From a Recent Study for the German Umweltbundesamt *

Insulation in Refrigerated Vehicles. A TEWI view on blowing agents HFC-365mfc and c-pentane

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Sequence of blowing agents

- EU regulation bans 141b use for all foams, as of 2004
- In Germany, mainly direct switch from CFC-11 to pentane, in the nineties
- Transition to 141b only where difficult to offset poorer insulation performance by increased thickness
- Example: Insulation of refrigerated vehicles with limited interior space of the cargo hold
- Minimum internal width > 2400 mm for side by side storage of 3 standard pallets (800 mm, each)

However, by 2003 the leading German manufacturers changed to c-pentane, despite of new liquid HFCs

Insulated Refrigerated Semitrailor

- Insulation must ensure u-value below 0.4 W/m²K for the total structure of 158 m²,
- in order to maintain interior temperature of –20°C at ambient temperatures of +30°C,
- by means of a refrigeration unit (mounted to the front wall) driven by an own diesel engine.

Vital for long-distance transport of perishable goods

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Dimensions 141b case

External width: 2,60 m

Foam thickness (except side walls)

Roof: 80 mm PU. Rear door: 80 mm PU.

Front: 50 mm PU. Floor: 100 mm XPS

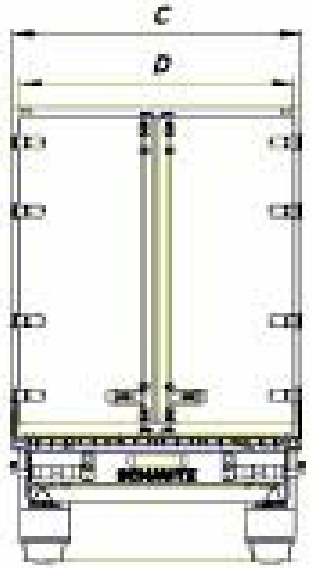
Thickness of each side wall

1 x 43.8 mm PU

2 x 0.6 mm diffusion proof steel sheets

2 x 3.5 mm profiled aluminium sheets

= 52 mm total wall thickness



Internal width: 2,49 m

Total foam volume (incl. XPS): 10.3 m³

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Dimensions c-pentane case

External width: 2,60 m

Foam thickness (except side wall)

Roof: 80 mm PU. Rear door: 80 mm PU.

Front: 50 mm PU. Floor: 100 mm XPS

Thickness of each side wall

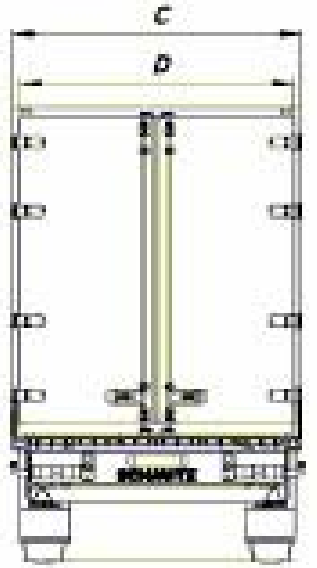
1 x 58.8 mm PU = + 15 mm

2 x 0.6 mm diffusion proof steel sheets

2 x 3.5 mm profiled aluminium sheets

= 67 mm total wall thickness = + 15 mm

Internal width: 2,46 m = - 0,03 m



Total foam volume (incl. XPS): 11.5 m^3 = + 1.2 m^3

Foam weight: from 552 to 628 kg

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C-pentane in place of HCFC-141b

Horizontal clearance = - 30 mm?

„Cargo hold dimensions still sufficient for standard pallets“

Side wall thickness = + 30 mm?

„Insulation performance at least maintained at the same level as before, i.e. 0.37 W/m²K“

Investment cost?

„EUR 1.5 million, due to ODS phase-out“

Comments of the manufacturer

Plausibility check

The insulation effect of PU rigid foam at a given thickness is higher with lower thermal conductivity λ of the blowing agent in the foam cells.

Applied λ -values for different blowing agents in PU rigid foam (mW/mK)

141b	365mfc	c–pent.	n–pent.
21	22	>23	24

<u>Offset:</u> The increase in overall foam volume (+ 11.6 %) is of the same order as the decrease of the λ of the foam with c-pentane instead of 141b (- 10.2 %).

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... and the same with HFC-365mfc?

Given the new foam thickness, what is the effect of using an even better insulating blowing agent?

C-pentane:

Lower GWP (4), lower cost (EUR 1.00/kg), higher λ (23.15)

HFC-365mfc:

Higher GWP (890), higher cost (EUR 6.50/kg), lower λ (22)

Compare the global warming emissions caused by refrigerated vehicles with foam either blown by c-pentane or blown by HFC-365mfc. The thicker side walls provide the common technical basis of the balance.

Basic data of the GHG balance

	C-pentane	HFC-365mfc
Blowing agent	17,6 kg	43,1 kg
GWP	4	890
Lambda foam	23.15	22
u-value structure	0.370	0.361
Price per kg	€ 1.00	€ 6.00
Refrigeration unit	1,500 h/y	1,500 h/y
Diesel per h	4.0 liter	3.9 liter
CO_2 per l diesel	2.75 kg	2.75 kg
Lifetime	12 y	12 y
Price l diesel	€ 0.85	€ 0.85

Notice: The difference between the u-values of the structure is half the difference between the respective lamba-values.

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Relation λ value foam to u-value structure

- Unlike even panels, no linear relation between lower λ and lower u-value of insulated structure.
- According to Bayer experiments, λ reduction by x% leads to maximum u-value decrease by half of x%.

Why?

- Container boxes have three dimensions.
- There are many thermal bridges (edges, bolts, foam cuts, seals etc.)

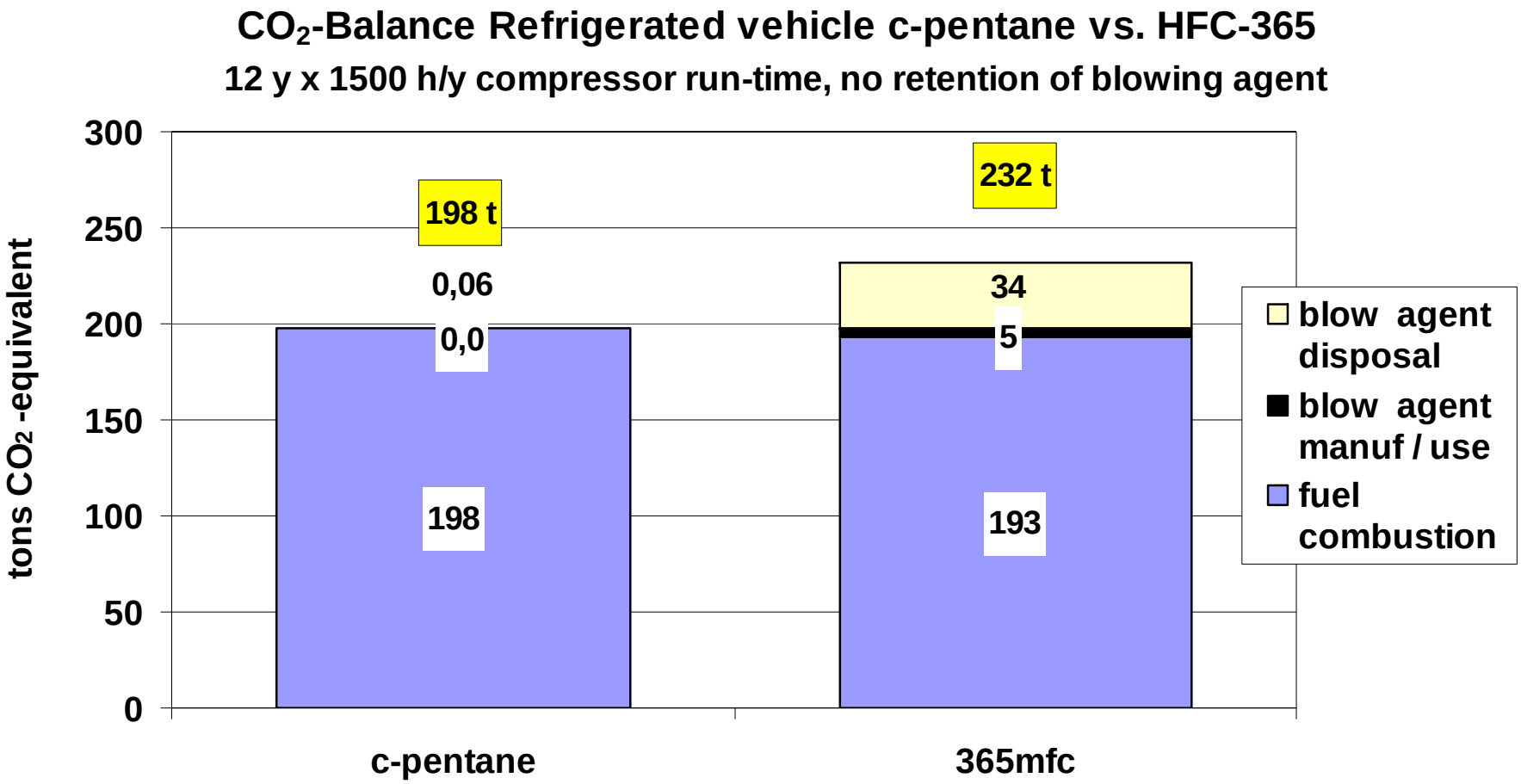
Model assumption

- HFC-365mfc with 5% lower λ reduces u-value not by 5% but by 2.5%, from 0.37 to 0.36.

Thermal bridges illustrated

Foto: Schmitz Cargobull Germany

GHG balance. Reference case



Due to (by 2.5%) higher insulation and hence less diesel combustion, lifetime CO_2 output is lower in HFC case. This advantage is over-compensated by direct blowing agent emission with high GWP. Note: No retention of blowing agents at end-of-live is assumed (today's reality). Lifetime: 12 years.

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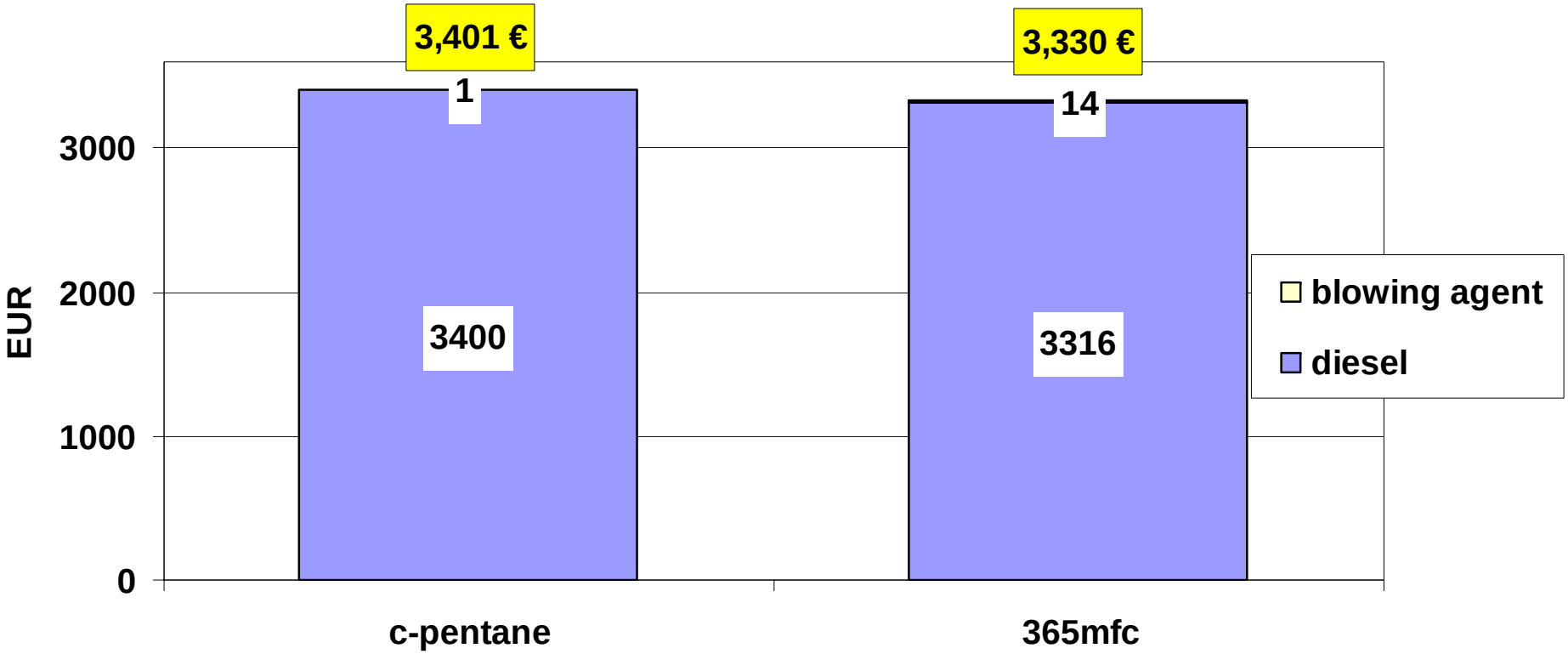
Running cost. Reference case

Annual Operating Cost c-pentane vs. HFC-365. Reference case

1500 h/year compressor running time, 12 years use



Caused by lower diesel consumption, (partial) annual running cost of vehicles with HFC-blown foam is lower. This difference is not compensated by higher (annualised) cost of blowing agent.

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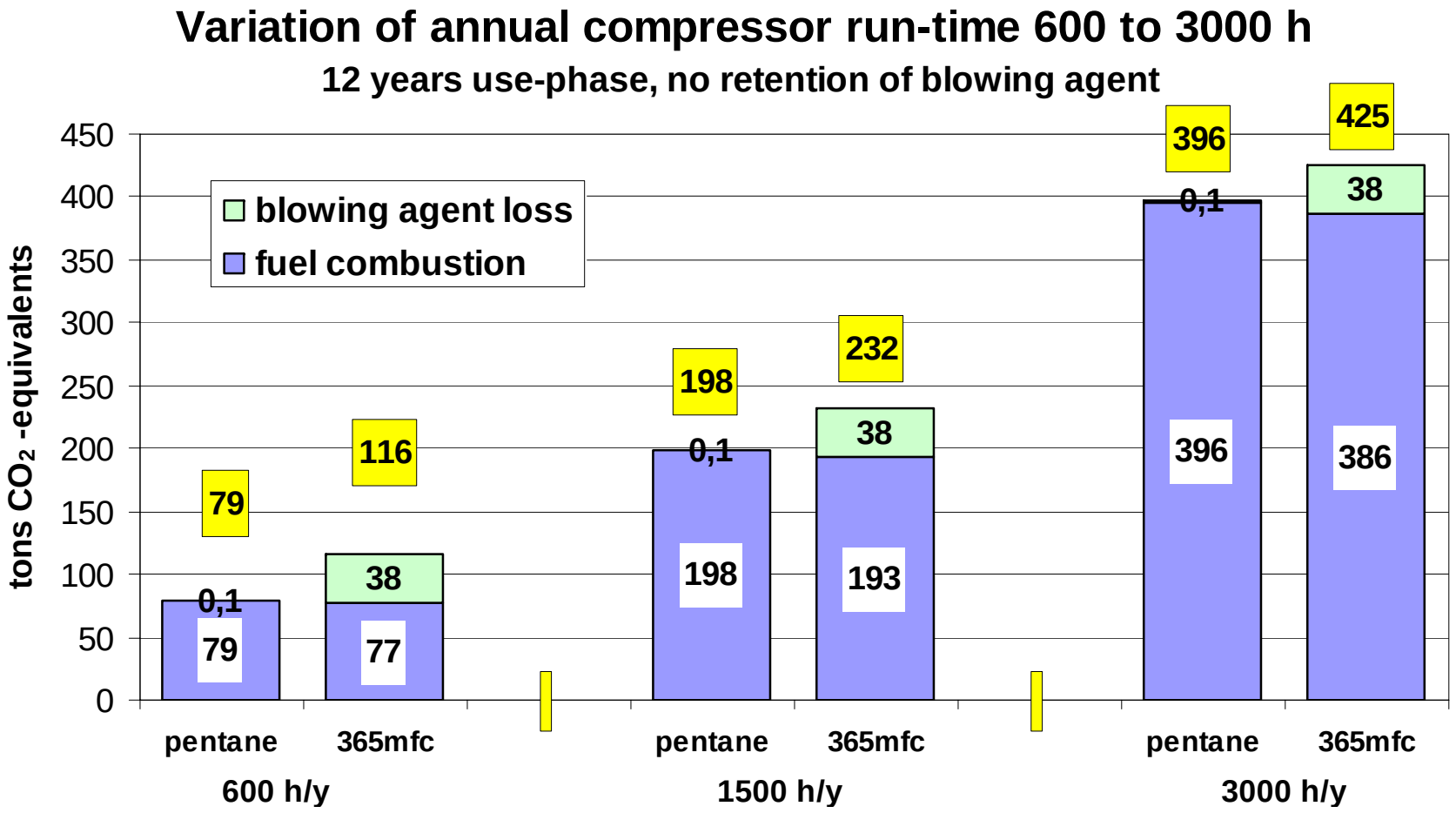
Sensitivity analysis I



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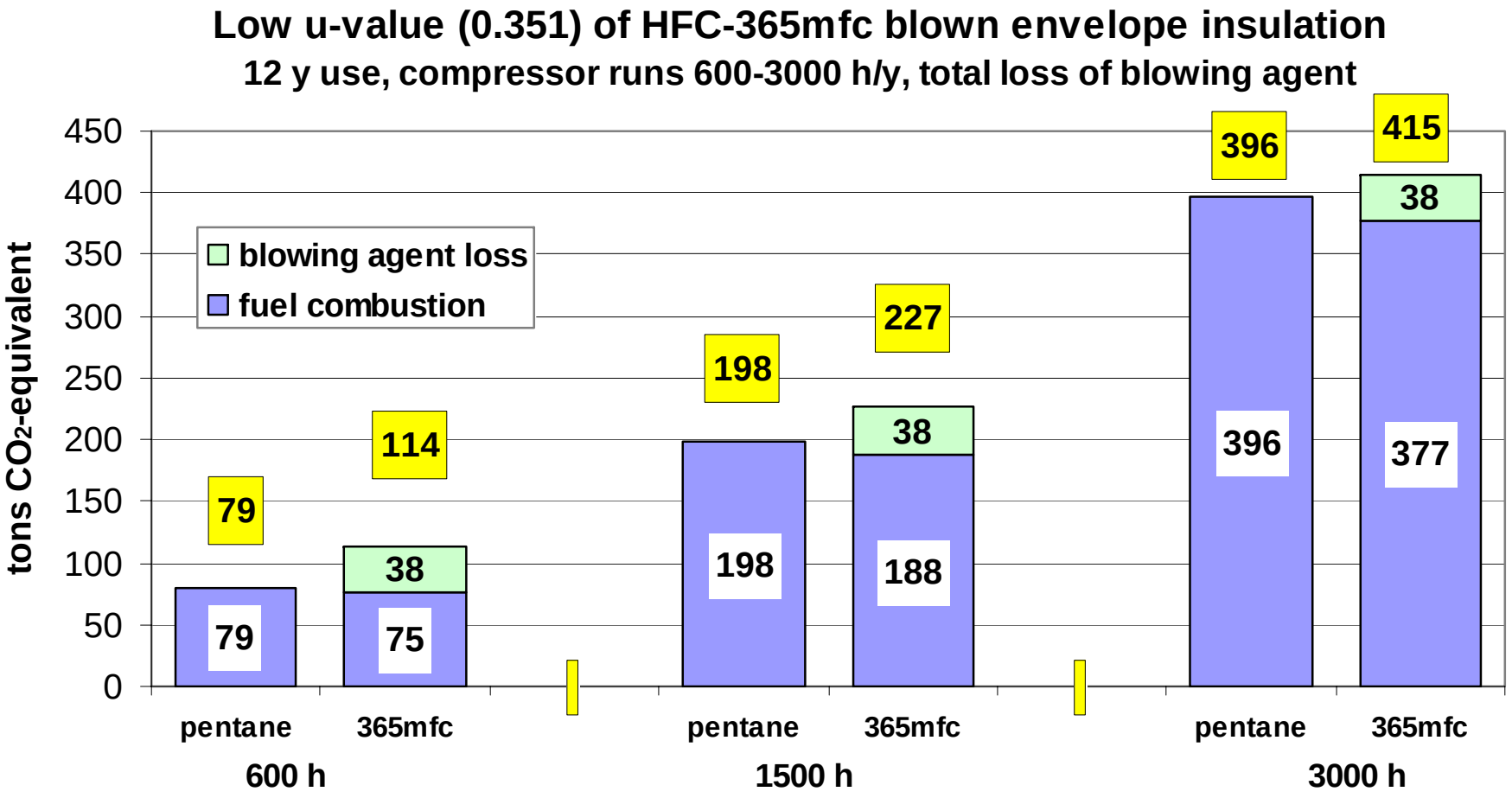
Interim finding

With the given boundary conditions ...

- **The ecological drawback of HFC insulation decreases in absolute and relative terms, the longer the compressor runs.**
- **However, due to blowing agent loss even in case of extensive running time the equivalent CO_2 emissions remain higher than with pentane.**
- **This would be the case even under the hypothecical assumption that 5% lower λ value could lead to 5% lower u-value of the box.**

Sensitivity analysis II



Higher GHG emissions with HFC even at extremely long run-times (3000 h compressor "on" ~ 9000 h cooling)

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Searching for HFC GHG optimum

Today's disposal reality

- Export of used vehicles to Middle East, Middle Asia

Future disposal reality

- Incineration of the foam with previous HFC dismantling losses below 30% of the remainder (optimum 10%).

Usage	Blowing	Assembly	Diffusion	Rest at decomissioning
12 years	10%	1.0%	0.1%/y	87.8%

Today's manufacturing reality

- Blowing emissions of 10% of HFC input

Future manufacturing reality

- Blowing emissions down to 5% of HFC input

Scenario „HFC Optimum" ➡

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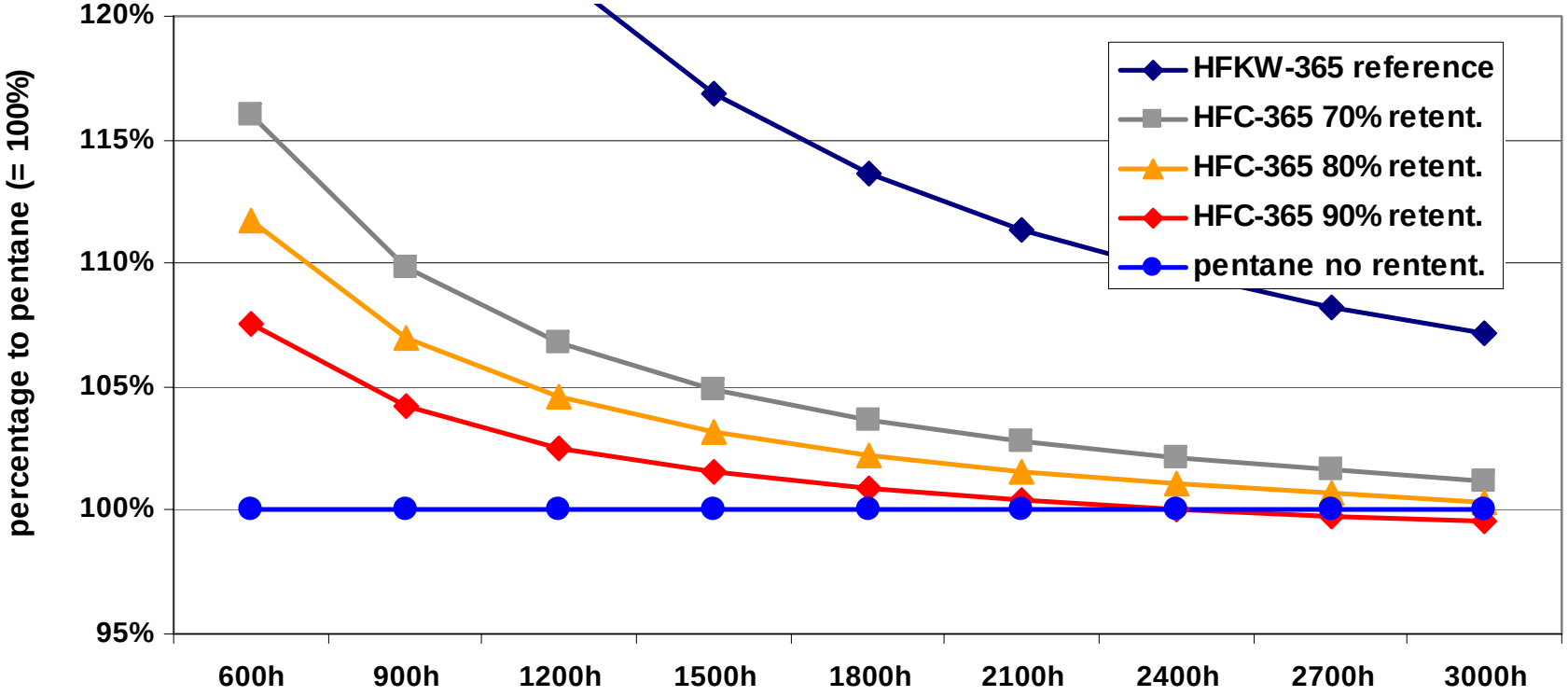
HFC optimum scenario I

HFC-caused GHG emissions under variation of recovery at disposal and annual run-time, in percent of pentane-caused GHG emissions



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At 90% recovery ....

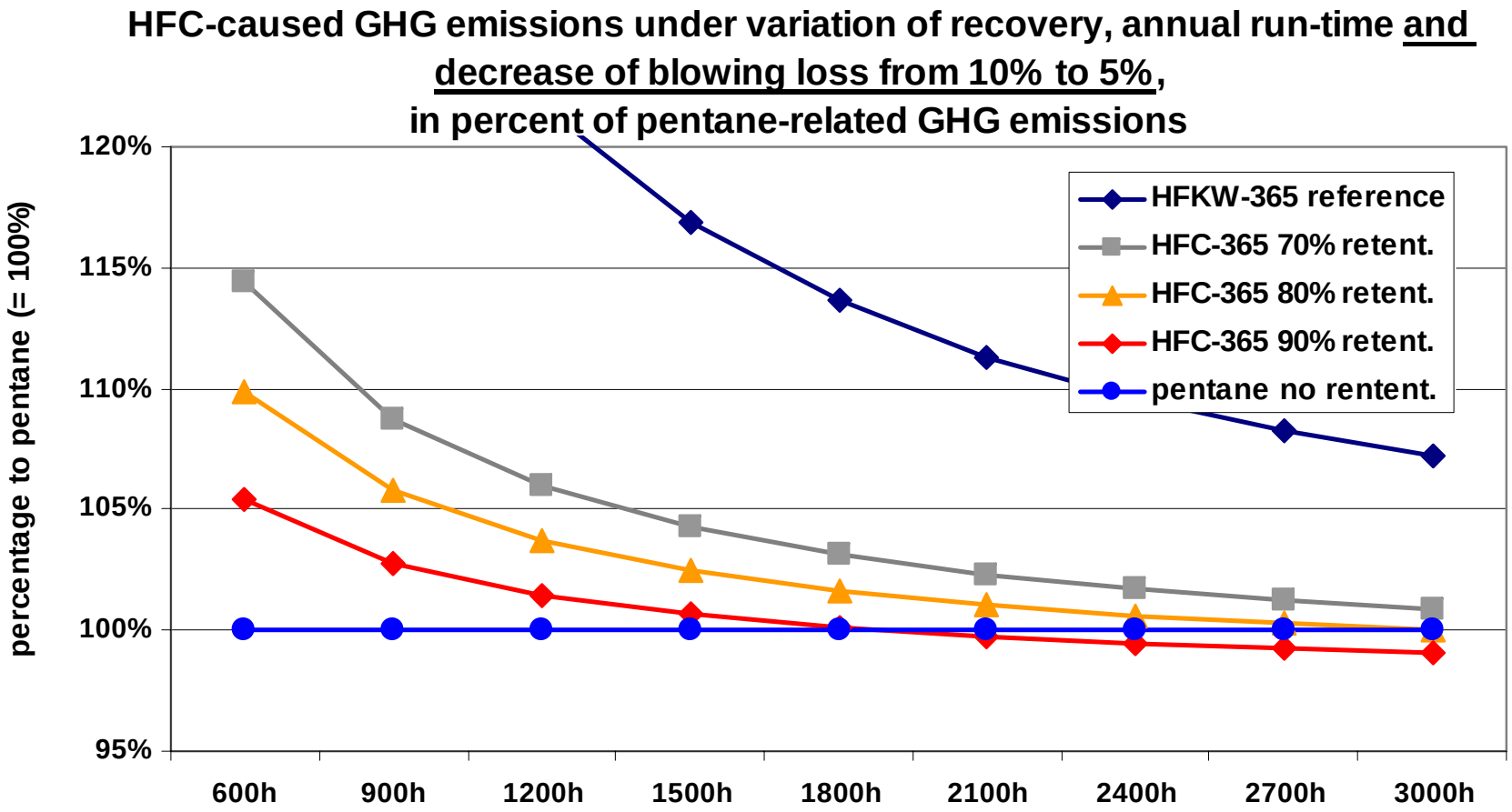
The total GHG emissions from refrigerated vehicles with HFC-blown insulation remain basically higher than with pentane.

However, beyond 2,100 h/y running time of the compressor, the emissions of the HFC case are equal to those of the pentane case,

if a recovery rate of 90% is assumed for the remaining blowing agent at end-of-live.

Manufacturing (blowing) emissions of 10% have not yet been changed.

Optimum conditions for HFC II



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High recovery at end-of-live and low manufacturing emissions ...

- At 1,800 h/y running time of the compressor the emissions in the HFC case are equal to those in the pentane case.
- Beyond 1,800 h/y running time, GHG emissions from the HFC case even slightly underpass those from the pentane case.
- Prerequisite: High recovery of 90% on disposal and low blowing loss of 5% on manufacturing.
- 80% recovery is not enough.

A look at manufacturing cost

Common basis:

Annual output of refrigerated vehicles : 1,500 semitrailers.

PU foam produced: 750 tons/y.

C-pentane:

Blowing agent: 17.6 kg/vehicle = 26,355 kg/y. Price per kg: EUR 1.00. Pentane cost per year = EUR 26,355.

Investment cost (because of flammability): EUR 1.5 million. Discount rate: 4%. Depreciation period: 10 years. Annualised investment cost: EUR 184,936.

Total annual cost of blowing agent: EUR 211,291

HFC-365mfc:

Blowing agent: 43.1 kg/vehicle = 64,650 kg/y. Price per kg: EUR 6.00.

Total annual cost of blowing agent: EUR 387,900

[For HFC-365mfc no switch-over cost is considered.]

Summary

In the example of refrigerated vehicles with rigorous limitation of foam thickness it was shown:

The differences with respect to global warming are not very high, and are dominated by CO_2 emissions from fuel combustion. This leads to a principle finanancial bonus to operators using better insulation (HFC-blown).

Looking closer from a global warming perspecive, the GHG balance is basically in favour of c-pentane. Additionally, the manufacturing cost is lower.

Only at very extensive running times of the refrigeration unit, HFC can be equivalent to pentane at all, on condition that strong efforts are made to enhance the recovery of blowing agents at end-of-live, and to lower HFC manufacturing emissions.

Thanks for your attention

"Risks and Benefits of fluorinated Greenhouse Gases in Techniques and Products under Special Consideration of the Properties Intrinsic to the Substance"

The study will be available for download soon: www.umweltbundesamt.de