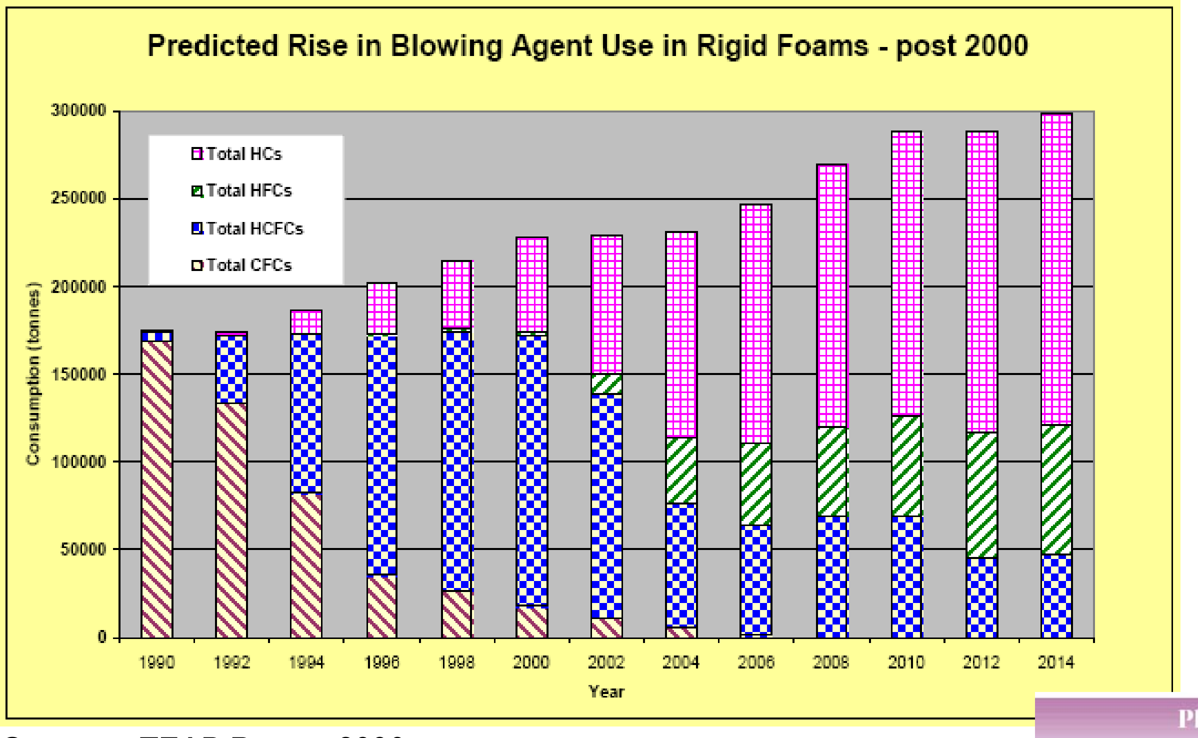
Challenges to Replace ODS in PU Appliance Foams in Developing Countries

Paulo Altoe – Dow Brazil

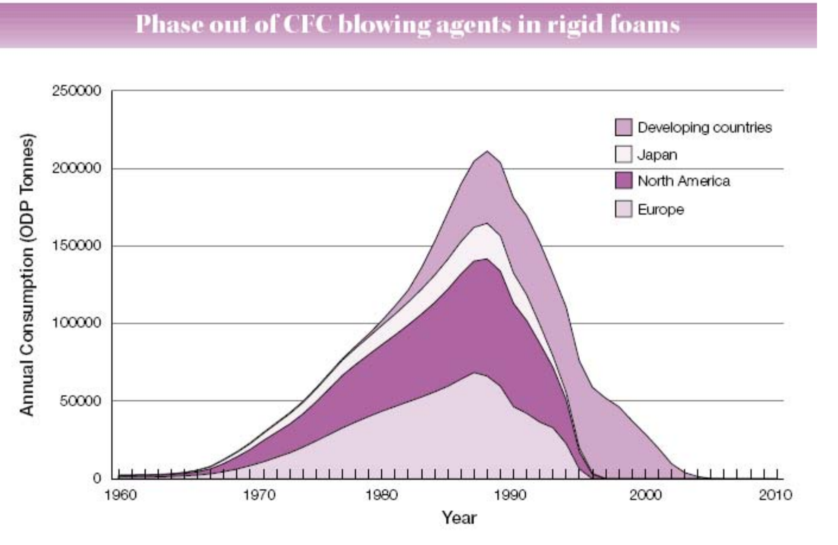
April 2008

Blowing Agent Status - Phase Out of CFC and Growth Predictions for Blowing Agents

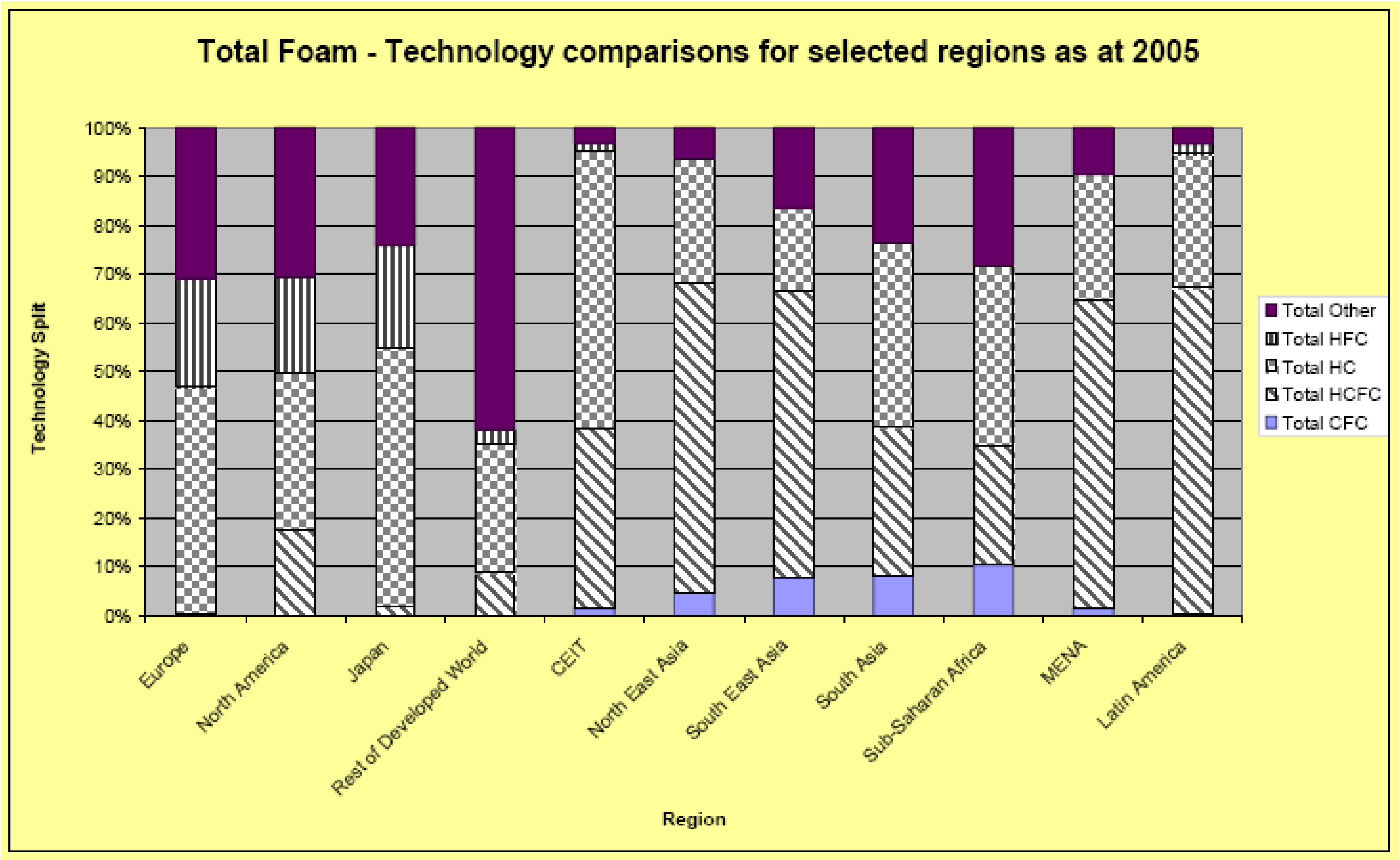


Source – TEAP Report 2006

Source – UNEP Report 2001

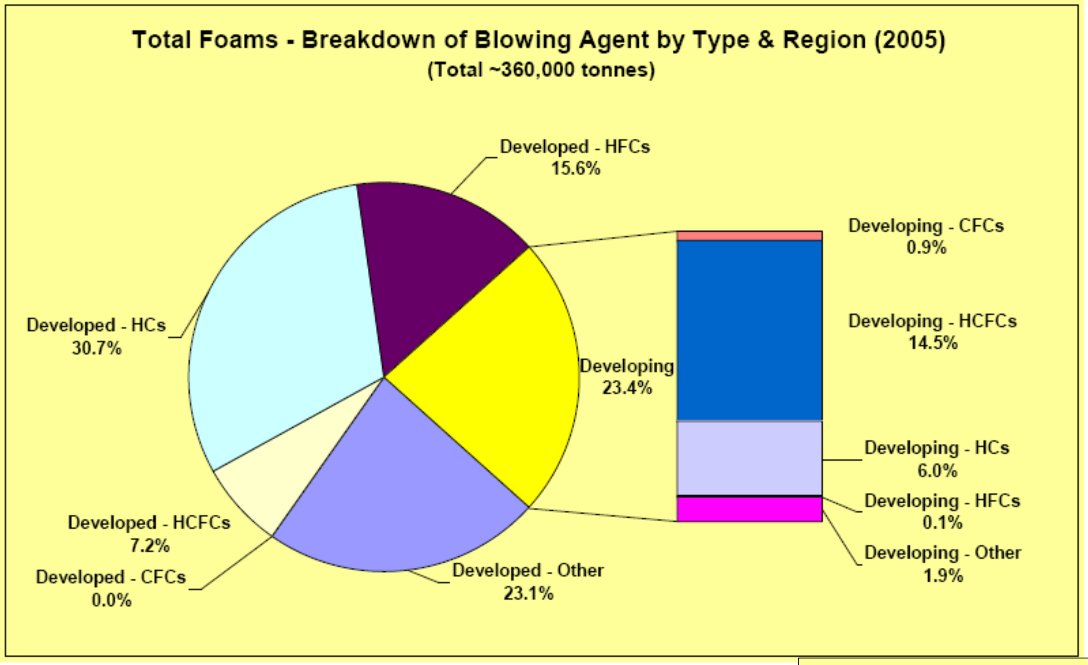


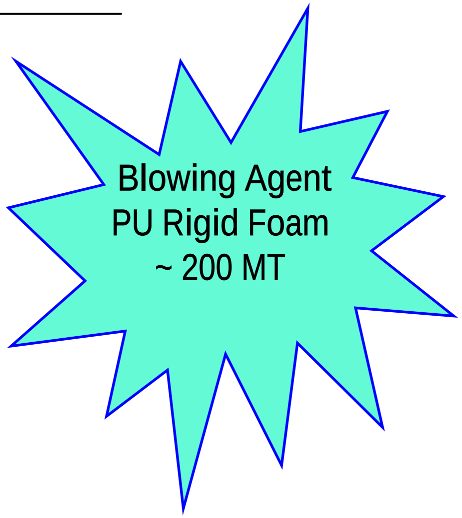
HCFC – Major Volume for Replacement →Developing Countries



Source – TEAP Report 2006

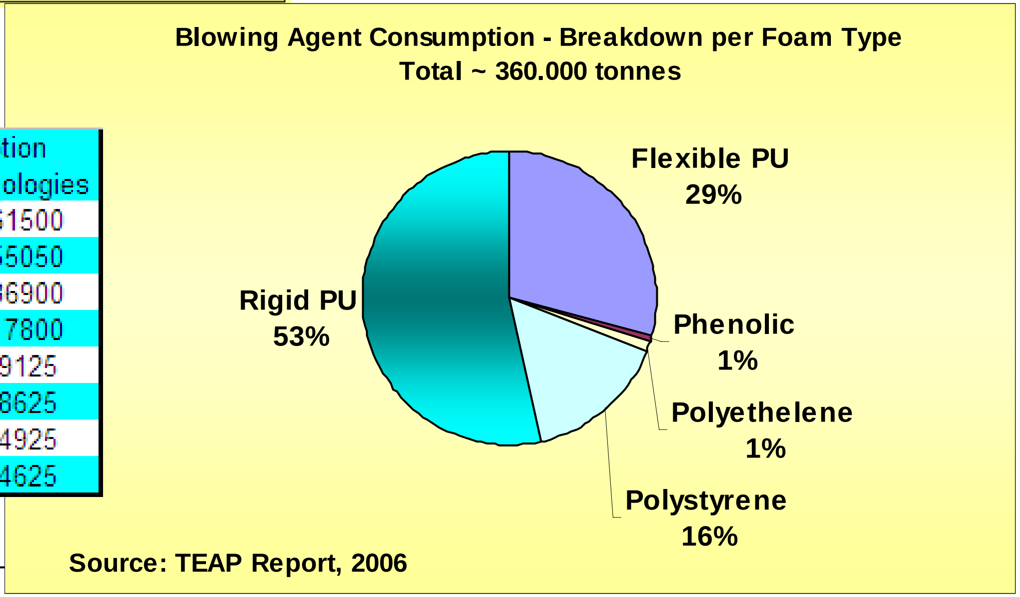
HCFC – Major Volume for Replacement → Developing Countries



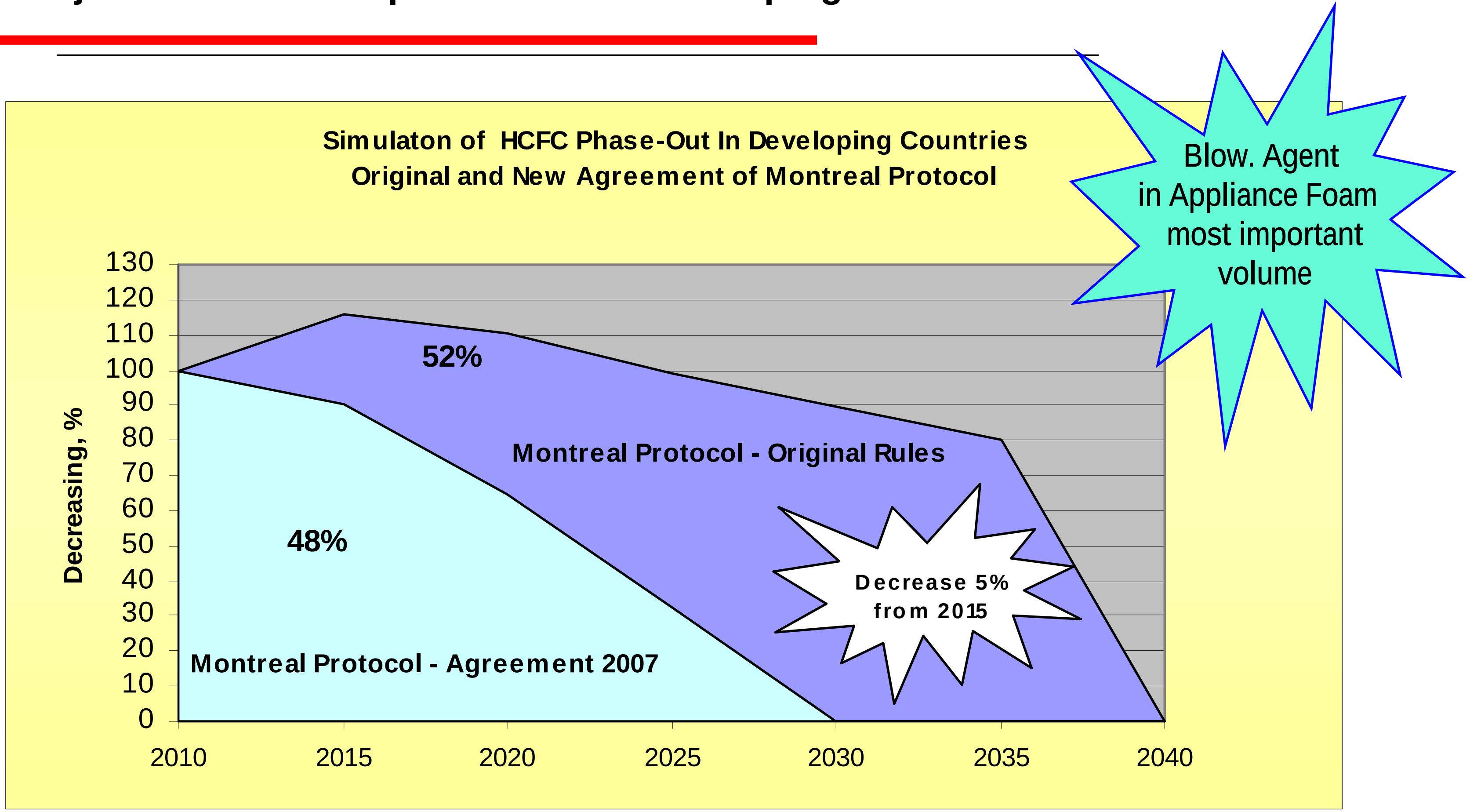


Source – TEAP Report 2006

Bl. Agent Consumption PU -Breakdown - Technologies	
Dom. Appliances	61500
Board Stock	55050
Panels	36900
Spray	17800
Commercial Appl.	9125
Pipe	8625
Reefers Containers	4925
One K	4625



HCFC – Major Volume for Replacement → Developing Countries



2010 Base Line
2013 Freeze Prod., consumption
2015 Reduction 10%
2020 Reduction 35%
2025 Reduction 75%
2040 Reduction 100%

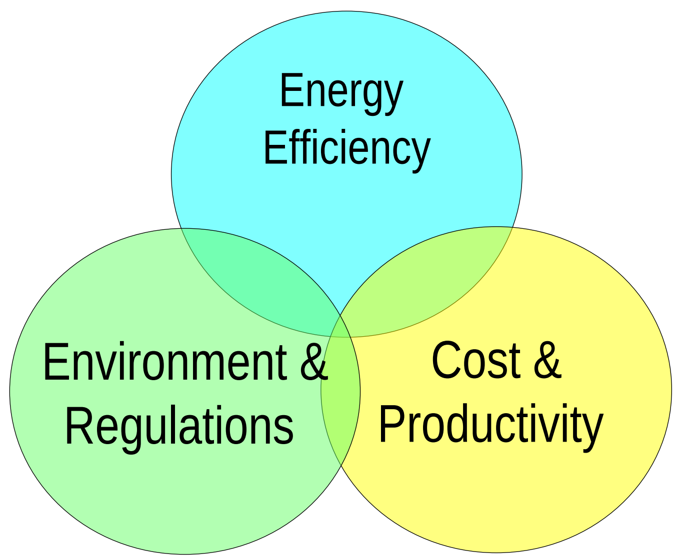
2015 Base Line

2016 Freeze Prod., Consumption

2040 Reduction 100%

Driving Forces in PU Rigid Foams for Appliances

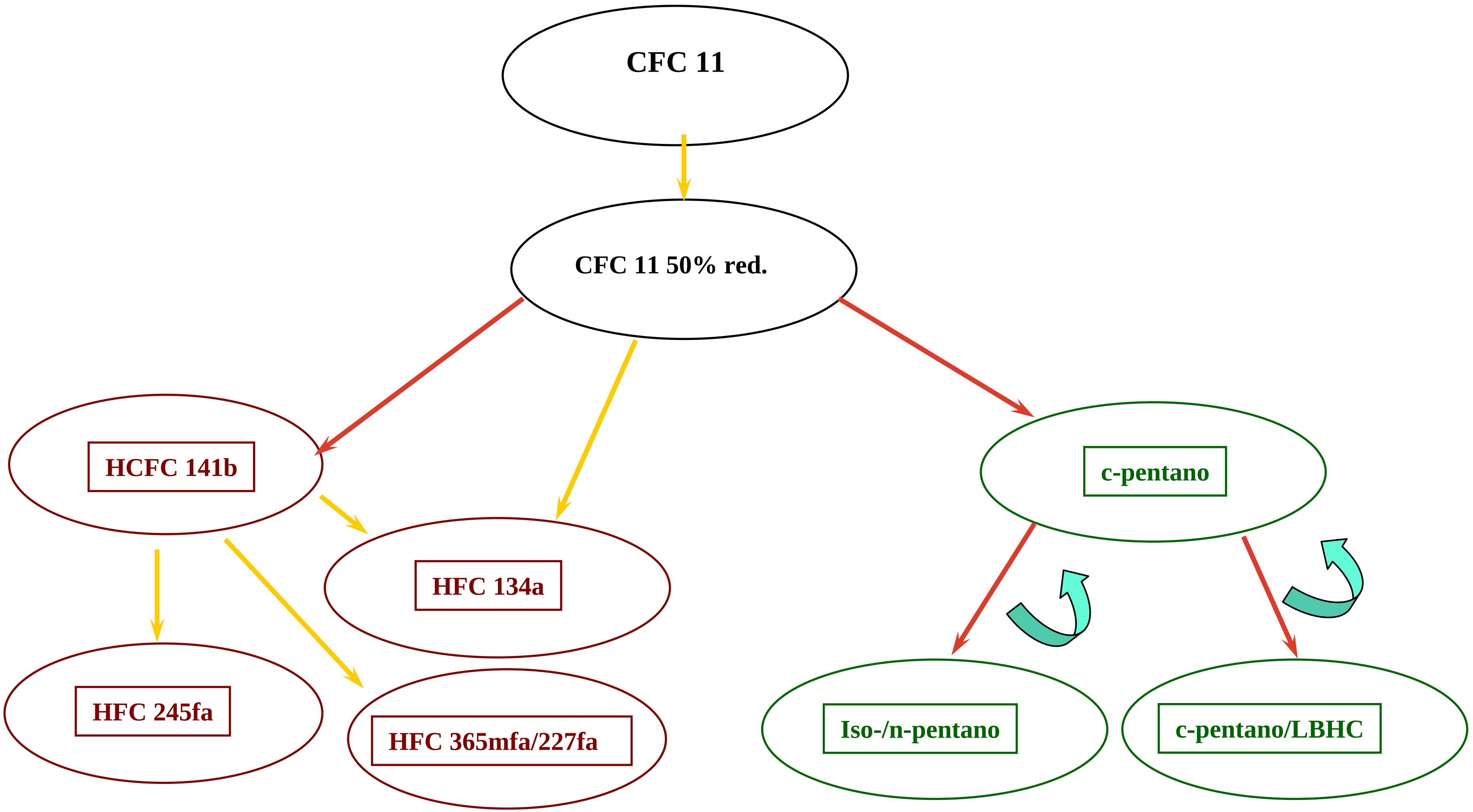
Low K → Bl. Agents
Vacuum Panels
Compressor Efficiency
Design
Multi-injections
Wall Thickness
Energy Labels



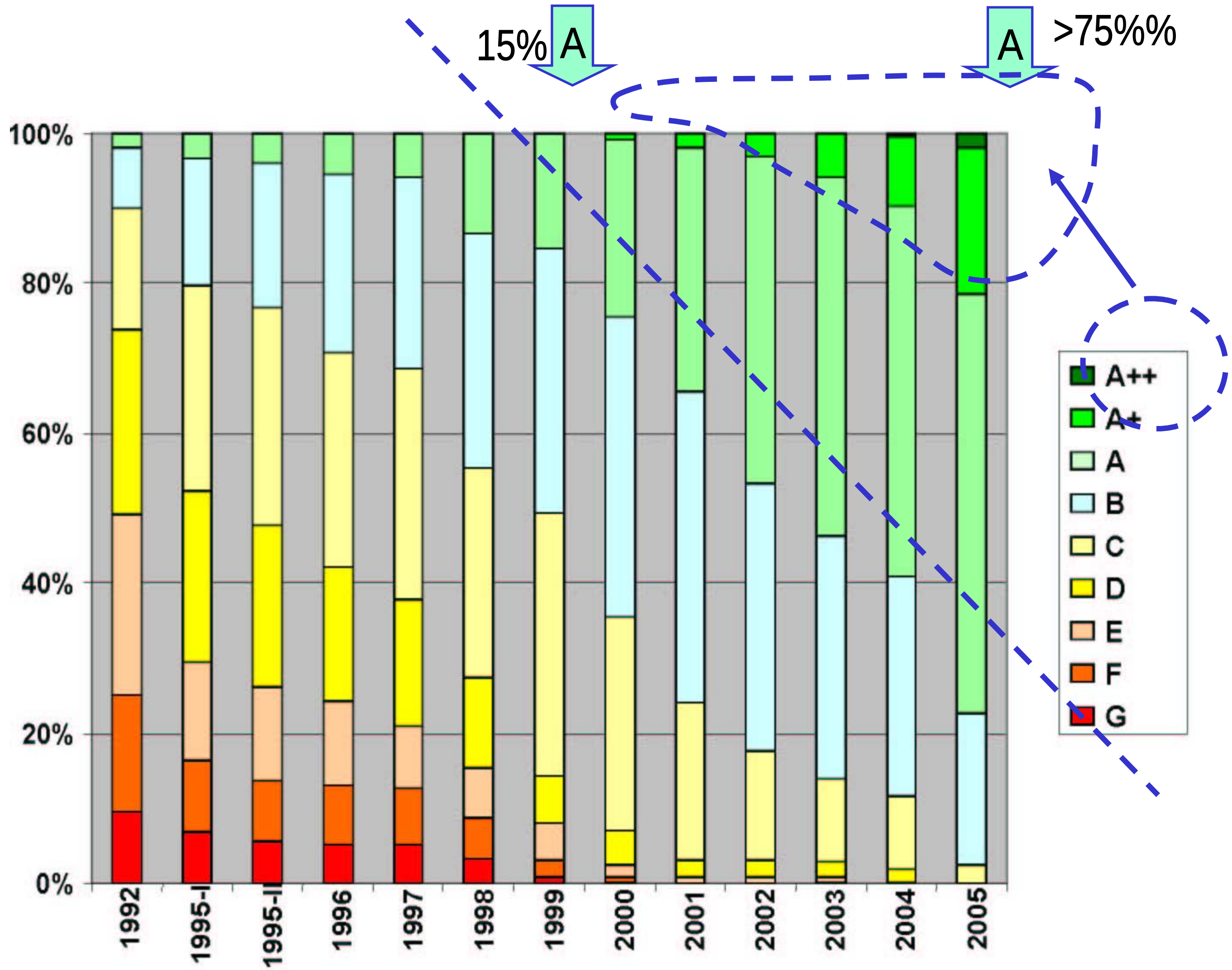
Montreal Protocol
Industrial Hygiene
Product Lifetime
Eco-design
Renewable RM
Recycling
Energy labels

Low Density
Low Blow. Ag. Level
Low "voids"
Flow ability
Fast Demold
Mech. Properties
Dim. Stability

Blowing Agents History in PU Rigid Foams Technology for Appliances



Energy Eficiency and Marketing Need: Refrigerator's energy classes 1992 – 2005 (CECED)



Differentiation

Class A has become market reference

Challenges of HCFC Replacement > Right Choice of Blowing Agents

Physical and Environmental Properties of Blowing Agents

How to address
Energy Efficiency
Environment & Regulations
and Costs ?

Fluorinated Blowing Agents										
	CFC-11	CFC-12	HCFC-22	HCFC-142b	HCFC-141b	HFC-134a	HFC-152a	HFC-245fa	HFC-365mfa	HFC-227ea
Chemical Formula	CFCl3	CCl2F2	CHClF2	CH3CClF2	CCl2FCH3	CCl2FCF3	CHF2CH3	CF3CH2CHF2	CF3CH2CF2CH3	CF3CHFCF3
Molecular Weight	137	121	86	100	117	102	56	134	148	170
Boiling Point, C	24	-22	-41	-10	32	-27	-25	15.3	40.2	-16.5
Gas Conductivity mW/mK at 10 C	7.4	10.5	9.9	8.4	8.8	12.4	14.3	12.5	10.6	11.6
Flammable Limit in air, Vol %	None	None	None	6.7-14.9	1.4-8.0	None	3.9-16.9	None	3.8-13.3	None
TLV or OEL (USA), ppm	1000	1000	1000	1000	500	1000	1000	N/A	N/A	1000
GWP (100yr)	4000	8500	1700	2000	630	1300	140	820	840	2900
ODP	1.0	1.0	0.055	0.055	0.11	0	0	0	0	0
Source: TEAP Report, 2006										

Non Fluorinated Blowing Agents										
	Methylene Chloride	Trans-1,2-dichloroethylene	Isopentane	Cyclo-pentane	n-pentane	Carbon Dioxide	Isobutane	n-butane	Mehtyl Formate Ecomate ®	Water CO2
Chemical Formula	CH3Cl2	C2H2Cl2	CH3CH(CH3)CH2CH3	(CH2)5	CH3(CH2)3CH3	CO2	C4H10	C4H10	CH3(HCOO)	H20
Molecular Weight	84.9	97	72.1	70.1	72.1	44.0	58.1	58.1	60	18
Boiling Point, C	40	48	28	49.3	36	-139	-11.7	0.5	31.5	100
Gas Conductivity mW/mK at 10 C	N/A	N/A	13.0	11.0	14.0	14.5	15.9	13.6	10.7	14.5
Flammable Limit in air, Vol %	None	6.7-18	1.4-7.6	1.4-8.0	1.4-8.0	None	1.8-8.4	1.8-8.5	5.0-23.0	None
TLV or OEL (USA), ppm	35 to 100	200	1000	600	610	N/A	800	800	100	None
GWP (100yr)	NA	<25	<25	<25	<25	1	<25	<25	<25	1
ODP	0	0	0	0	0	0	0	0	0	0
Source: TEAP Report, 2006										

Closed cell : Thermal conductivity contribution factors

~ 60% ~20% ~20%

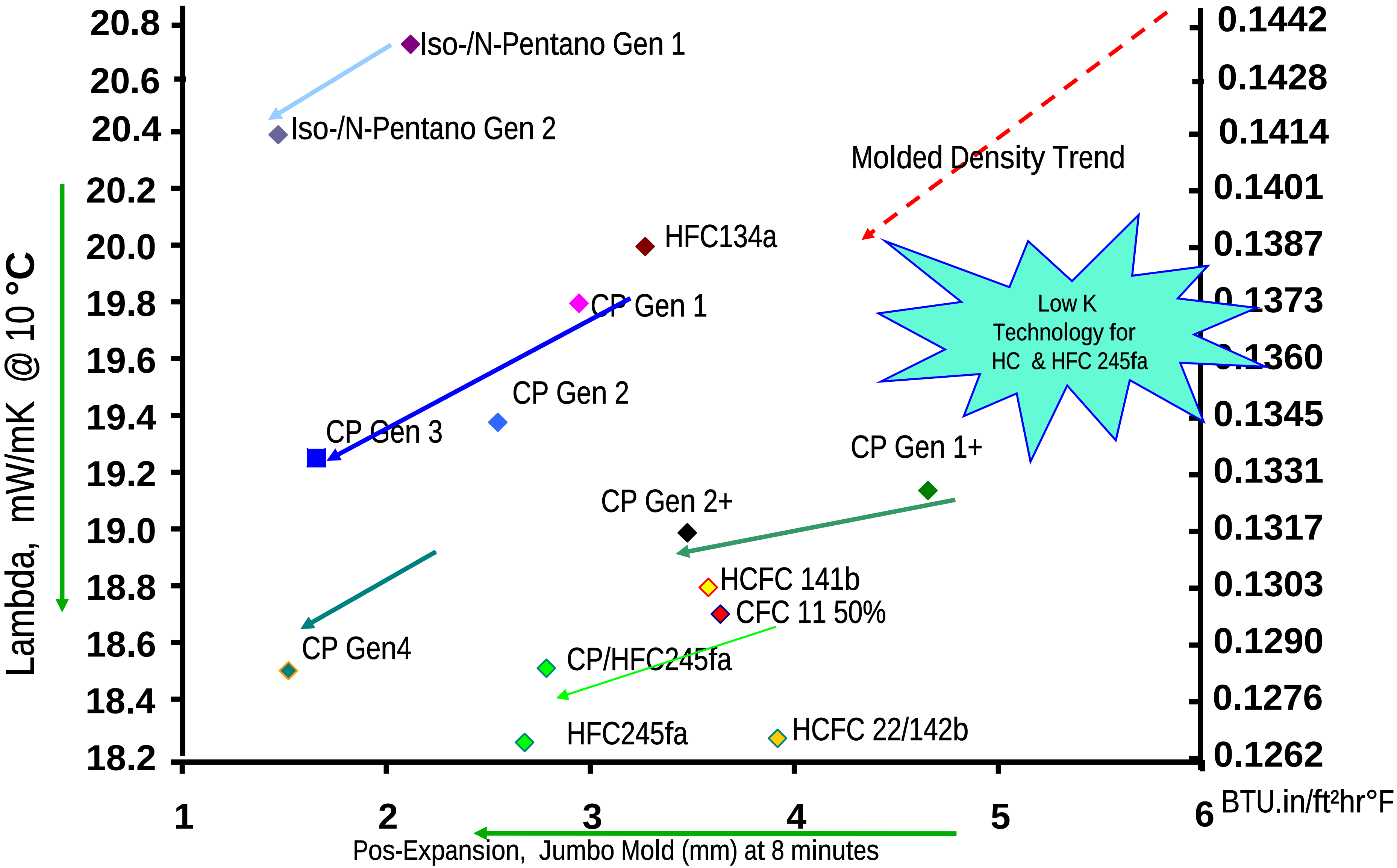
$$\lambda_{Foam} = \lambda_{gas} + \lambda_{solid} + \lambda_{radiative}$$

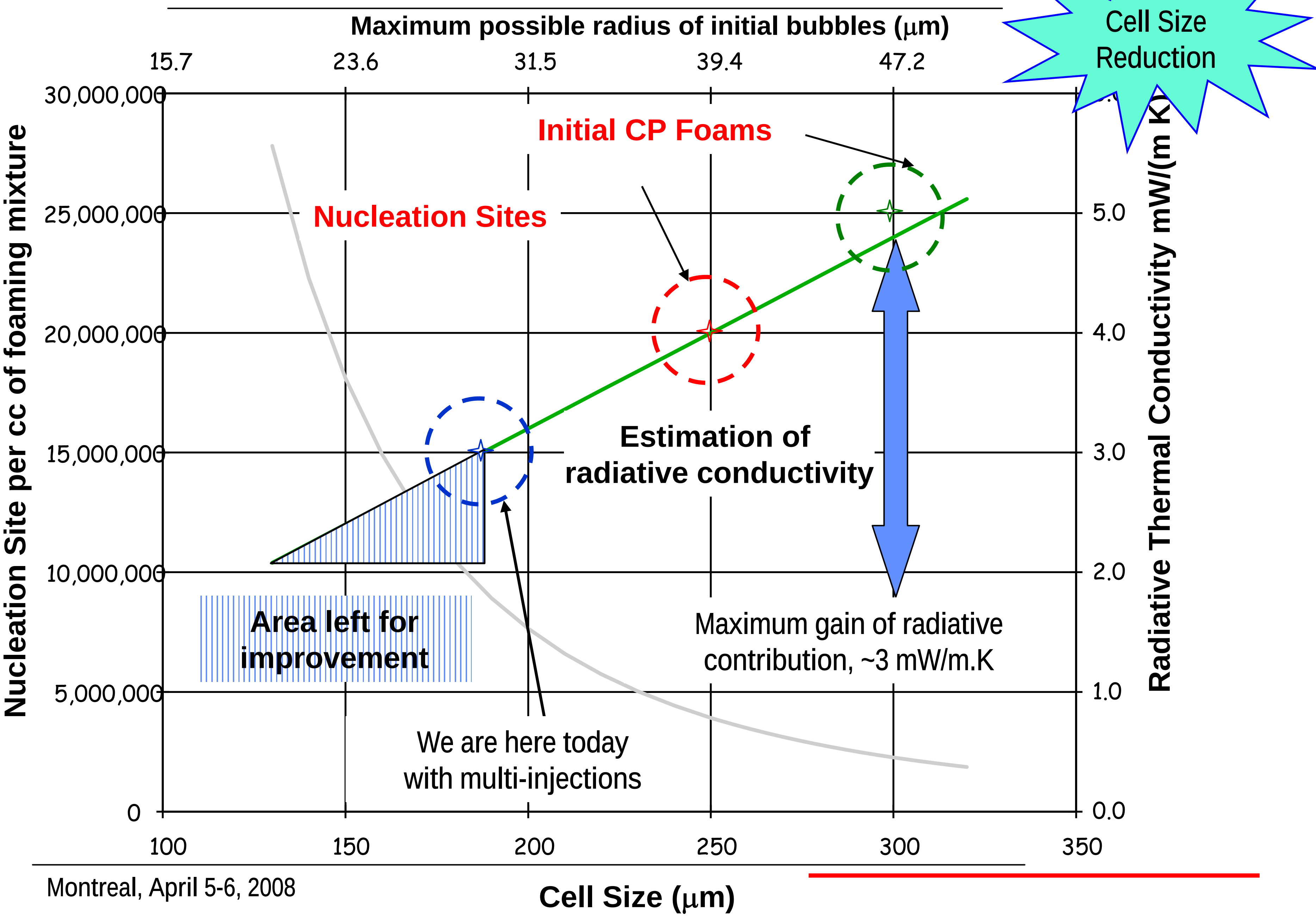
λ_{gas} = *Gases inside foam cells*

λ_{solid} = *Bulk polymer {215-245 [mW/mK]/[g/cc]}*

$\lambda_{radiative}$ = *Radiative processes (10 - 16 [mW/mK]/[mm of cell diameter]}*

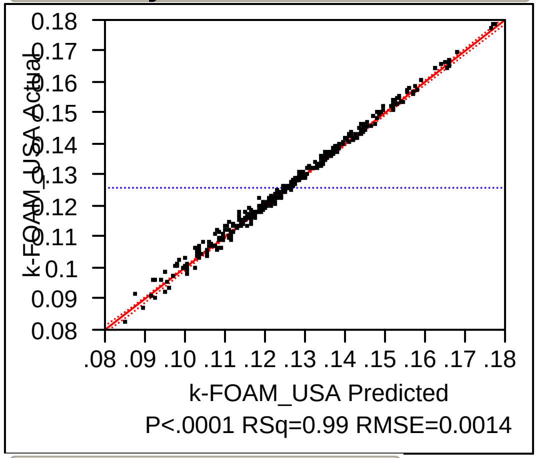
Developments are focused on Bl. Agent and Radiative factor with cell size reduction


Lambda, mW/mK @ 10 °C
20.8
20.6
20.4
20.2
20.0
19.8
19.6
19.4
19.2
19.0
18.8
18.6
18.4
18.2
0.1442
0.1428
0.1414
0.1401
0.1387
0.1373
0.1360
0.1345
0.1331
0.1317
0.1303
0.1290
0.1276
0.1262
BTU.in/ft²hr°F
1
2
3
4
5
6
Pos-Expansion, Jumbo Mold (mm) at 8 minutes
Iso-/N-Pentano Gen 1
Iso-/N-Pentano Gen 2
Molded Density Trend
HFC134a
CP Gen 1
Low K Technology for HC & HFC 245fa
CP Gen 2
CP Gen 3
CP Gen 1+
CP Gen 2+
HCFC 141b
CFC 11 50%
CP Gen4
CP/HFC245fa
HFC245fa
HCFC 22/142b


Cell Size Reduction
Maximum possible radius of initial bubbles (µm)
15.7
23.6
31.5
39.4
47.2
Nucleation Site per cc of foaming mixture
30,000,000
25,000,000
20,000,000
15,000,000
10,000,000
5,000,000
0
Radiative Thermal Conductivity mW/(m K)
5.0
4.0
3.0
2.0
1.0
0.0
Initial CP Foams
Nucleation Sites
Estimation of radiative conductivity
Area left for improvement
Maximum gain of radiative contribution, ~3 mW/m.K
We are here today with multi-injections
100
150
200
250
300
350
Cell Size (µm)

Response k-FOAM_USA HFC 245fa

Actual by Predicted Plot



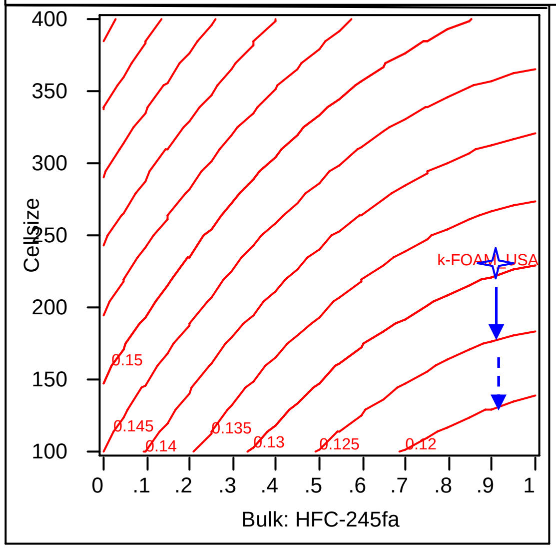
Summary of Fit

RSquare	0.994215
RSquare Adj	0.993953
Root Mean Square Error	0.001433
Mean of Response	0.125992
Observations (or Sum Wgts)	301

Contour Profiler

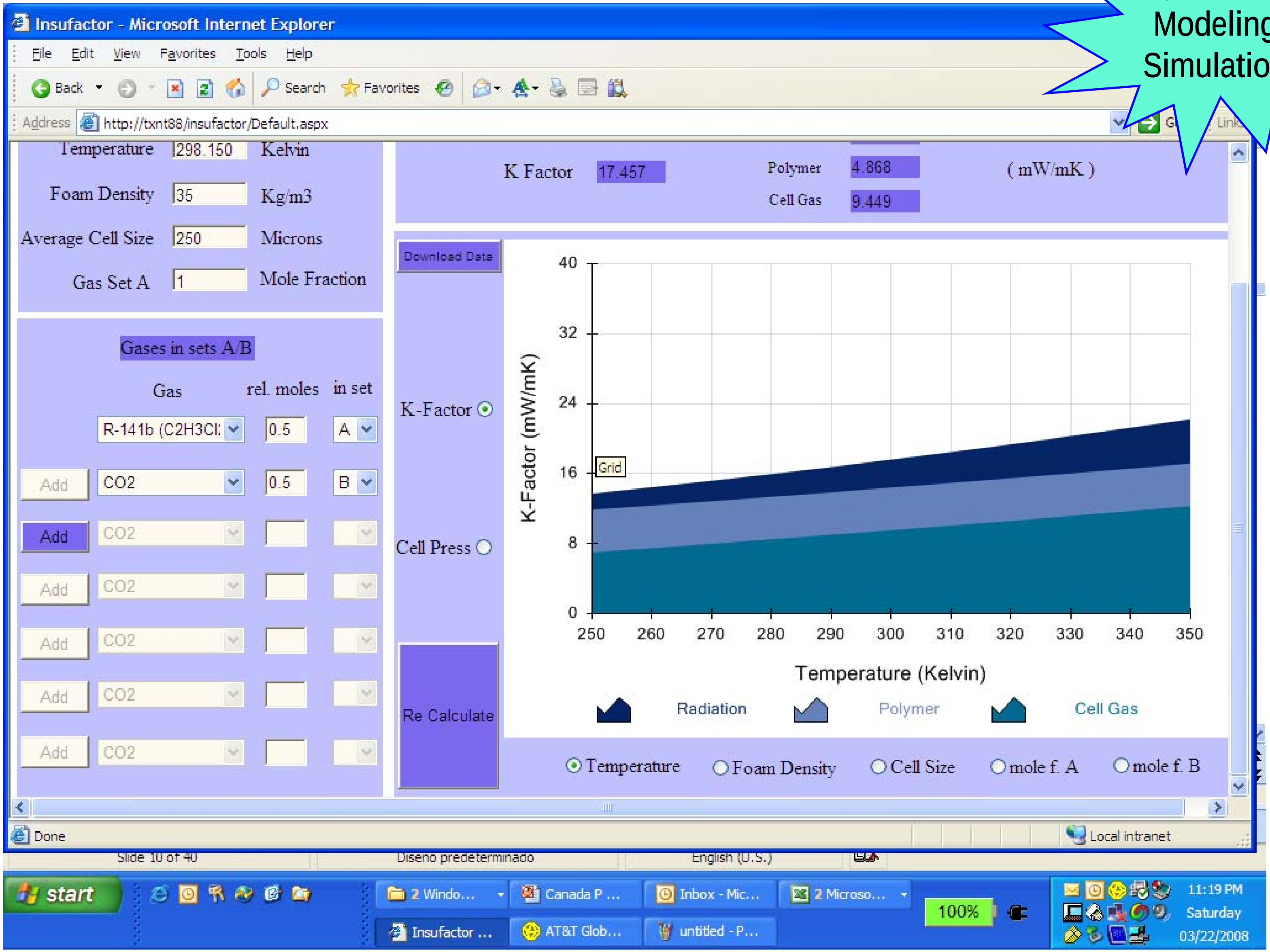
Horiz	Vert	Factor	Current X
○	○	Temperature	24
⦿	○	Bulk: HFC-245fa	0.91
○	⦿	Cellsize	225
○	○	Core Density 2	2

Response	Contour	Current Y	Lo Limi	Hi Limit
k-FOAM_USA	0.13	0.1301849	.	.

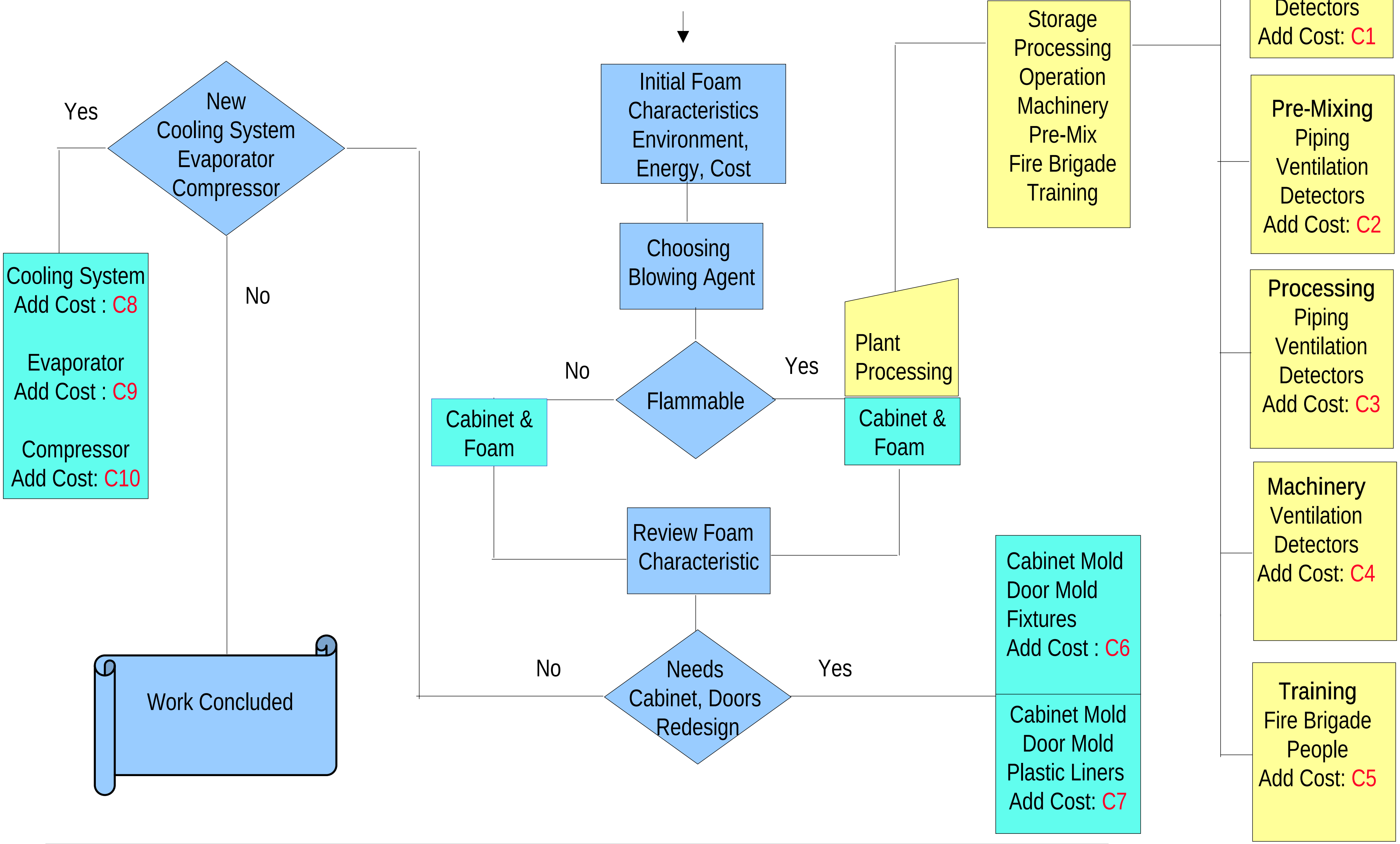


- General rule is: 10 micron reduction in cell size yields 0.001 btu improvement in foam k-factor
- Target needs to be approaching 100 microns hoping to get a k-factor near 0.120 btu
- Maybe as large as 140 micron cells size if consider 100% HFC-245fa
- Issues: Density, Cost, Processing !

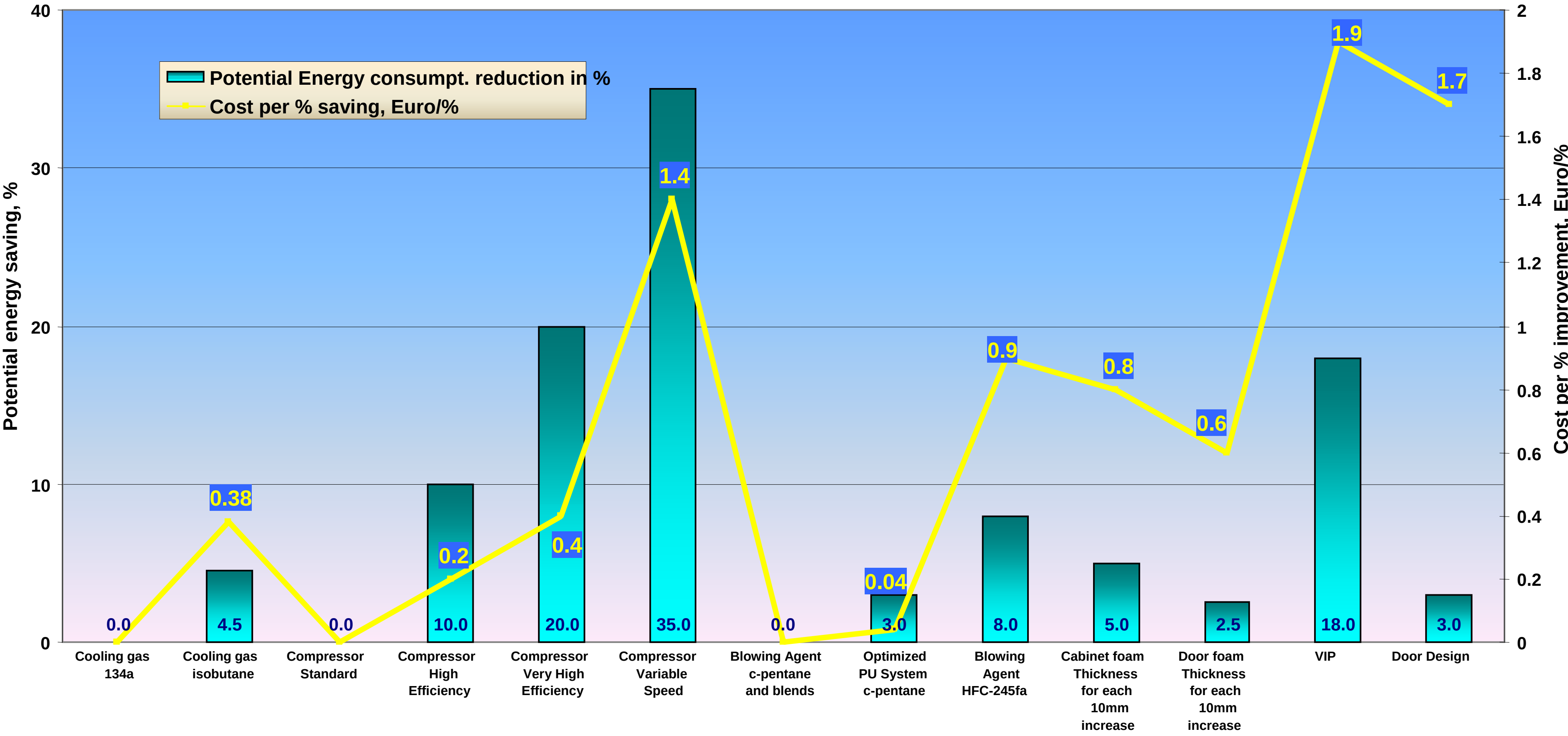
Modeling Simulation



Choosing the preferred Blowing Agent - Diagram



Challenges of HCFC Replacement - *Energy Improvement - Options and Cost*



Challenges of HCFC Replacement-Simulation of Cabinet Costs

Spreasheet for Foam Formulation Comparison - Blowing Agent Options   Simulation for Brazil, China and India

BA Costs indicated are only for calculation and do not reflect exactly the market prices (Ckeck prices locally - It could change drastically your analysis)

Blowing Agent Options	HCFC 141b Reference	H2O	Cycl. Pent	Combination of Bl. Angent CP/IsoB (80/20)	Combination of bl.agent CP/IsoP(75/25)	HFC 134fa	HFC 245fa USA	HFC 245fa China	iso But
Lambda 18.5 - 19.5 mW/mK Foam thickness, mm	35								
Raw Material Cost									
Polyol Cost, US$/kg	2.5	2.6	2.6	2.6	2.5	2.6	2.6	2.6	
Blowing Agent cost US$/kg	3.3	0.01	2.7	2.5	2.60	7	8.5	4.5	1.7
MDI Cost, US$/kg	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	
Foam Cost per Fridge									
Foam Molded Density, kg/m3	35	40	34.5	33	34	32	32	32	
Volume to be filled, liters	150	150	150	150	150	150	150	150	
Foam Weight per cabine, g	5250	6000	5175	4950	5100	4800	4800	4800	
Foam Formulation									
Polyol	100	100	100	100	100	100	100	100	
Blowing Agent	35	5	14.5	14.5	14.5	22	25	30	
MDI	140	160	144	135	144	138	144	144	
Total	275	265	258.5	249.5	258.5	260	269	274	
Cost per Foam component, per cabinet									
Polyol	4.77	5.89	5.21	5.16	4.93	4.80	4.64	4.55	
Blowing Agent	2.21	0.00	0.78	0.72	0.74	2.84	3.79	2.36	
MDI	6.68	9.06	7.21	6.70	7.10	6.37	6.42	6.31	
Total Cost of Foam per cabinet, US$	13.66	14.94	13.20	12.57	12.78	14.01	14.86	13.23	
Cost differences compared to Reference		-1.28	0.46	1.09	0.88	-0.35	-1.20	0.43	
Units produced per year Model X	500000	500000	500000	500000	500000	500000	500000	500000	
Cost Saving (+) or Losses (-), US$ per year		-642491.42	231897.97	543074.33	440469.05	-176381.12	-597736.57	216634.04	

Lengend:

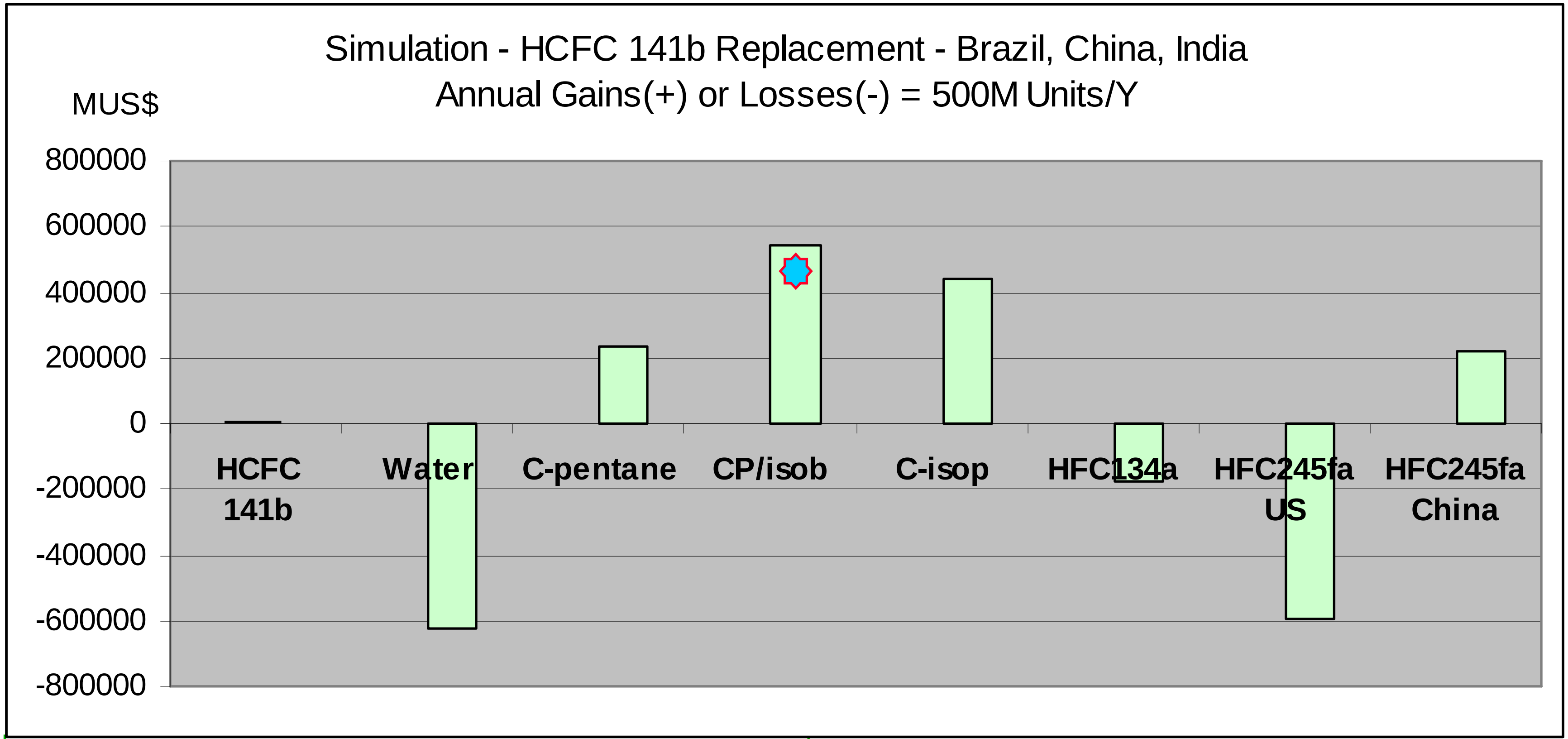
In Red: input the values

In black: the spreadsheet calculates

In Green: Use HCFC 141b as Reference

For Cabinet Re-design increase volume for modified cabinets

Challenges of HCFC Replacement-Simulation of Foam Cost vs Blowing Agent



Protocol:

Foam = HCFC141b, 35 kg/m3 and lambda 18.5-19.5 mW/mK @ 24C

Cabinet with 35 mm thickness

Challenges of HCFC Replacement-Simulation of Cabinet Costs

Spreasheet for Foam Formulation Comparison - Blowing Agent Options Simulation for Andean Countries & Mexico

BA Costs indicated are only for calculation and do not reflect exactly the market prices (Ckeck prices locally - It could change drastically your analysis)

Blowing Agent Options	HCFC 141b Reference	H2O	Cycl. Pent	Combination of Bl. Angent CP/isoB (80/20)	Combination of bl.agent CP/IsoP(75/25)	HFC 134fa	HFC 245fa USA	HFC 245fa China	iso But
Lambda 18.0 - 19.0 mW/mK Foam thickness, mm	35								
Raw Material Cost									
Polyol Cost, US$/kg	2.5	2.6	2.6	2.6	2.5	2.6	2.6	2.6	
Blowing Agent cost US$/kg	3.3	0.01	2.7	2.5	2.60	7	8.5	4.5	1.7
MDI Cost, US$/kg	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	
Foam Cost per Fridge									
Foam Molded Density, kg/m3	34	40	34.5	33	34	32	32	32	
Volume to be filled, liters	150	150	150	150	150	150	150	150	
Foam Weight per cabine, g	5100	6000	5175	4950	5100	4800	4800	4800	
Foam Formulation									
Polyol	100	100	100	100	100	100	100	100	
Blowing Agent	35	5	14.5	14.5	14.5	22	25	30	
MDI	140	160	144	135	144	138	144	144	
Total	275	265	258.5	249.5	258.5	260	269	274	
Cost per Foam component, per cabinet									
Polyol	4.64	5.89	5.21	5.16	4.93	4.80	4.64	4.55	
Blowing Agent	2.14	0.00	0.78	0.72	0.74	2.84	3.79	2.36	
MDI	6.49	9.06	7.21	6.70	7.10	6.37	6.42	6.31	
Total Cost of Foam per cabinet, US$	13.27	14.94	13.20	12.57	12.78	14.01	14.86	13.23	
Cost differences compared to Reference		-1.68	0.07	0.70	0.49	-0.74	-1.59	0.04	
Units produced per year Model X	500000	500000	500000	500000	500000	500000	500000	500000	
Cost Saving (+) or Losses (-), US$ per year		-837627.79	36761.61	347937.97	245332.69	-371517.48	-792872.93	21497.68	

Lengend:

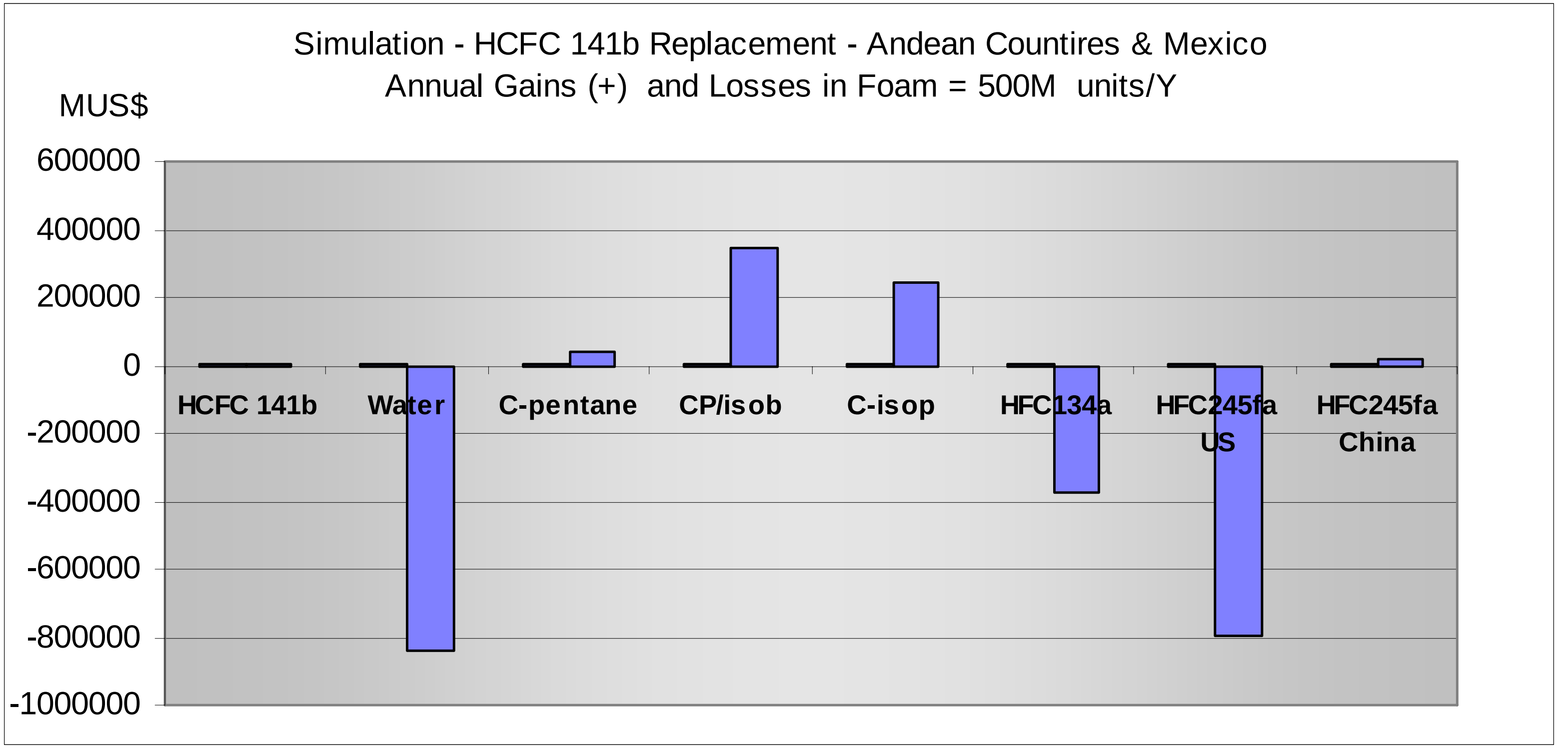
In Red: input the values

In black: the spreadsheet calculates

In Green: Use HCFC 141b as Reference

For Cabinet Re-design increase volume for modified cabinets

Challenges of HCFC Replacement-Simulation of Foam Cost vs Blowing Agent

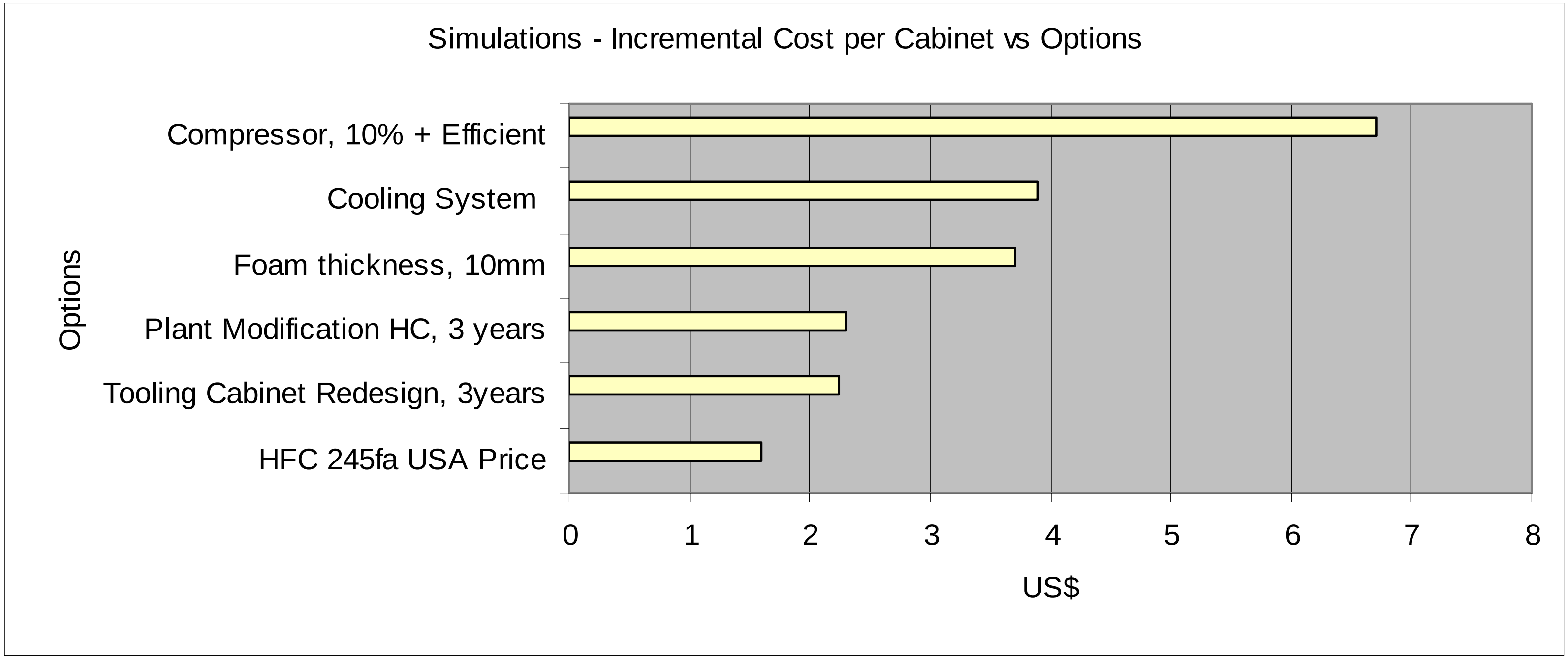


Protocol:

Foam = HCFC141b, 34 kg/m3 and lambda 18.0-19.0 mW/mK @ 24C

Cabinet with 35 mm thickness

Challenges of HCFC Replacement- Simulation – Incremental Cost per Cabinet vs Options



Additional Cost per cabinet - 500M Units/Y		
Additional for Cabinet Re-Design		
Tool PU Mold Plug = 75M US$ each	20	1500000
Tool PU Mold Doors = 75M US$ each	10	1500000
Tool Plastic Liner Thermoform = 100M each	2	200000
Tool Plastic Door small & Big Thermoform = 80M each	2	160000
Total		3360000

Plant Modification to Hydrocarbons From 0.8 – 3.5 MM US depending on the size

Conclusion

* HCFCs Elimination is a Very Difficult Task Apart From all Technology Advances

* HCFC Elimination by HFC 24fa – Favorable for Energy Efficiency, Non Flammable, High Cost, High GWP

Additional costs - Predominantly in Cabinets
- Less in Machinery & Processing
Cost in cabinets - Remain until the cabinet model is produced, limited payback
Investment - Low in Machinery, High in Raw Material (High cost of Blowing Agent)

* HCFC Elimination by Hydrocarbons – Favorable to the Environment, Medium for Energy, Very Low GWP

Additional costs - Predominantly in Machinery & Plant Processing
- Less in Cabinets
-Cost in cabinets – Depending on the re-design
Investment - High in Machinery & Plant Processing with Payback,
- Low in Raw Material (Low cost of Blowing Agent)

* Other Options – To be evaluated case by case

Blends of HC/HCFC can be an option for China where HFC245fa has lower price
Higher water blown content with other blowing agents will depend on applied molded density and Energy Efficiency requirements

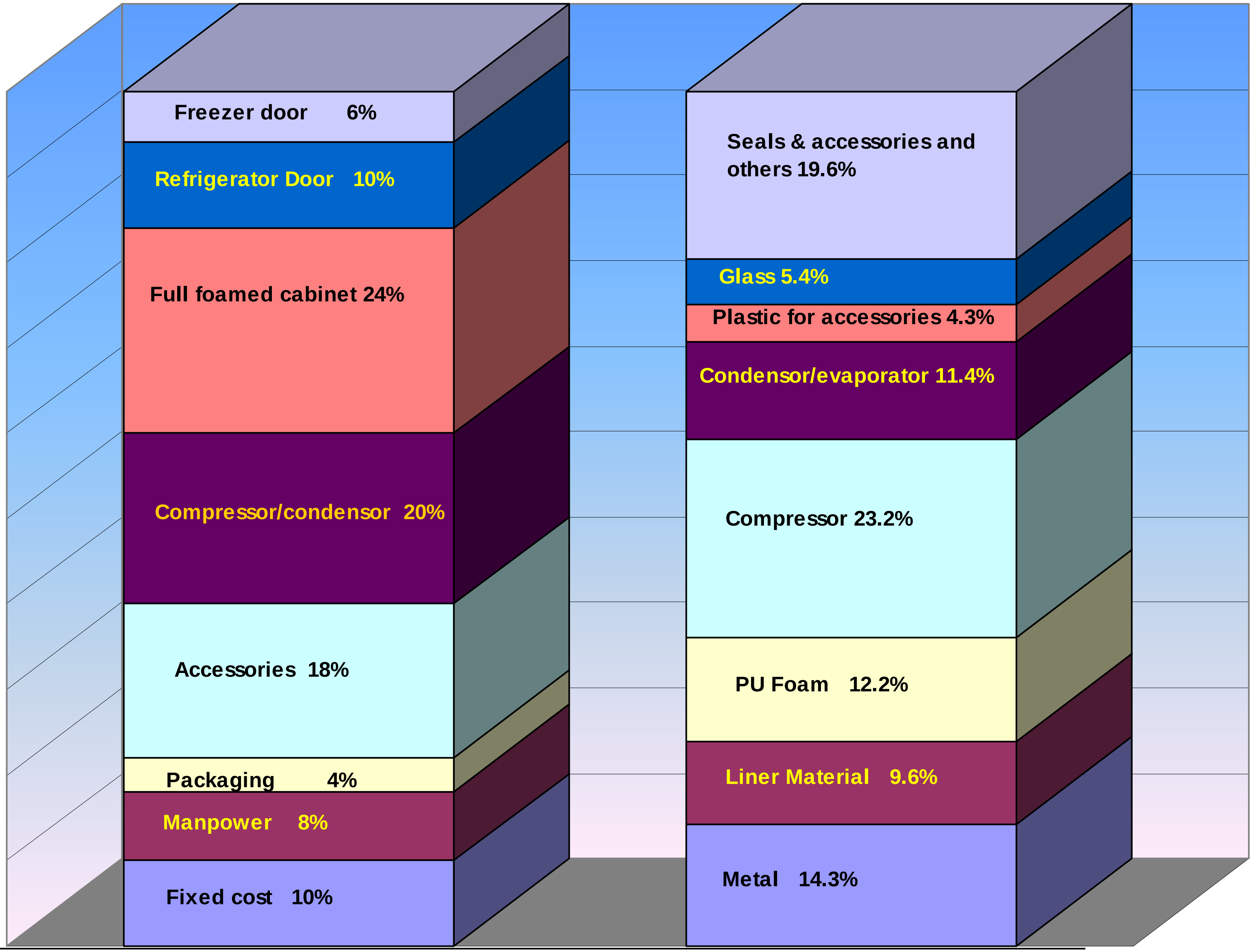
•Modeling, Simulations and Formulation Science are great help for Bl. Agent comparison before final decision is taken

Back Up - Slides

Paulo Altoe – Dow Brazil

April 2008

Challenges of HCFC Replacement - *Energy Improvement - Options and Cost*



** excludes Manpower and fixed costs

Conversion Cost to Hydrocarbons	US$
Storage	100000
Ventilation	80000
Safety Control - Cabinets	35000
White Book	22000
Safety Report	15000
Pre-Mix Polyol + Hydrocarbon	150000
PU Machine + Mixing Head	300000
Civil Construction	
Engineering	
Man Power	
Total	702000