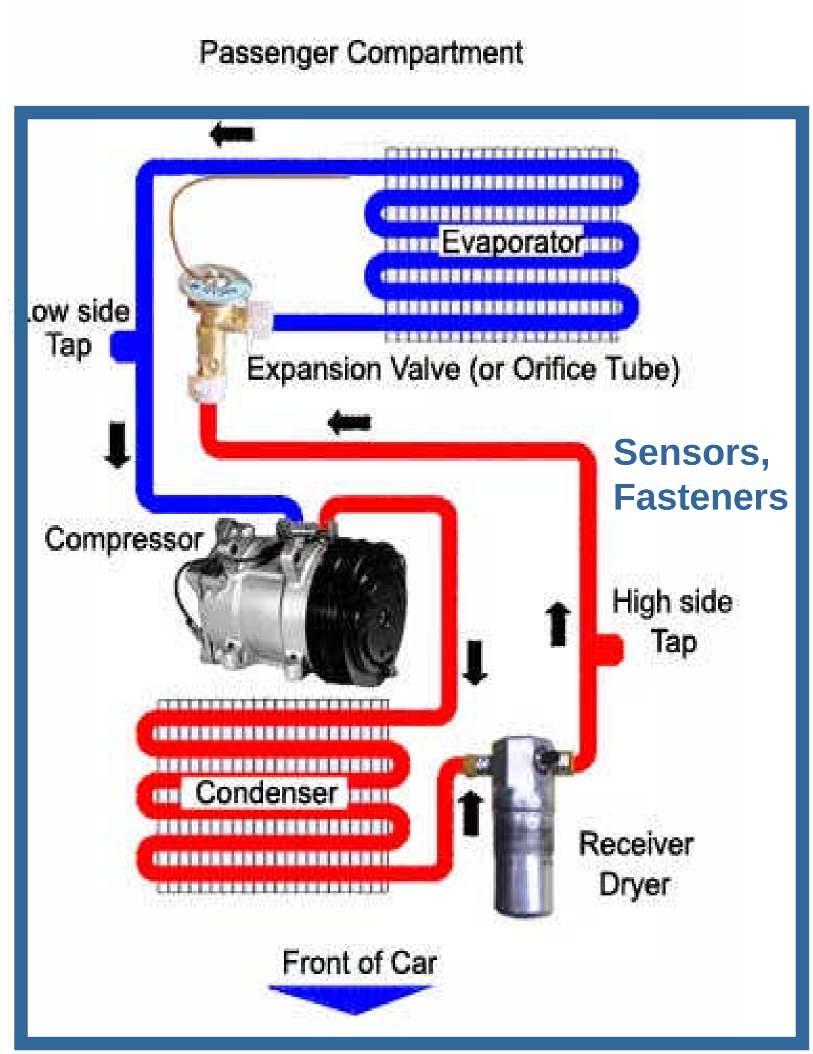
- **Environmental Assumptions:**
  - CO_2-eq from refrigerant production
  - Transportation, End-of-Life and By-Product Emissions
  - Ambient Temperature Operation
  - Humidity effects



Refrigerant System Boundaries

Mass Boundaries

➢Includes all refrigerant components and sensors [front end sealing components need to be included as they change with CO_2]



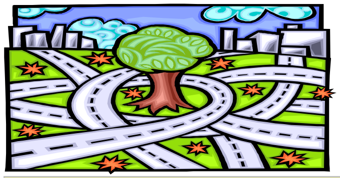
Vehicle assumptions

- Engine Efficiency
- Alternator Efficiency
- Belt Efficiency
- Compressor to Engine Ratio
- Alternator to Engine Ratio
- Engine & Transmission Ratio during designated driving cycle
- Alternative Fuels
- Choice of vehicle size (Compact, Midsize, SUV)

EXAMPLE

Vehicle:	Baseline - Midsize Sedan
Engine:	V6
Displacement [L]:	3.1
Transmission:	6 spd auto
% Automatic Controls:	65%
%Manual Controls:	35%
Alternator Efficiency:	65%
Belt Efficiency:	95%
Engine/Compressor Ratio:	1.35
Alternator/Engine Ratio:	2.9
Engine Efficiency:	31%

THE USER NEEDS TO ENTER DATA IN THE PURPLE CELLS



Climate-Drive Assumptions

2. CLIMATE-DRIVE INPUT

Ambient Temperature and Humidity -TMY2 Weather Database (1960-1991)

% Drive Time in Ambient during 6AM - 24PM

CLIMATE	USA				EU/Cold	EU/Warm	Japan			India			Australia	China	
Ambient Temperature [oC]	Phoenix	Houston	Boston	Miami	Frankfurt	Athens	Tokyo	Kagoshima	Sapporo	Bangalore	Bombay	New Delhi	Sydney	Beijing	Shanghai
<=2	0%	0%	24%	0%	11%	0%	7%	0%	32%	0%	0%	0%	0%	19%	0%
3-11	7%	9%	27%	0%	39%	17%	32%	16%	21%	0%	0%	4%	2%	20%	33%
12-20	26%	30%	22%	6%	37%	38%	29%	34%	28%	4%	1%	18%	50%	21%	22%
21-29	27%	44%	23%	80%	10%	35%	28%	40%	15%	79%	59%	33%	44%	33%	34%
30-37	31%	17%	3%	15%	3%	10%	3%	10%	3%	16%	40%	41%	3%	6%	11%
>=38	9%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	5%	0%	0%	0%
Correction Factor (Data corrected for global warming based on studies of 2000-2005 weather as compared to 1960-1991)															
12-20	-3%														
30-37	3%														

3. DRIVING TIME & VEHICLE LIFETIME

	Phoenix	Houston	Boston	Miami	Frankfurt	Athens	Tokyo	Kagoshima	Sapporo	Bangalore	Bombay	New Delhi	Sydney	Beijing	Shanghai
Driving Distance (km)	20,050	19,635	19,665	19,832	14,231	14,231	10,842	10,842	10,842	14,600	14,600	14,600	14,650	15,000	15,000
Driving Time (Hrs.)	427	418	562	422	431	431	452	452	452	749	749	749	444	452	452
Driving Time (Sec)	1,537,200	1,504,800	2,023,200	1,519,200	1,551,600	1,551,600	1,627,200	1,627,200	1,627,200	2,695,418	2,695,418	2,695,418	1,598,400	1,626,051	1,626,051
Vehicle Lifetime (Yrs.)	9	9	9	9	10	10	11	11	11	15	15	15	10	15	15

4. CABIN COMFORT -% Time with A/C ON

		USA				EU/Cold	EU/Warm	Japan			India			Australia	China	
MANUAL	Ambient	Phoenix	Houston	Boston	Miami	Frankfurt	Athens	Tokyo	Kagoshima	Sapporo	Bangalore	Bombay	New Delhi	Sydney	Beijing	Shanghai
Percent of Manual																
	<=2	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	3-11	10%	15%	20%	20%	25%	15%	35%	15%	25%	20%	20%	20%	5%	15%	15%
	12-20	2%	1%	2%	0%	3%	1%	4%	0%	2%	0%	0%	4%	1%	4%	1%
	21-29	34%	32%	36%	31%	48%	45%	46%	48%	46%	53%	36%	61%	46%	39%	33%
	30-37	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	>=38	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
AUTOMATIC	Ambient	Phoenix	Houston	Boston	Miami	Frankfurt	Athens	Tokyo	Kagoshima	Sapporo	Bangalore	Bombay	New Delhi	Sydney	Beijing	Shanghai
Percent of Automatic																
	<=2	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	3-11	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	12-20	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	21-29	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	30-37	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	>=38	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

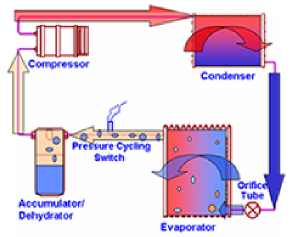
How to Use the Model?

- GREEN-MAC-LCCP© consists of many interlinked spreadsheets of data required to run the model. Most of the input data are fixed based on the harmonization process.

- Only a small amount of input data is required to be introduced by the user. For each GAR such data include:
  - Component Mass
  - Refrigerant Mass & GWP values
  - Leakage Rates
  - COP and Qe data obtained from bench or vehicle tests

- A baseline HFC-134a result is provided as a reference [It is based on AR [Alternate Refrigerant] CRP testing data from both Phase I and II]

- The model output provides the LCCP CO_2-eq emissions of any GAR [Lifetime and Annual]



How to Use the Model?

Example Refrigerant Component Manufacturing Input

A/C Component Manufacturing - Energy Consumption & CO_2-Equivalents Emissions

Refrigerant: HFC-134a-Baseline

Refrigerant System	CO2-Eq. from Production (kg/kg)	CO2-Eq (kg/kg)	
Refrigerant	NA	50.3	[Calculation resulting from inputs below]
CO2-Eq. emissions for virgin refrigerant		8.0	
CO2-Eq. emissions for recycled refrigerant		2.1	
CO2-Eq. fugitive emissions of other gases from manufacture			Included above in the case of R134a
CO2-Eq. due to refrigerant Leakage during transport/delivery		42.3	
CO2-Eq. due to fuel consumption during Transportation			Included above in the case of R134a
Atmospheric Reaction Byproducts			Not considered now
GWP		1410	

MAC Components		Energy of Production (MJ/kg)	CO2-Eq (kg/kg)	% of each component	(kg)	(MJ)	Total CO2-Eq (kg)
Refrigerant	Original Refrigerant Charge				0.55		27.67
	Additional Refrigererant Charge				0.20		0.42
Lubricant	[lubricating oil]	54.50	1.3		0.20	10.90	0.26
Compressor				100%	6.40	238.50	12.43
	Aluminum Castings	35.95	1.6	40%	2.56	92.03	4.01
	Aluminum Forgings	36.00	1.64	20%	1.28	46.08	2.10
	Elastomers	103.00	3.1	5%	0.32	32.96	0.99
	Steel Forging	18.90	2.3	15%	0.96	18.14	2.21
	Copper Alloys	55.00	3.3	8%	0.51	28.16	1.69
	Steel Castings	17.00	1.6	10%	0.64	10.88	1.02
	Plastics	80.00	3.0	2%	0.13	10.24	0.38
	Assembly					1.00	0.02
Piping/Hoses				100%	3.00	160.41	16.43

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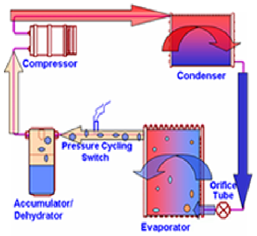


How to Use the Model?

Example Leakage Rates Input Baseline HFC-134a

INPUT DATA for Estimating Service LOSS during lifetime

Lifetime [yrs]	9	10	11	15	11	15
Loss in each service	35	35	35	35	35	35
Number of services	1	1	1	2	1	2
Estimated loss before Service is required	200	200	200	200	200	200

HFC-134a-Baseline	USA	EUROPE	JAPAN	INDIA	AUSTRALIA	CHINA
REFRIGERANT LEAKAGES & SERVICE	Baseline-HFC-134a	Baseline-HFC-134a	Baseline-HFC-134a	Baseline-HFC-134a	Baseline-HFC-134a	Baseline-HFC-134a
(function of climate)	Warm	Warm	Warm	Warm	Warm	Warm
Regular [g/y]	10	10	10	10	10	10
Irregular (Accidental) [g/y]	16	16	13	16	16	16
Service loss[g/lifetime]*	48	59	56	133	72	133
EOL with 90% refrigerant capture[g/lifetime]	46	45	44	40	45	40
Assembly Plants (fixed loss) [g/lifetime]	3.5	3.5	3.5	3.5	3.5	3.5

Service loss=(Regular+Irregular leakage)(lifetime in years/200)*loss in each service

HFC-134a-Baseline	USA	EUROPE	JAPAN	INDIA	AUSTRALIA	CHINA
REFRIGERANT LEAKAGES & SERVICE	Baseline-HFC-134a	Baseline-HFC-134a	Baseline-HFC-134a	Baseline-HFC-134a	Baseline-HFC-134a	Baseline-HFC-134a
(function of climate)	Cold	Cold	Cold	Cold	Cold	Cold
Regular [g/y]	7	7	7	7	7	7
Irregular (Accidental) [g/y]	16	16	13	16	16	16
Service loss[g/lifetime]*	42	52	49	118	63	118
EOL with 90% refrigerant capture[g/lifetime]	46	45	44	40	45	40
Assembly Plants (fixed loss) [g/lifetime]	3.5	3.5	3.5	3.5	3.5	3.5

Service loss=(Regular+Irregular leakage)(lifetime in years/200)*loss in each service

THE USER NEEDS TO ENTER DATA IN THE PURPLE CELLS

The Regular emissions are corrected for the cold climates, assuming that the cold temps will drop the leakage by 30% compared to the warm temps

How to Use the Model?

Example of Capacity Input Data

REF XXX							
		Idle Condition Weighting Factor:					
		30%	70%				
	Humidity	900 (+15K)	900	1500	2500	4000	Weighting Factor
15°C CAP	Average	0.79	0.76	0.50	0.55	0.56	100%
10°C	80%	0.58	0.52	0.34	0.39	0.39	70%
3°C	80%	1.27	1.30	0.88	0.94	0.97	30%
25°C CAP	Average	3.57	3.64	2.43	2.38	2.42	100%
10°C	80%	3.90	3.77	2.70	2.65	2.82	35%
3°C	80%	3.90	4.15	3.51	3.44	3.67	15%
10°C	50%	3.23	3.30	1.75	1.72	1.62	35%
3°C	50%	3.23	3.63	2.28	2.23	2.10	15%
35°C CAP	Average	4.15	4.78	6.25	6.95	7.00	N/A
	40%	4.15	4.78	6.25	6.95	7.00	
45°C CAP	Average	3.35	3.81	5.06	5.74	5.75	N/A
	25%	3.35	3.81	5.06	5.74	5.75	

THE USER NEEDS TO ENTER DATA IN THE PURPLE CELLS

How to Use the Model?

Example of COP Input Data

REF XXX								
		Idle Condition Weighting Factor:						
		30%	70%					
	Humidity	900 (+15K)	900	1500	2500	4000	Weighting Factor
15°C COP	Average	3.63	6.44	3.75	2.64	1.71	100%
10°C	80%	3.80	6.96	3.87	2.64	1.71	70%
3°C	80%	3.23	5.22	3.48	2.64	1.71	30%
25°C COP	Average	2.60	5.04	4.57	4.21	3.62	100%
10°C	80%	2.70	5.37	4.73	4.66	4.22	35%
3°C	80%	2.70	3.76	3.31	3.03	2.53	15%
10°C	50%	2.49	5.71	5.31	4.75	4.00	35%
3°C	50%	2.49	4.00	3.72	3.09	2.40	15%
35°C COP	40%	2.43	3.17	2.61	1.89	1.43	N/A
45°C COP	25%	1.90	2.51	2.12	1.58	1.21	N/A

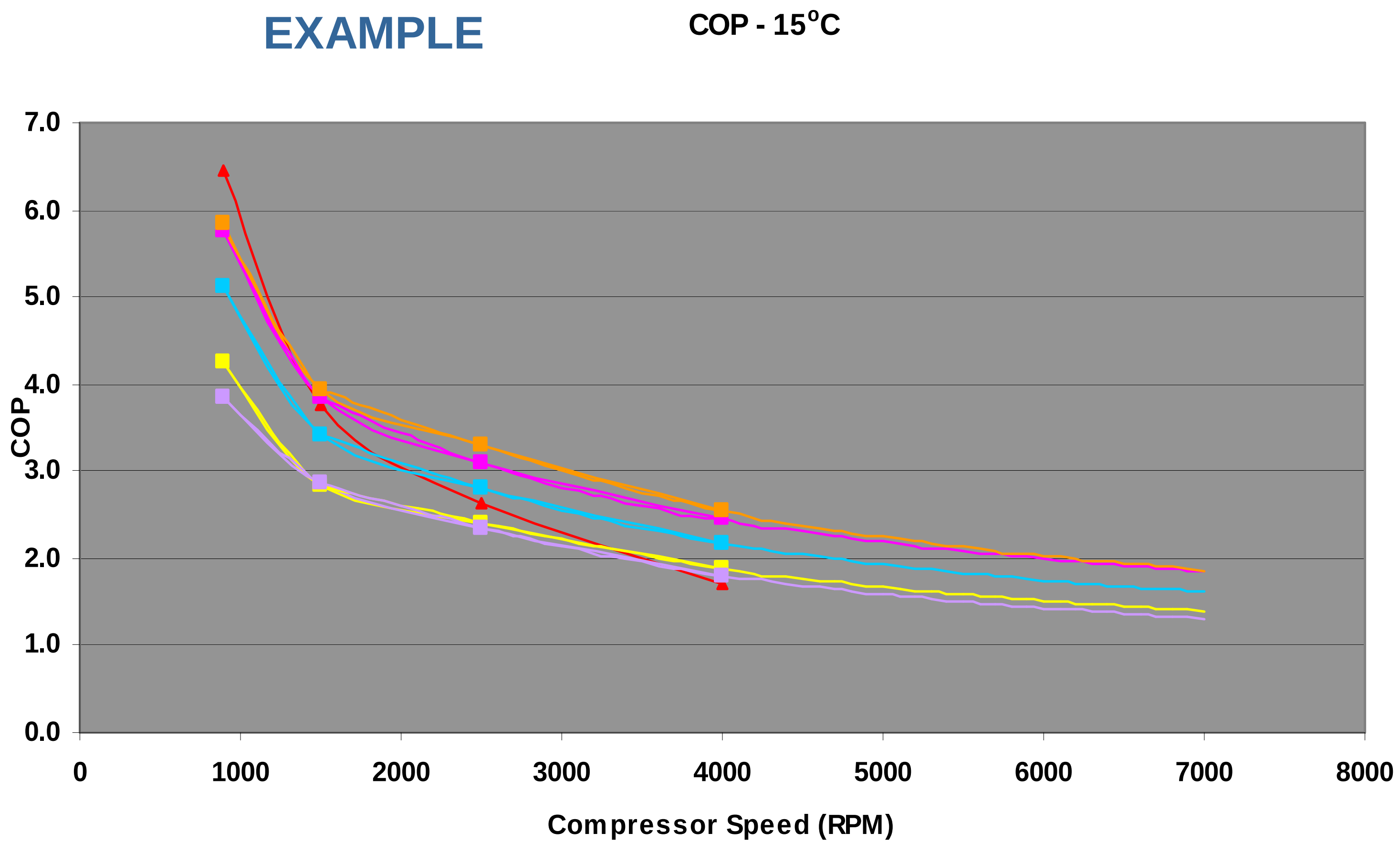
THE USER NEEDS TO ENTER DATA IN THE PURPLE CELLS

COP Curve Fits from bench data

Measure compressor power/COP

The COP obtained for various RPMs and various Temperatures from bench tests are curve fit. For compressor speeds less than 900 RPM, the COP is set to the 900 RPM data point. For Compressor Speeds between 900 and 1500 RPM, a second order polynomial equation is developed from the 900,1500, & 2500 data points. For Compressor Speeds between 1500 and 4000 RPM, a second order polynomial equation is developed from the 1500, 2500, & 4000 data points. For Compressor Speeds above 4000, a power equation is developed from the 2500 & 4000 data points.

EXAMPLE

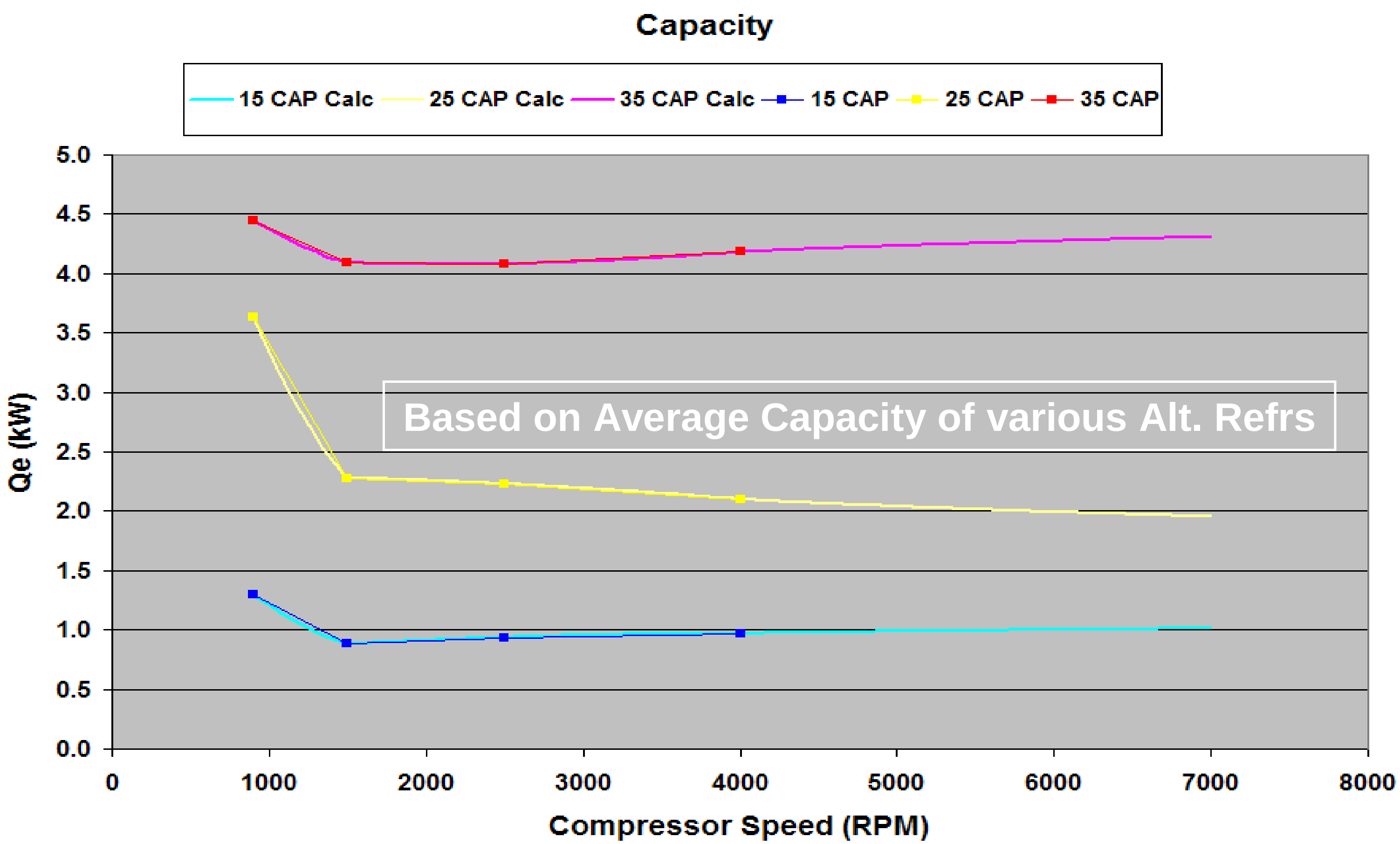


The curve fits are generated automatically by the model

Capacity Curve Fits from bench data

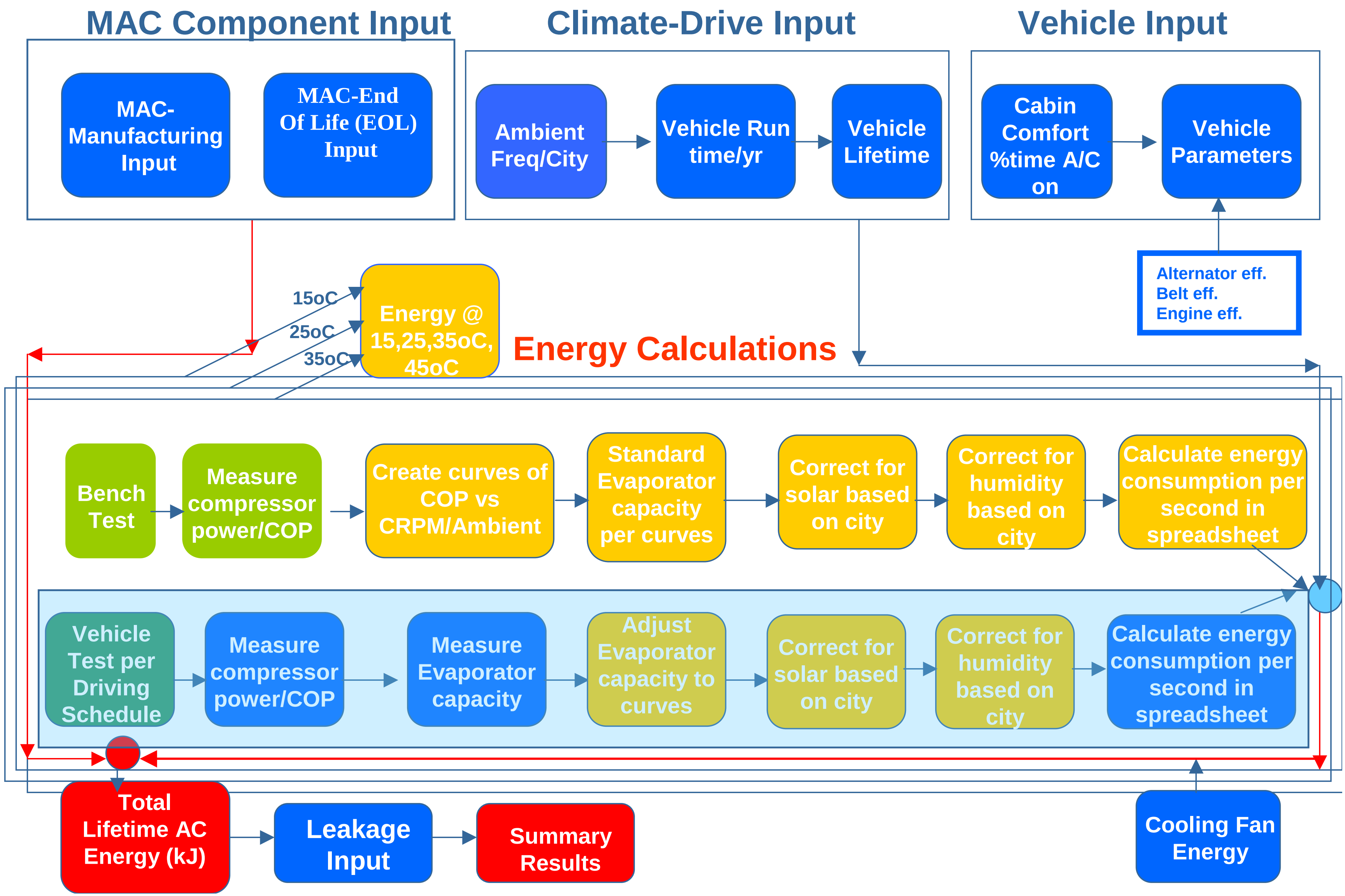
Measure /Qe

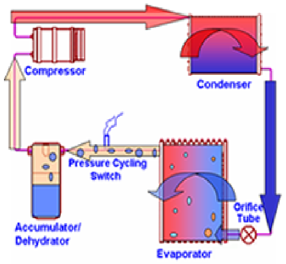
The Evaporator Capacity (Qe) obtained for various RPMs and Temperatures from bench tests are curve fit. For compressor speeds less than 900 RPM, the COP is set to the 900 RPM data point. For Compressor Speeds between 900 and 1500 RPM, a second order polynomial equation is developed from the 900,1500, & 2500 data points. For Compressor Speeds between 1500 and 4000 RPM, a second order polynomial equation is developed from the 1500, 2500, & 4000 data points. For Compressor Speeds above 4000, a power equation is developed from the 2500 & 4000 data points.



The curve fits are generated automatically by the model

LCCP Model - Energy Calculation Flow Chart





Refrigerant System Assumptions

Bench Tests

obtained from various Organizations

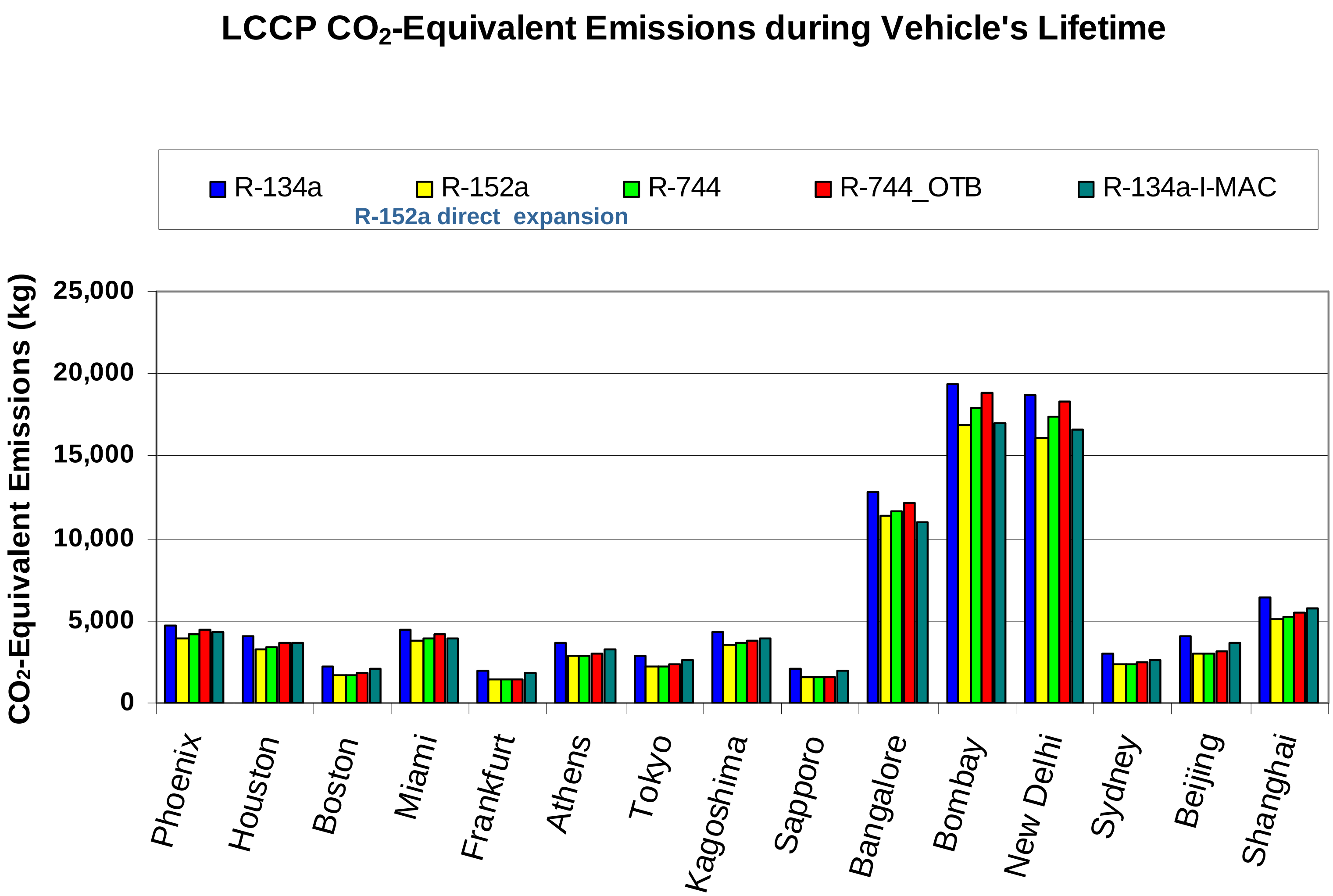
	ALTERNATIVE REFRIGERANTS - BENCH STUDIES							
Organizations	Evaporator Control points	R-134a	R-152a	R-744	"H"	AC-1	DP-1	Solvay
Uof Illionois - ARCRP-I	3/10 C	x		x1, x2	NA	NA	NA	NA
Uof Illionois - ARCRP-II	5 C	x	x	x1,x2,x3	NA	NA	NA	NA
Uof Illionois - I-MAC	10 C	x			NA	NA	NA	NA
CTS - CRP-150 dual evaporator	3/10 C	x			x	x		
CTS - CRP-150 single evaporaotor	3/10 C	x				x		x
VDA	3/10 C	x1,x2,x3,x4 ,x5,x6,x7			Valeo/ Behr	Visteon/ Delphi	Denso/ Behr	
JAMA/JAPIA[a]	3 C	x1,x2,x3,x4 ,x5,x6,x7		x	x	x	x	
LAR	??	x	x	x	x	x	x	

Total Lifetime AC Energy (kJ)

Model Output

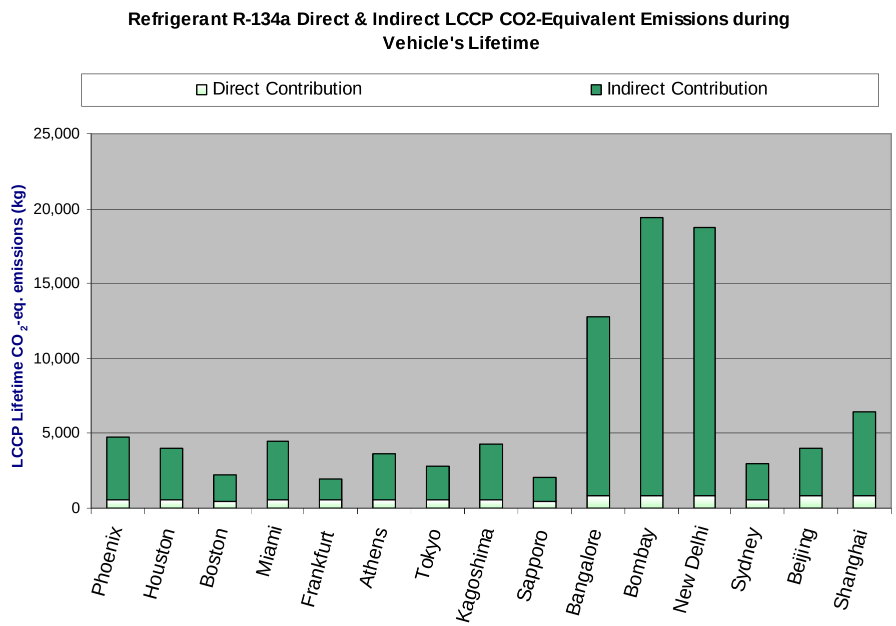
- LCCP CO_2 Equivalent Emissions for Alternative Refrigerant systems
- Annual LCCP CO_2 Equiv. Emissions
- Lifetime LCCP CO_2 Equiv. Emissions
- We have exercised the model using publicly available ARCRP-II data. I-MAC data are also publicly available
- Due to confidentiality, CRP-150 data can not be publicly analyzed and shared in this presentation

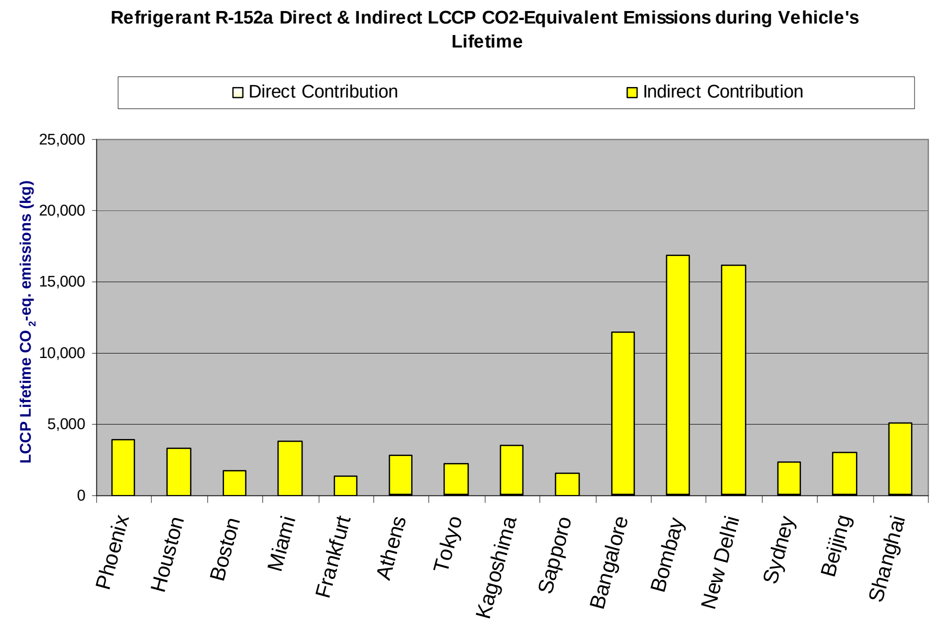
Lifetime LCCP Results based on ARCRP-II Bench for R-134a, R-152a, R-744, R-744-with Orifice

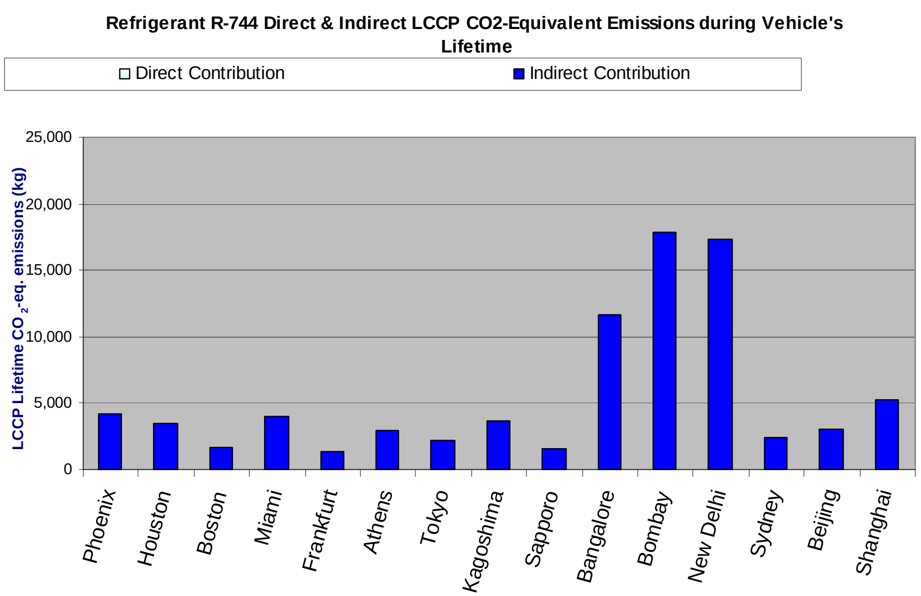


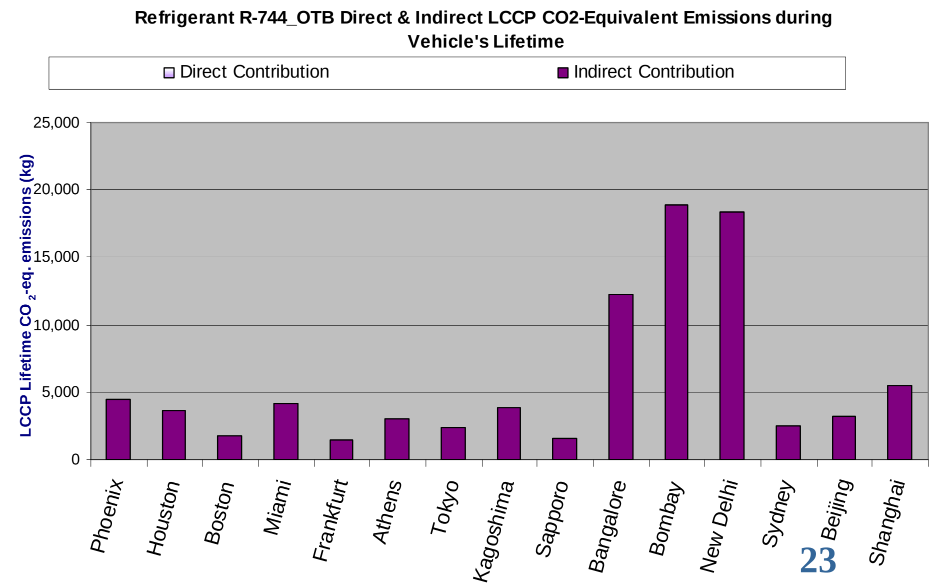
All tests are based on Single Evaporator Systems

Lifetime LCCP Direct & Indirect Contributions for R-134a, R-152a, R-744, R-744-with Orifice









CONCLUSION

1. GREEN-MAC-LCCP© [version 2] has been finalized in June and shared with OEMs and other organizations worldwide for GAR analysis

2) The excel model provides the reference Baseline Refrigerant (HFC-134a) based on a Midsize vehicle with 6-cylinder engine based on ARCRP-II data [5 C evaporator control]

3) Six alternative refrigerants can be analyzed and compared

4) Test results from some global users suggest that the GREEN-MAC-LCCP© model is:
   - Transparent, Robust, and Flexible to the users
   - Satisfactorily predicts LCCP CO_2-eq emissions based either on bench or vehicle data
   - Provides a comprehensive tool for engineers and policy makers to use during the GAR decision process

ACKNOWLEDGEMENTS

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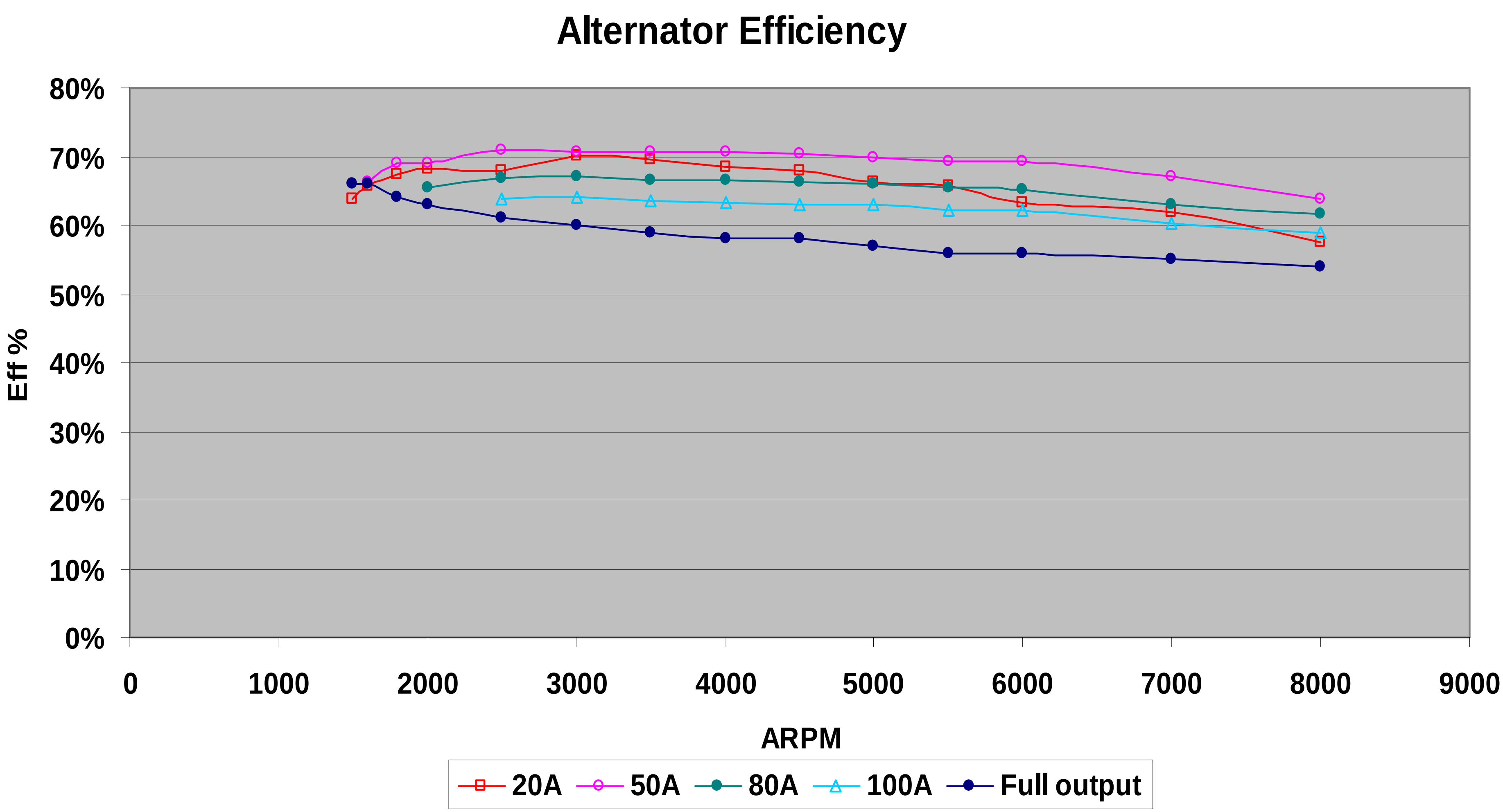
- **Chemical Companies:**
  Ineos (Bob Low), DuPont (Mary Koban), Honeywell (Ian Shankland, Mark Spatz, Richard Winick), for sharing energy manufacturing data

THANK YOU!

BACKUP

Alternator Efficiency

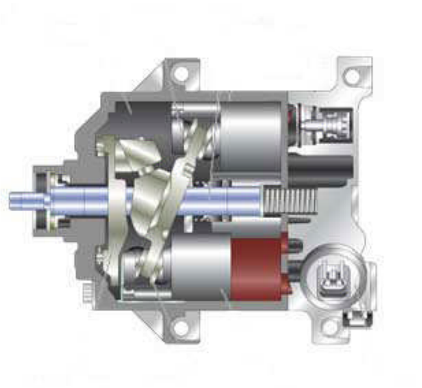


JAMA will confirm it again.

What is Life Cycle Climate Performance?

[from National Renewable Energy Lab (NREL) presentation]

- CO_2 equivalent global warming impact over the total lifetime of the unit
  - **Direct** – refrigerant release directly to atmosphere
  - **Indirect** – energy consumption over lifetime and recycling
    - Fuel use to power compressor and blower
    - Fuel use to carry around mass of A/C system
    - Manufacturing of refrigerant and A/C components



Weather Data

TMY2 and IWEC Databases

- The LCCP model obtains Weather data from reported in the TMY2 database for the USA and The IWEC for all non-US cities.

- The TMY2 data files provide ‘typical” weather for 239 US stations from 1961-1990

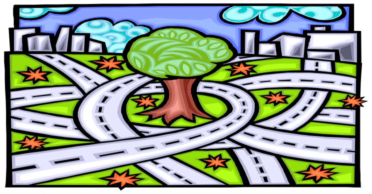
- The IWEC data files are 'typical' weather for 227 locations outside the USA and Canada from 1982-1999.

- **Source:** **http://www.eere.energy.gov/buildings/energyplus/weatherdata_sources.html**

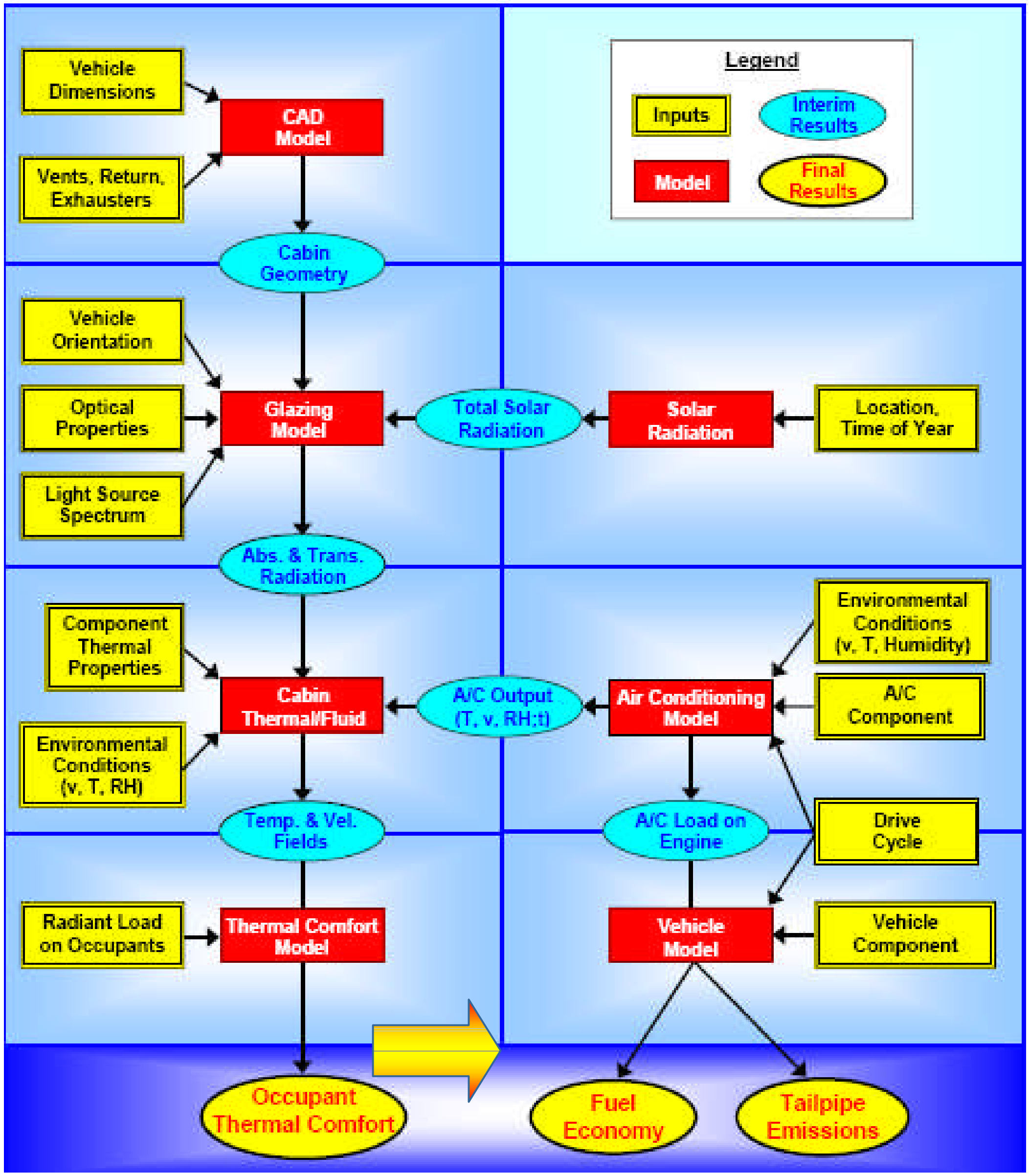
•Comparison of a 30-year TMY temperature data with a 6-year avg. from 2000-2005 Ts show a warming trend due to Global Warming. The 2000-2005 data are not public

Temperature Correction Factor

		Avg.		**CORRECTION FACTOR**:
Temp. Range (^{o}C)	**12-29**	**- 3.6%**	**12-20**	**- 3.0%**
	30-38	**+3.2%**	**30-37**	**+3.0%**



AC on Time



- AC on time was originally estimated per city and per temperature bin based on [National Renewable Energy Lab] NREL comfort modeling
- Percentages were changed based on consensus
- For automatic system, AC is on continuous

Vehicle Usage Assumptions

USA 2001 Household and Vehicle Characteristics	All Vehicle Types	All Vehicle Types	FTP assume for U.S Cities except Boston	SC03 assume for Boston
	mi/yr	Distance Travelled km/yr	Avg. Speed km/hr	Avg. Speed km/hr
			47	35
			Total Driving Hrs.	Representative Cities
Census Region and Division				
New England.................	12.3	19,665	562	Boston
South Atlantic................	12.4	19,832	422	Miami
East South Central.........	12.3	19,635	418	Houston
West South Central........	12.5	20,050	427	Phoenix

JAPAN	Distance Travelled	Avg. Speed
	km/person/year	Km/hr
		24
2001	11,080	
2002	10,946	
2003	10,812	
2004	10,547	Total hrs. driven
Average	10,846	452

JAMA: 10,842 km

EU Country - 2003	Nr. of Vehicles	km/person/	Avg. Speed
		Vehicle	Km/hr
Belgium	4,821,000	15,197	33
Germany	44,657,000	12,751	
Greece	3,840,000	11,111	
Spain	18,688,000	12,343	
France	29,360,000	16,771	
Italy	34,310,000	13,815	
Netherlands	6,908,000	14,100	
Austria	4,054,000	13,370	
Portugal	5,996,000	10,785	
Sweeden	4,075,000	15,755	
UK	26,992,000	16,721	Total hrs. driven
TOTAL	183,701,000	km-driven Weighted Avg.	
		14,231	431
Australia		14,650	444

Japan Ministry of Land Infrastructure and Transport
Ref. http://toukei.mlit.go.jp/56/monthly/geppou-e.xls

Ref. for EU http://ec.europa.eu/transport/index_en.html
Ref. for Australia http://www.environment.sa.gov.au/reporting/human/transport/total.html
Ref. for USA http://www.eia.doe.gov/emeu/rtecs/nhts_survey/2001/index.html-USA -Table 15

Measure compressor power/COP And Qe

Bench Test Matrix

Same for all Refrigerant Systems

Agreed proposal: bench				
	SAE/JAMA			
Ambient	45	35	25	15
RH%	-	40	50	80
Solar [W/m^2]	-	-	-	-
Target temperature setting++	-	FC	3/10	3/10
Air Intake simulation	-	REC	OSA	OSA
Fan Speed	-	High	2nd	1st
Condenser flow [m/s]	1.5/2.0/3.0/4.0			
Elevated Condenser Air Inlet	All ambient temp.+ 8℃			
Compressor RPM	900/1500/3000/4000			
Air Output	-	VENT	VENT	VENT
++Evap out air temp		*same as SC03		

At Idle conditions there will be two tests one at 0K and second at 15K
A weighted average of the two data points is included in the LCCP model

Measure compressor power/COP

COP Curve Fit Polynomials

Based on the input data entered in purple cells the coefficients of the equations will change

R-134a - Phase II - COP

	Idle Condition Weighting Factor:					
	30%	70%	[Input in capacity spreadsheet]			
	900 (+15K)	900	1500	2500	4000	Weighting Factor
15 COP	3.08	4.53	3.59	2.64	1.71	100%
10°C	3.23	4.90	3.70	2.64	1.71	70%
3°C	2.75	3.68	3.33	2.64	1.71	30%
25 COP	2.49	3.25	3.39	2.77	2.11	100%
10°C	2.49	3.35	3.72	3.09	2.40	70%
3°C	2.49	3.02	2.60	2.01	1.44	30%
35 COP	2.43	3.07	2.50	2.10	1.90	N/A

Equation: y = (c2 * x^2) + (c1 * x ^1) + b

c2: =INDEX(LINEST(y,x^{1,2}),1)

C1: =INDEX(LINEST(y,x^{1,2}),1,2)

b = =INDEX(LINEST(y,x^{1,2}),1,3)

Compressor Speed	900	950	1000	1050	1100	1150	1200	1250	1300	1350	1400	1450
15 COP Calc	4.53	4.44	4.36	4.27	4.19	4.11	4.03	3.95	3.87	3.80	3.73	3.66
25 COP Calc	3.25	3.28	3.30	3.32	3.34	3.35	3.37	3.38	3.38	3.39	3.39	3.39
35 COP Calc	3.07	3.02	2.96	2.91	2.85	2.80	2.76	2.71	2.66	2.62	2.58	2.54

15 COP

Poly c2	3.90938E-07	**Poly c1**	-0.00251075	**Poly b**	6.475515625
Poly2 c2	1.30267E-07	**Poly2 c1**	-0.001468067	**Poly2 b**	5.498
Power c	3690.796808	**Power b**	-0.925615907		

For Compressor Speeds less than 900, COP = COP @ 900 RPM

For Compressor Speeds between 900 and 1500, COP = 3.9E-07 $\cdot x^2$ + -0.00251 $\cdot x$ + 6.47552

For Compressor Speeds between 1500 and 4000, COP = 1.3E-07 $\cdot x^2$ + -0.00147 $\cdot x$ + 5.49800

For Compressor Speeds Greater than 4000, COP = 3690.8 $\cdot x$ + -0.9256

25 COP

Poly c2	-5.25604E-07	**Poly c1**	0.001482767	**Poly b**	2.343659375
Poly2 c2	7.358E-08	**Poly2 c1**	-0.00091397	**Poly2 b**	4.5906
Power c	245.9873631	**Power b**	-0.573621452		

For Compressor Speeds less than 900, COP = COP @ 900 RPM

For Compressor Speeds between 900 and 1500, COP = -5E-07 $\cdot x^2$ + 0.00148 $\cdot x$ + 2.34366

For Compressor Speeds between 1500 and 4000, COP = 7.4E-08 $\cdot x^2$ + -0.00091 $\cdot x$ + 4.59060

For Compressor Speeds Greater than 4000, COP = 245.987 $\cdot x$ + -0.5736

35 COP

Poly c2	3.47917E-07	**Poly c1**	-0.001791667	**Poly b**	4.4046875
Poly2 c2	1.064E-07	**Poly2 c1**	-0.0008256	**Poly2 b**	3.499
Power c	11.20957379	**Power b**	-0.214061992		

For Compressor Speeds less than 900, COP = COP @ 900 RPM

For Compressor Speeds between 900 and 1500, COP = 3.5E-07 $\cdot x^2$ + -0.00179 $\cdot x$ + 4.40469

For Compressor Speeds between 1500 and 4000, COP = 1.1E-07 $\cdot x^2$ + -0.00083 $\cdot x$ + 3.49900

For Compressor Speeds Greater than 4000, COP = 11.2096 $\cdot x$ + -0.2141

Measure /Qe

Capacity Curve Fit Polynomials

Based on the input data entered in purple cells the coefficients of the equations will change

R-134a - Phase II - CAP

Idle Condition Weighting Factor:	
30%	70%

[second value is calculated from to first to add to 100%]

	900 (+15K)	900	1500	2500	4000	Weighting Factor
15 CAP	1.73	1.89	1.30	1.33	1.41	100%
10°C	1.27	1.30	0.88	0.94	0.97	70%
3°C	2.794	3.26	2.29	2.25	2.43	30%
25 CAP	3.23	3.74	2.49	2.43	2.29	100%
10°C	3.23	3.63	2.28	2.23	2.10	70%
3°C	3.23	3.99	2.96	2.90	2.73	30%
35 CAP	4.15	4.45	4.09	4.08	4.18	N/A

Equation: y = (c2 * x^2) + (c1 * x ^1) +

c2: =INDEX(LINEST(y,x^{1,2}),1)

C1: =INDEX(LINEST(y,x^{1,2}),1,2)

b = =INDEX(LINEST(y,x^{1,2}),1,3)

Compressor Speed	900	950	1000	1050	1100	1150	1200	1250	1300	1350	1400

15 CAP

Poly c2 6.25471E-07 **Poly c1** -0.00247568 **Poly b** 3.610831188

Poly2 c2 9.96933E-09 **Poly2 c1** -1.3673E-05 **Poly2 b** 1.302699

Power c 0.523678135 **Power b** 0.119206396

For Compressor Speeds less than 900, CAP =	CAP @ 900 RPM				
For Compressor Speeds between 900 and 1500, CAP =	6.25471E-07	$\cdot x^2 +$	-0.00248	$\cdot x +$	3.61083
For Compressor Speeds between 1500 and 4000, CAP =	9.96933E-09	$\cdot x^2 +$	-0.00001	$\cdot x +$	1.30270
For Compressor Speeds Greater than 4000, CAP =	0.523678135	$\cdot x +$	0.11921		

15 CAP Calc	1.89	1.82	1.76	1.70	1.64	1.59	1.54	1.49	1.45	1.41	1.37

25 CAP

Poly c2 1.27188E-06 **Poly c1** -0.005142 **Poly b** 7.33648125

Poly2 c2 -1.59867E-08 **Poly2 c1** 9.44667E-06 **Poly2 b** 2.507

Power c 6.606508866 **Power b** -0.12779527

For Compressor Speeds less than 900, CAP =	CAP @ 900 RPM				
For Compressor Speeds between 900 and 1500, CAP =	1.27188E-06	$\cdot x^2 +$	-0.00514	$\cdot x +$	7.33648
For Compressor Speeds between 1500 and 4000, CAP =	-1.59867E-08	$\cdot x^2 +$	0.00001	$\cdot x +$	2.50700
For Compressor Speeds Greater than 4000, CAP =	6.606508866	$\cdot x +$	-0.1278		

25 CAP Calc	3.74	3.60	3.47	3.34	3.22	3.11	3.00	2.90	2.80	2.71	2.63

35 CAP

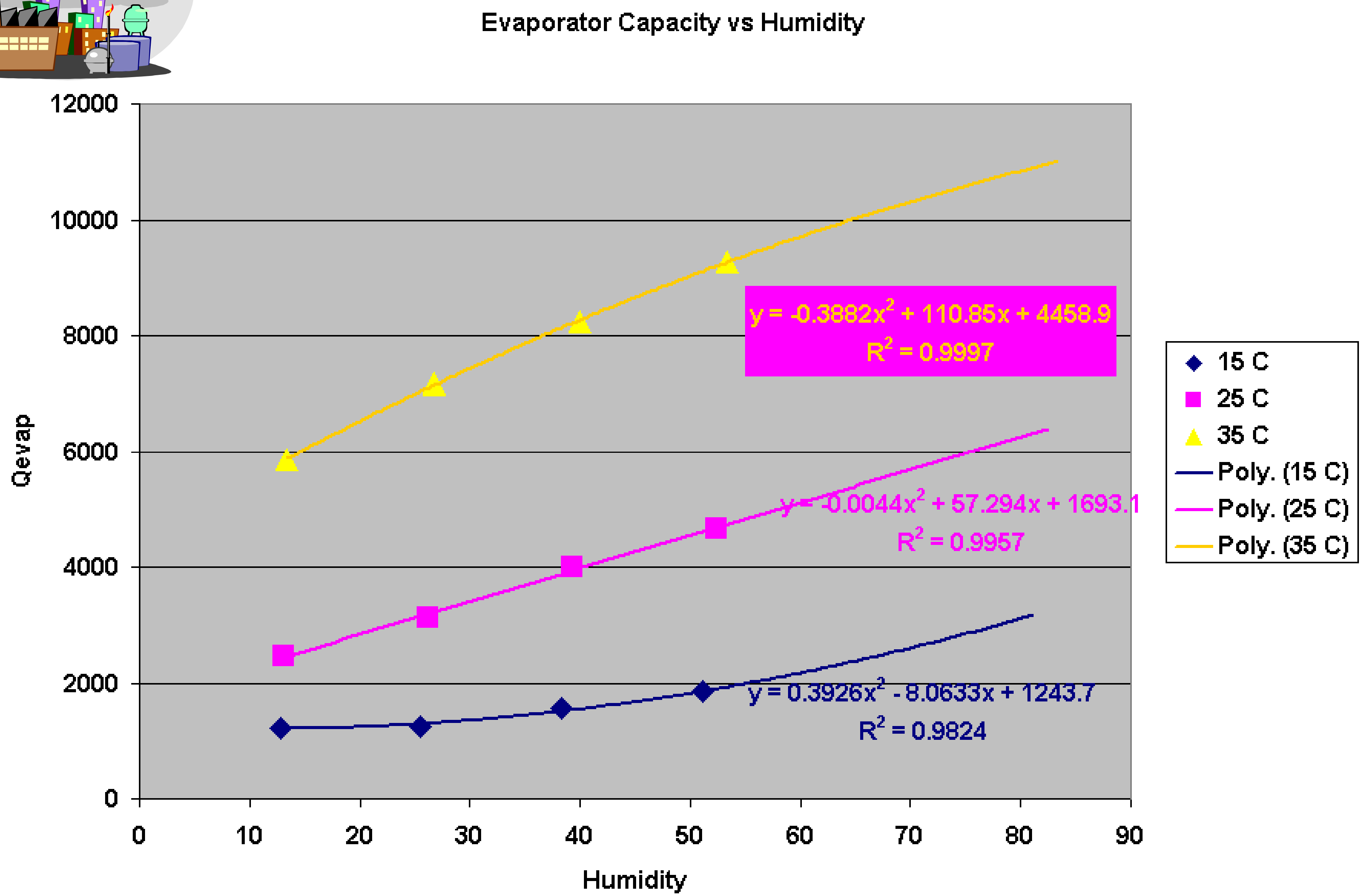
Poly c2 3.68333E-07 **Poly c1** -0.00148233 **Poly b** 5.48575

Poly2 c2 3.08E-08 **Poly2 c1** -0.0001322 **Poly b** 4.22

Power c 2.706709148 **Power b** 0.052511642

For Compressor Speeds less than 900, CAP =	CAP @ 900 RPM				
For Compressor Speeds between 900 and 1500, CAP =	3.68333E-07	$\cdot x^2 +$	-0.00148	$\cdot x +$	5.48575
For Compressor Speeds between 1500 and 4000, CAP =	3.08E-08	$\cdot x^2 +$	-0.00013	$\cdot x +$	4.22000
For Compressor Speeds Greater than 4000, CAP =	2.706709148	$\cdot x +$	0.05251		

35 CAP Calc	4.45	4.41	4.37	4.34	4.30	4.27	4.24	4.21	4.18	4.16	4.13



Evaporator Capacity vs Humidity
Qevap
Humidity
0
2000
4000
6000
8000
10000
12000
0
10
20
30
40
50
60
70
80
90
$y = -0.3882x^2 + 110.85x + 4458.9$
$R^2 = 0.9997$
$y = -0.0044x^2 + 57.294x + 1693.1$
$R^2 = 0.9957$
$y = 0.3926x^2 - 8.0633x + 1243.7$
$R^2 = 0.9824$
15 C
25 C
35 C
Poly. (15 C)
Poly. (25 C)
Poly. (35 C)