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sustainable flame retardants

Life Cycle Costing & Environmental Impact Considerations

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This activity has received funding from the European Institute of Innovation and Technology (EIT), a body of the European Union, under the Horizon 2020, the EU Framework Programme for Research and Innovation

Online 16 December 2020

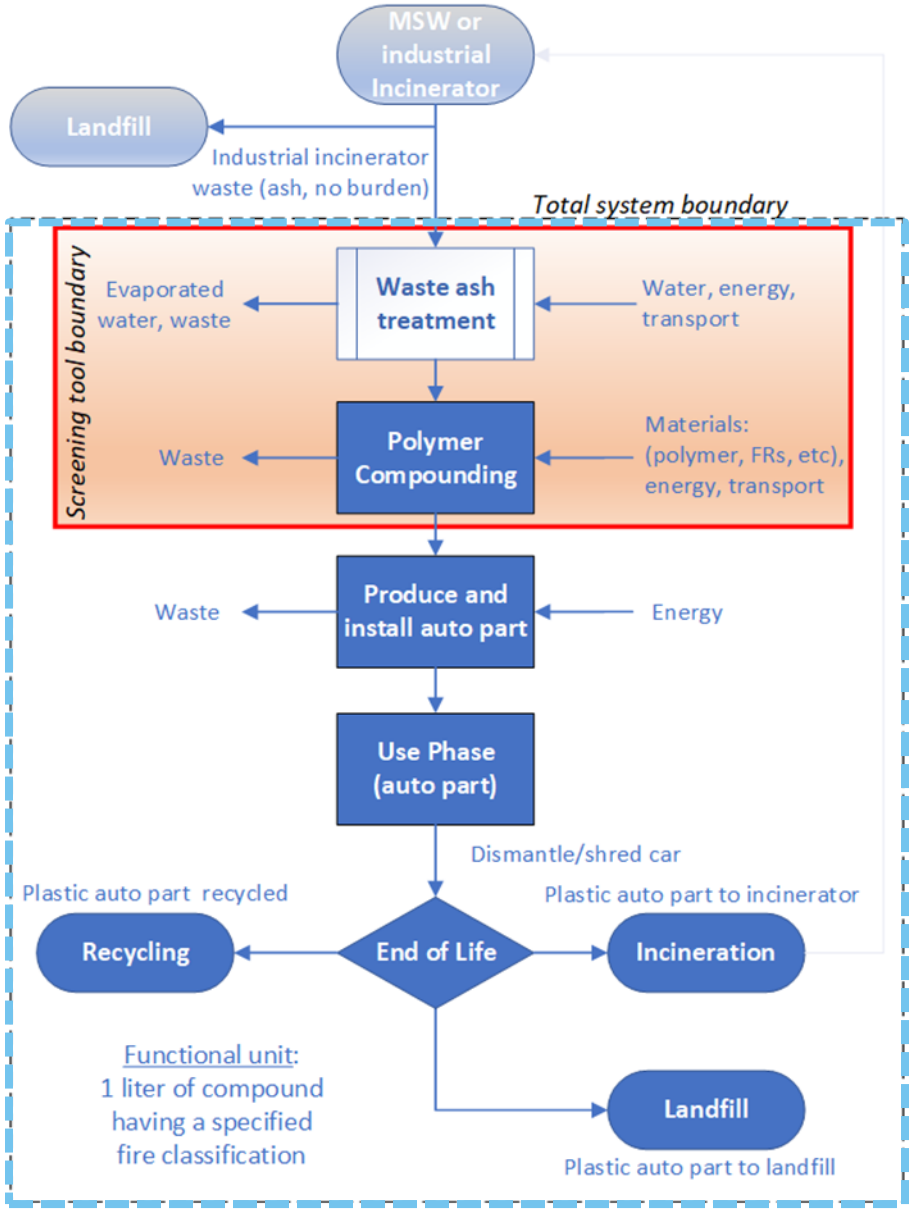
Approach

First, screening tools to help develop formulations

- Life Cycle Costing (LCC) tool for screening costs
- Life Cycle Assessment (LCA) tool for screening environmental impacts
- Cradle to compounder‘s gate
- Compound manufacturer‘s perspective
- Comparisons with common reference compounds

Second, full LCCs and LCAs of selected solutions

- Includes screening tool results, production of a part, use phase, and end-of-life phase
- Cradle to grave
- Consumer‘s perspective



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LCC screening tool

- Screening tool is divided into 4 sections
  - Production and consumption quantities
  - Costs
  - Present Value
  - Results
- Limited selection of costs were included
  - Materials, transport of materials, pre-treatment of materials
- Other costs were assumed to be the same for all compounds, so were set to = 0
- 10 year analysis period, 43 000 tons of compound/year, 5 % discount rate
- Results in €/kg and €/litre

	Compound Name:	Blank		
Section 1: Production and consumption quantities				
Processing quantities	Material 1		fraction of material in compound	Note: transport distances/costs are not necessary if they are already included in the material cost.
	Material 2			
	Material 3			
	Material 4			
	Material 5			
	Material 6			
	Material 7			
	Material 8			
	Electricity		kWh/t	
	Fresh water		m3/t	/t indicates quantity per ton of full compound
	Wastewater		m3/t	
	Production waste		t/t	
	Compound density		kg/liter	
Transport distance	Material 1		km	
	Material 2		km	
	Material 3		km	
	Material 4		km	
	Material 5		km	
	Material 6		km	
	Material 7		km	
	Material 8		km	
Personnel	Work effort		h/t	
Maintenance	MTBF		h/failure	
	Work effort		h/failure	
	Time in operation		h/yr	
Storage	Finished goods		t/yr	
	Interest rate		%	
Equipment	Utilities for compound		%	
	Rent for compound		%	
	Service life		yr	
Total compound production			t	
Analysis Period			yr	

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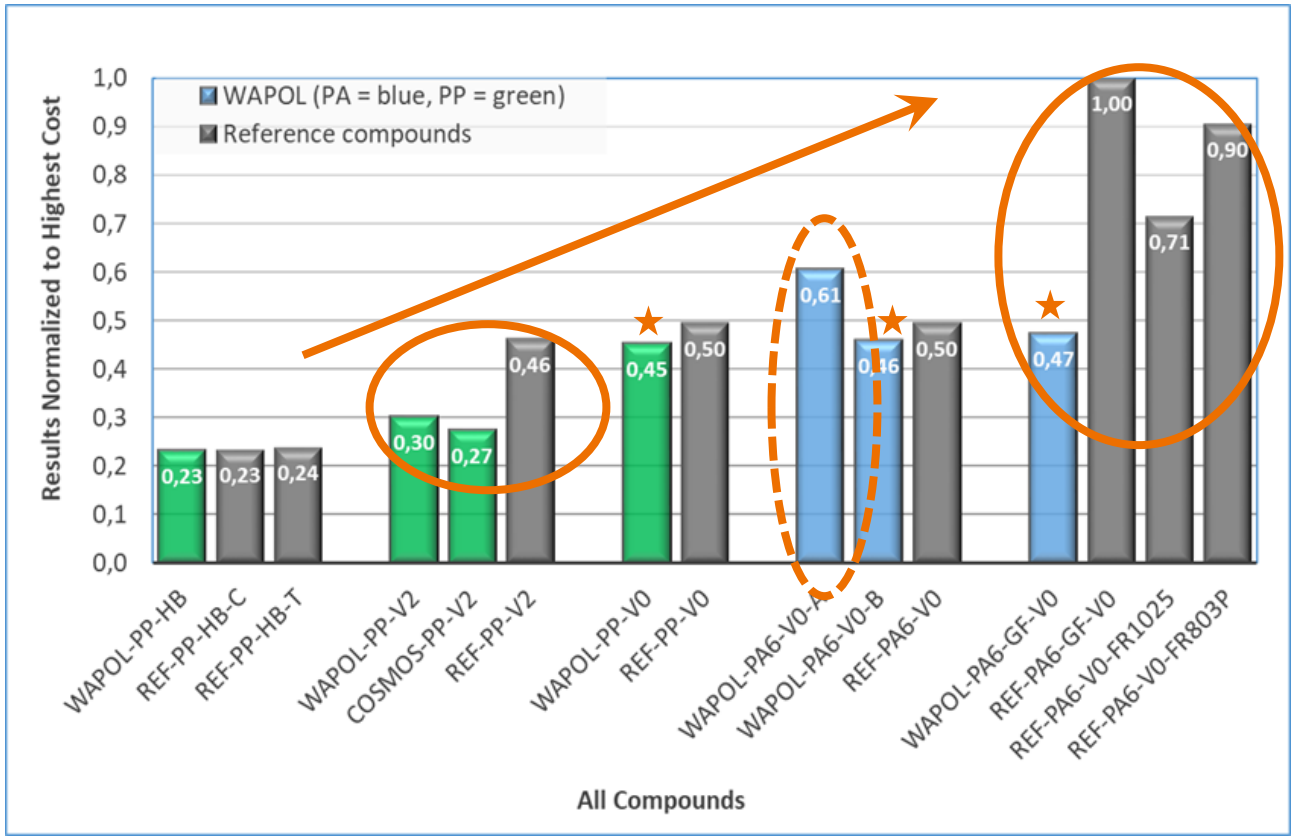
LCC screening results

- The WAPOL results are less than or equal to their reference compounds, except WAPOL-PA6-V0-A.
- Best cost savings are for the PP-V2 and PA6-GF-V0 comparisons.
- General trend toward higher cost with higher UL94 rating.
- The results for WAPOL-PP-V0, WAPOL-PA6-V0-B and WAPOL-PA6-GF-V0 are nearly the same. Consider other factors such as strength, weight, or environmental impact for decisions.



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LCA screening tool

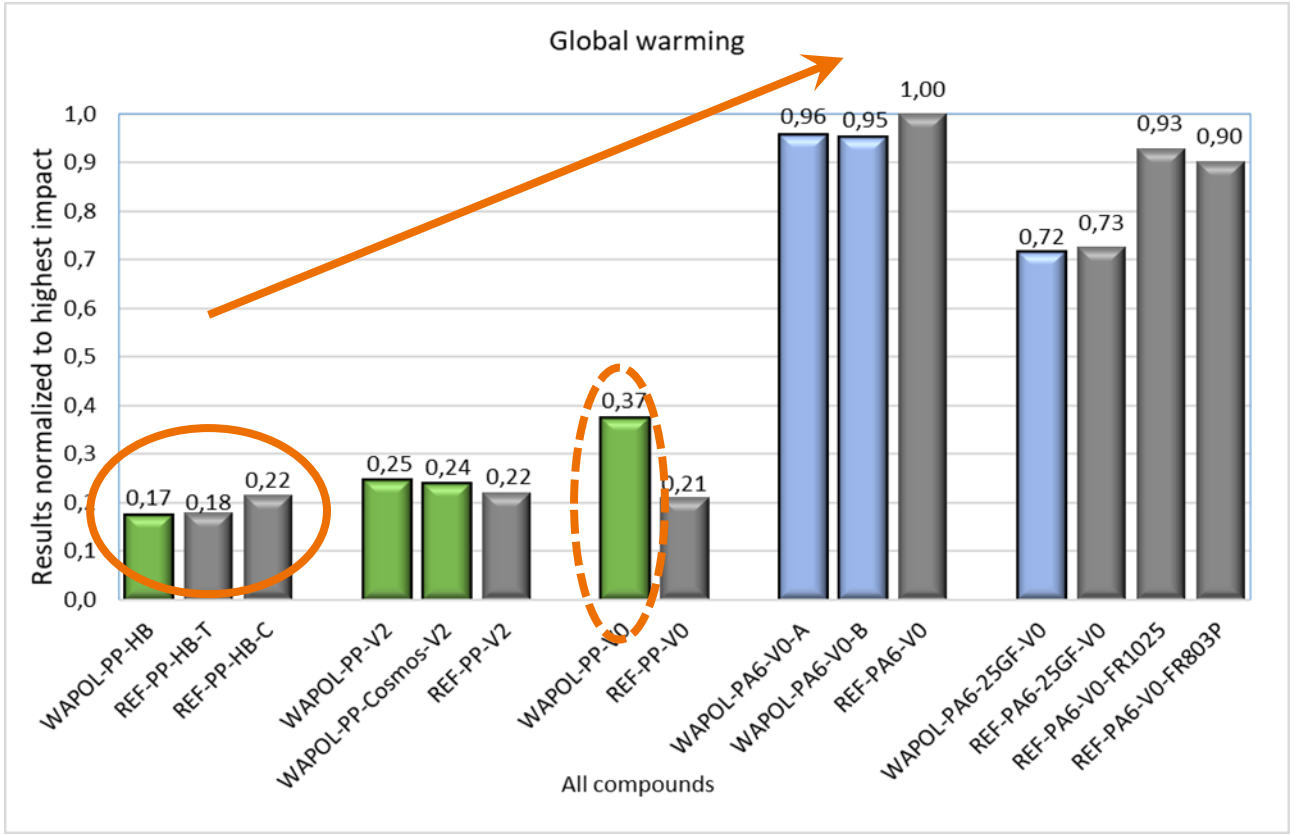
- Identity of materials and quantities concealed for confidentiality reasons
  - One (trusted) person uses tool at request from partners

- LCA results are from SimaPro software and Ecoinvent database, based on 1 kg of material
  - Tool calculates impacts from input of materials and quantities

Product	PP	Mat B	Mat D	Mat E	Mat G	AP766	Mat H	Mat A	Mat J
WAPOL-PP-HB	XX	X							
WAPOL-PP-V2	XX								
WAPOL-PP-V0	XX			X					X
REF-PP-HB	XX								X
REF-PP-V2	XX	X							
REF-PP-V0	XX						X		
WAPOL-PP_Cosmos-V2	XX			X					

LCA screening results

- Impact categories:
  - Fine particulate matter formation
  - Fossil resource scarcity
  - Freshwater ecotoxicity
  - Global warming
  - Mineral resource scarcity
  - Terrestrial ecotoxicity
- General trend toward higher cost with higher UL94 rating.
- WAPOL-PP-HB compound has the lowest, or nearly lowest, impacts in all categories.
- WAPOL-PP-V0 compound always has higher impacts than other PP-based compounds (both WAPOL and reference).



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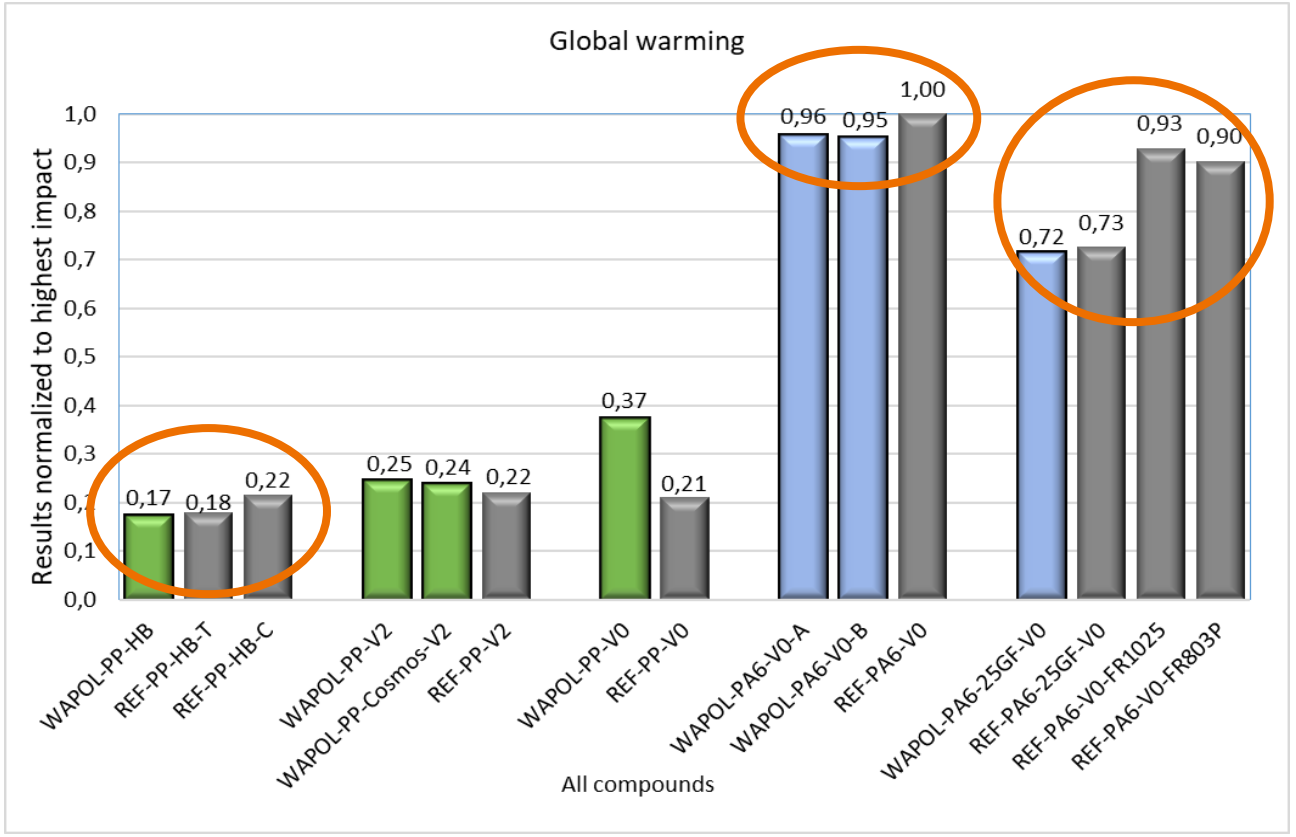
LCA screening results

- ATO/bromine reference compounds (REF-PA6-V0-FR1025 and -FR803P) impacts are high, usually highest.
- PA-based compounds have higher impacts than PP-based compounds in fossil resource scarcity and global warming.
- WAPOL-PA6-V0-A and -B impacts are consistently lower than their references.



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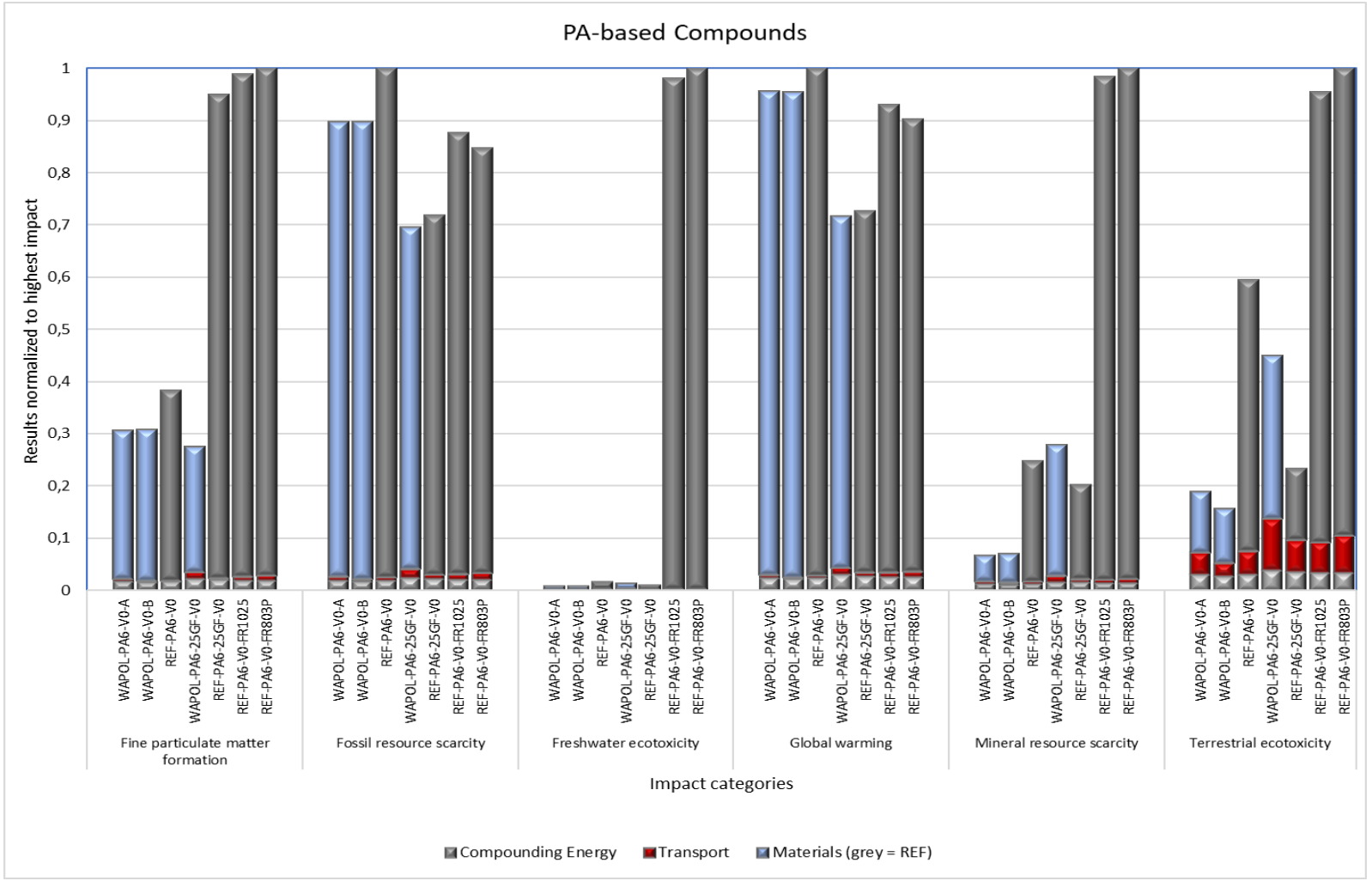
LCA screening results

- Results are similar for PP-based compounds
- Materials have the highest impacts
- Low sensitivity to compounding energy and transport distance



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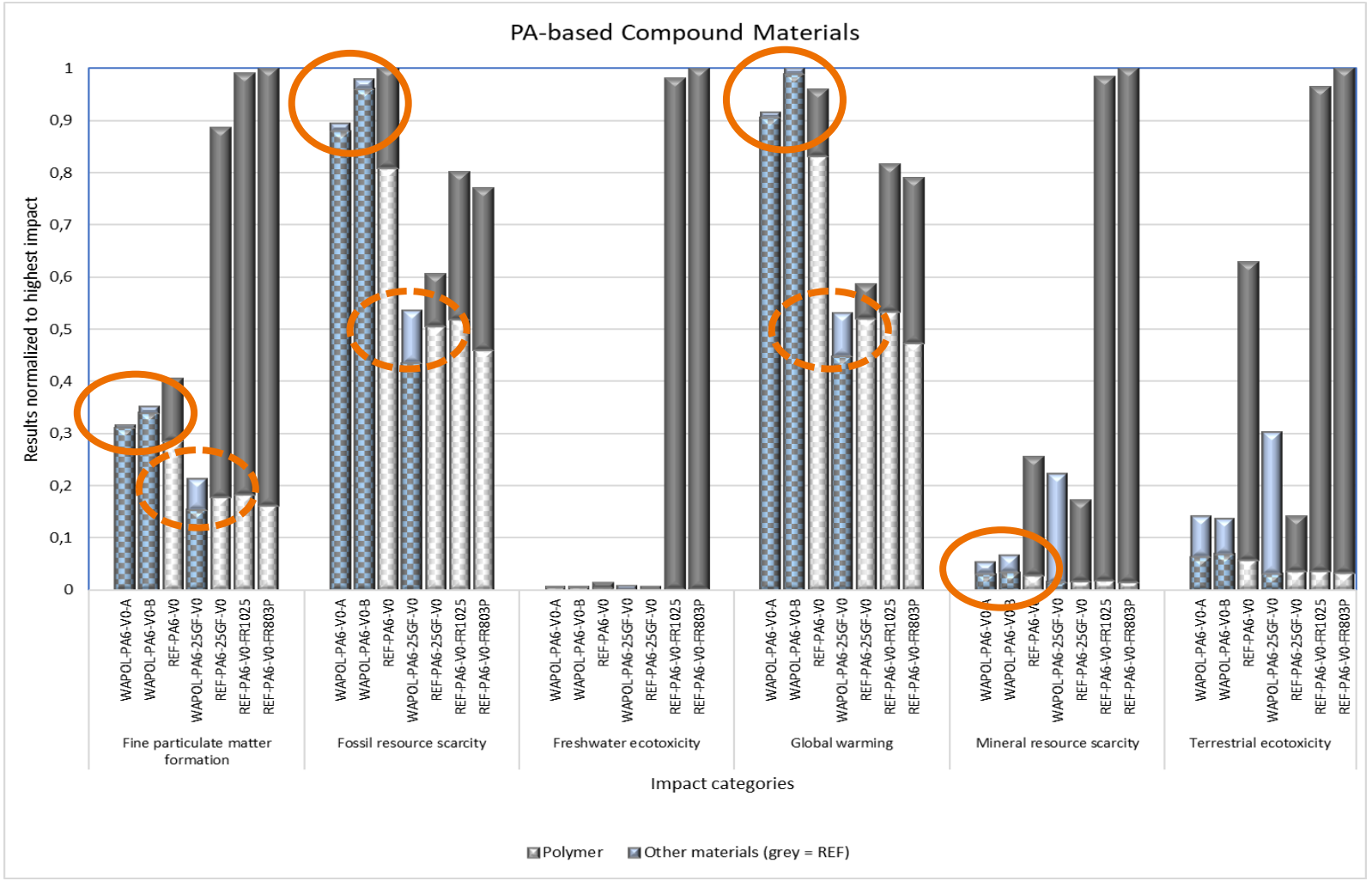
LCA screening results

- Results are similar for PP-based compounds
- Base polymer (checkered bars) has higher impacts than FR/other materials (solid bars) in fossil resource scarcity and global warming.
- ATO/bromine compounds have very high impacts in most categories.
- WAPOL-PA6-V0 compounds have low impacts for FRs
- WAPOL-PA6-25GF-V0 has low impacts in 3 categories



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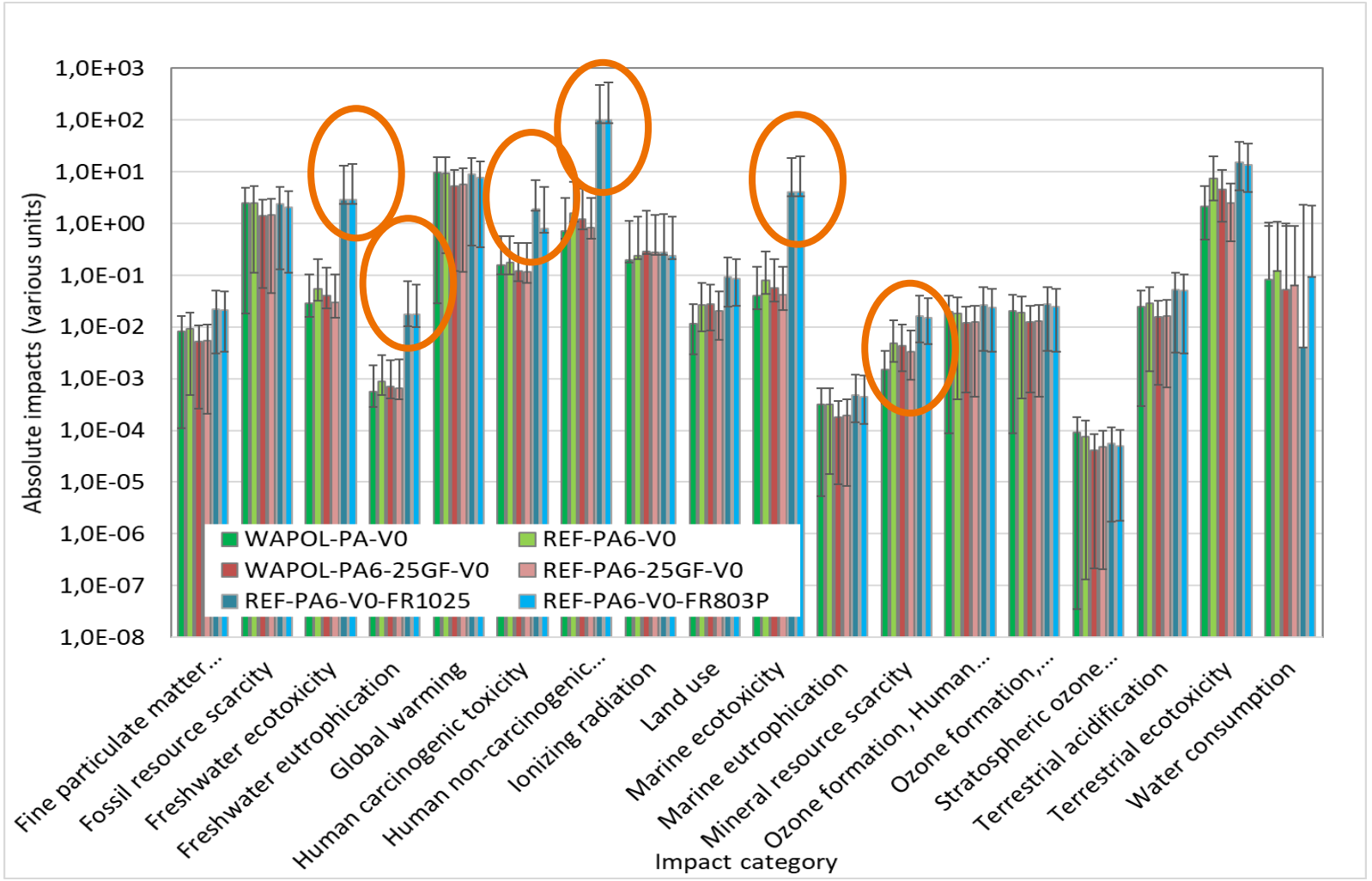
LCA screening results

- Results are similar for PP-based compounds
- Uncertainty based on variations of model input data only.
- Monte Carlo analysis with 95 % confidence interval, 1000 iterations
- All impact categories considered
- WAPOL compounds have less impact than ATO/Br compounds in 6 categories



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Overall conclusions

- ***The WAPOL-PP-HB compound is both inexpensive and has low environmental impacts across all categories***
  - This could be important if there are choices to be made about the targeted UL94 fire performance rating.

- ***There is only one case where the LCC for a WAPOL compound (WAPOL-PA6-V0-A) is higher than its reference compound***
  - In all other comparisons the WAPOL compound LCC results are lower or equal to their reference compounds.

- ***The WAPOL-PA6-V0-A and -B environmental impacts are consistently lower than those of their reference compounds, sometimes by a wide margin.***
  - ***This indicates that the WAPOL-PA6-V0-B compound is beneficial from both a cost and environmental perspective.***

Overall conclusions

- ***The LCC results for WAPOL-PP-V0, WAPOL-PA6-V0-B and WAPOL-PA6-GF-V0 are nearly the same and the LCA results for these compounds are mixed***
  - Therefore, the results in the impact categories that are most important to the compound developers would guide the decisions regarding which compounds to produce if there are no other important non-cost or non-environmental factors to consider.

- Both the LCC and the LCA model results are sensitive to the cost and amount of materials used in the compounds and, to a much lesser extent, sensitive to the compounding cost and energy required.

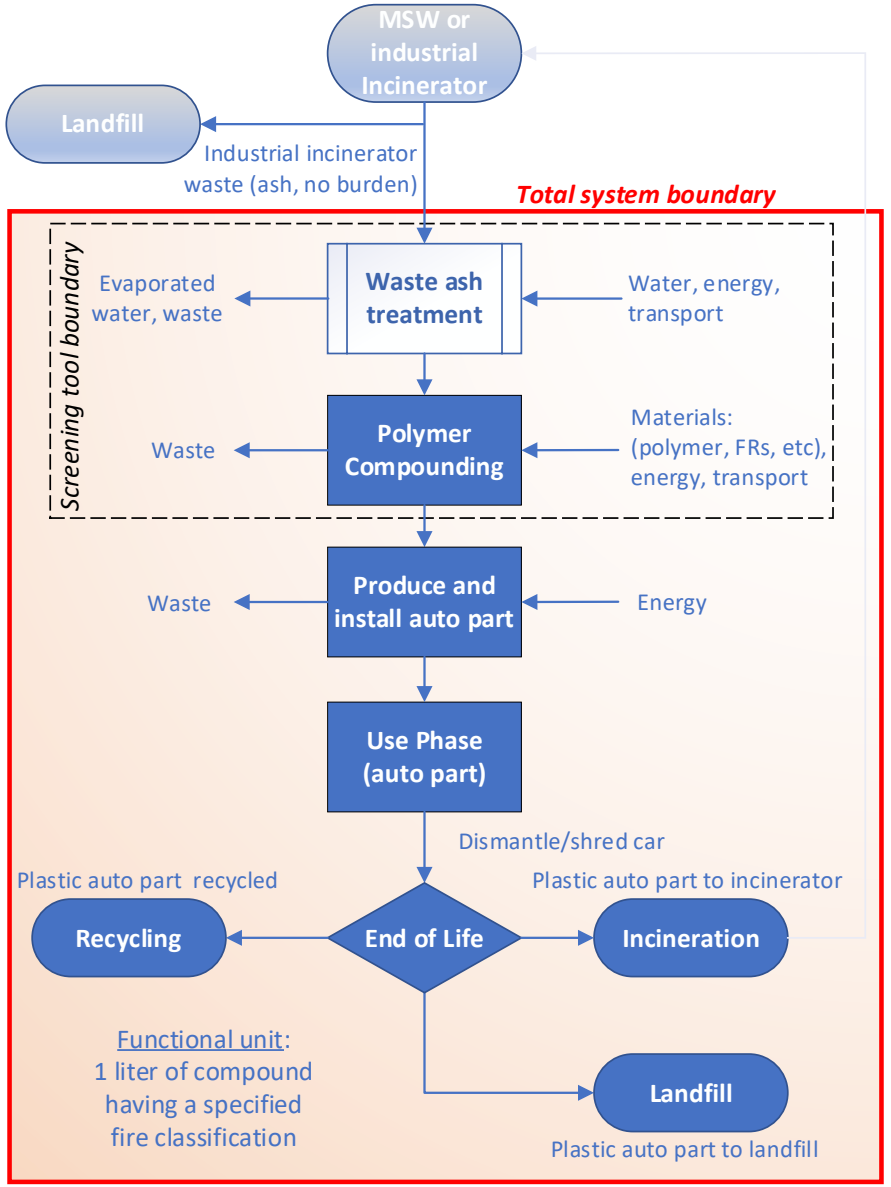
- ***The uncertainties in the LCA analysis indicate that the WAPOL compounds have lower environmental impacts than the ATO/Br compounds in 6 categories***

Step 2: Full Life Cycle Analyses of End Products

- Full LCCs and LCAs (cradle to grave)
- Results are presented for PA6 and REF-PA66 compounds

Assumptions

- Producing the part- the new and reference parts have the same densities, so the weight of the part doesn‘t change. Production equipment doesn‘t change
- Owning & maintaining the part in the vehicle (use phase)- the fuel efficiency and emissions from the vehicle don‘t change, all parts have the same service life (100 000 km), so the use phase doesn’t change
- Disposing of the part (end-of-life phase)- the parts will go to landfill, incineration at cement kiln, incineration with energy recovery, or recycling at end of life. There is no cost to the consumer at end of life



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Life Cycle Costing Comparisons

- Compound cost
  - Includes materials, transport of materials, energy to pre-treat materials and make compounds. Does not include other costs (no total compounding costs reported)
- Production cost
  - Includes transport of compounds and part manufacturing
- Use phase costs
  - Includes estimated fuel cost for 100 000 km, allocated to part by weight
- End of life costs
  - Assumed to be 0 € to the consumer

Vehicle specifications

- Vehicle that will receive the part(s) (Fiat Panda or similar)

Fiat Panda characteristics	
Weight [kg]	1055
Fuel type	Petrol
Combined cycle fuel consumption [l/100 km]	5.7 – 4.9
Carbon dioxide emission [g/km]	131 -111

- Average emissions per km (Alpha Guiletta, CRF 2020)

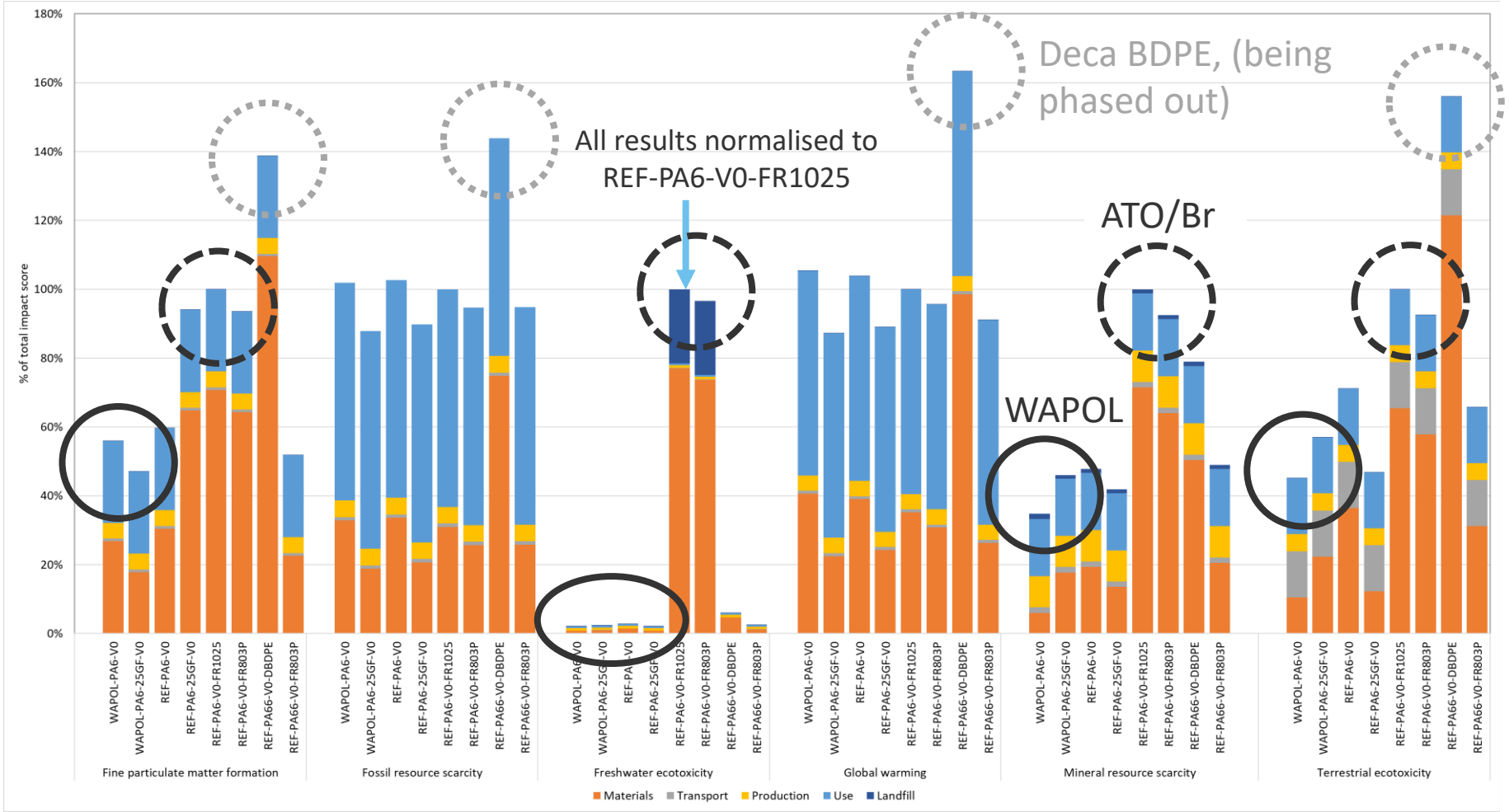
	Total hydrocarbons [THC] [mg/km]	Carbon monoxide [CO] [mg/km]	Carbon dioxide [CO_2] [g/km]	Nitrogen oxides [NO_x] [mg/km]	Particulate Matter [PM] [mg/km]
Average values	20	352	186.3	48	0.52

LCC Results- total cost of using the vehicle

Compound Name	Compound cost [€/kg]	Production cost [€/kg]	Use cost [€/kg]	Total LCC [€/kg]
WAPOL-PA6-V0	1,8	2,8	5,8	10,4
WAPOL-PA6-25GF-V0	1,4	2,8	5,8	10,0
REF-PA6-V0	2,2	2,8	5,8	10,8
REF-PA6-25-GF-V0	2,9	2,8	5,8	11,5
REF-PA6-V0 FR-1025	2,7	2,8	5,8	11,3
REF-PA6-V0 FR-803P	2,6	2,8	5,8	11,2
REF-PA66-V0 FR-803P	2,9	2,8	5,8	11,5
REF-PA66-V0-DBDPE	2,8	2,8	5,8	11,4

Assumed to be the same for all parts

LCA Results- Landfill as End-of-Life Scenario



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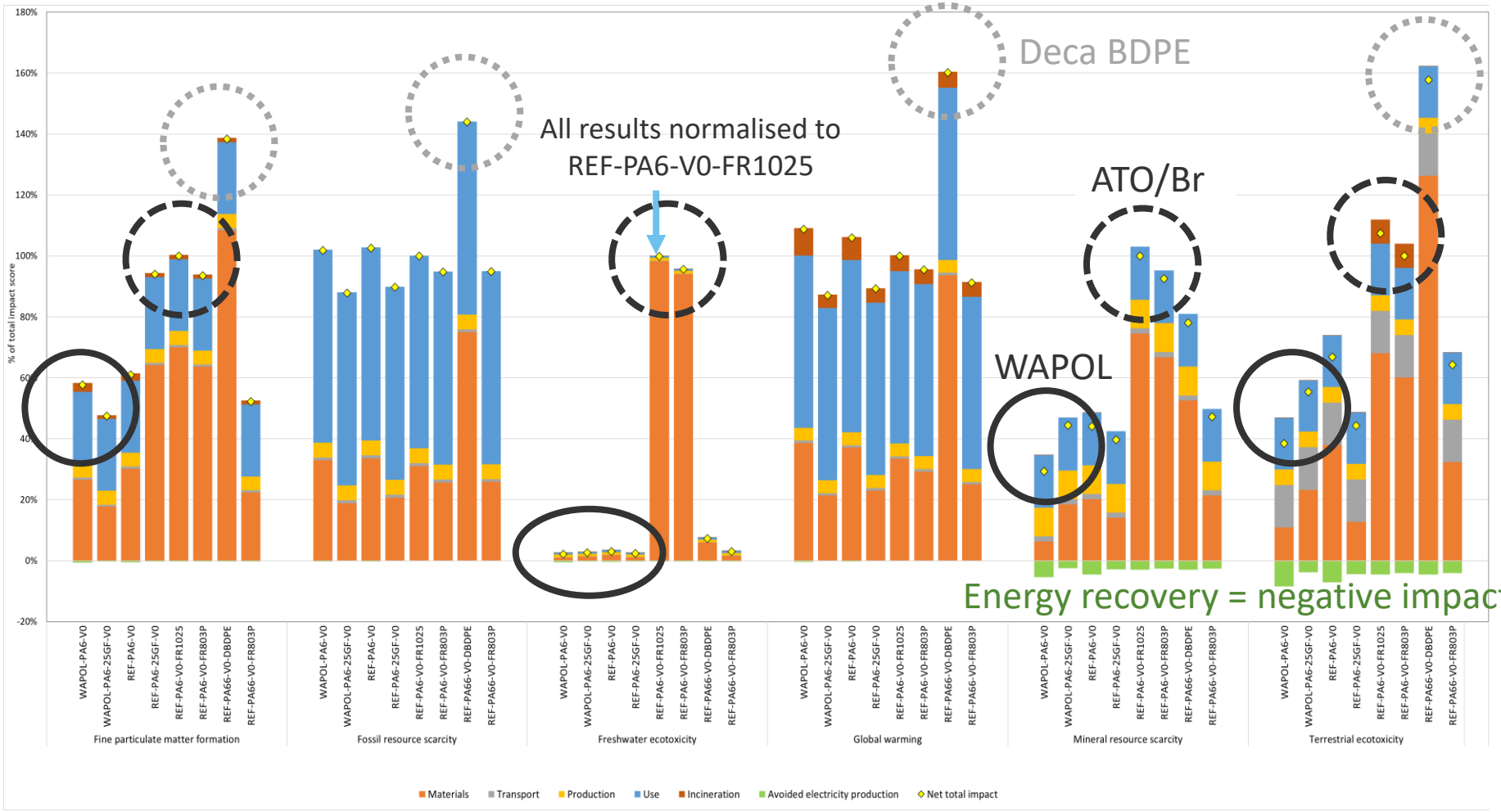
LCA Results- Incineration (waste to energy plant)



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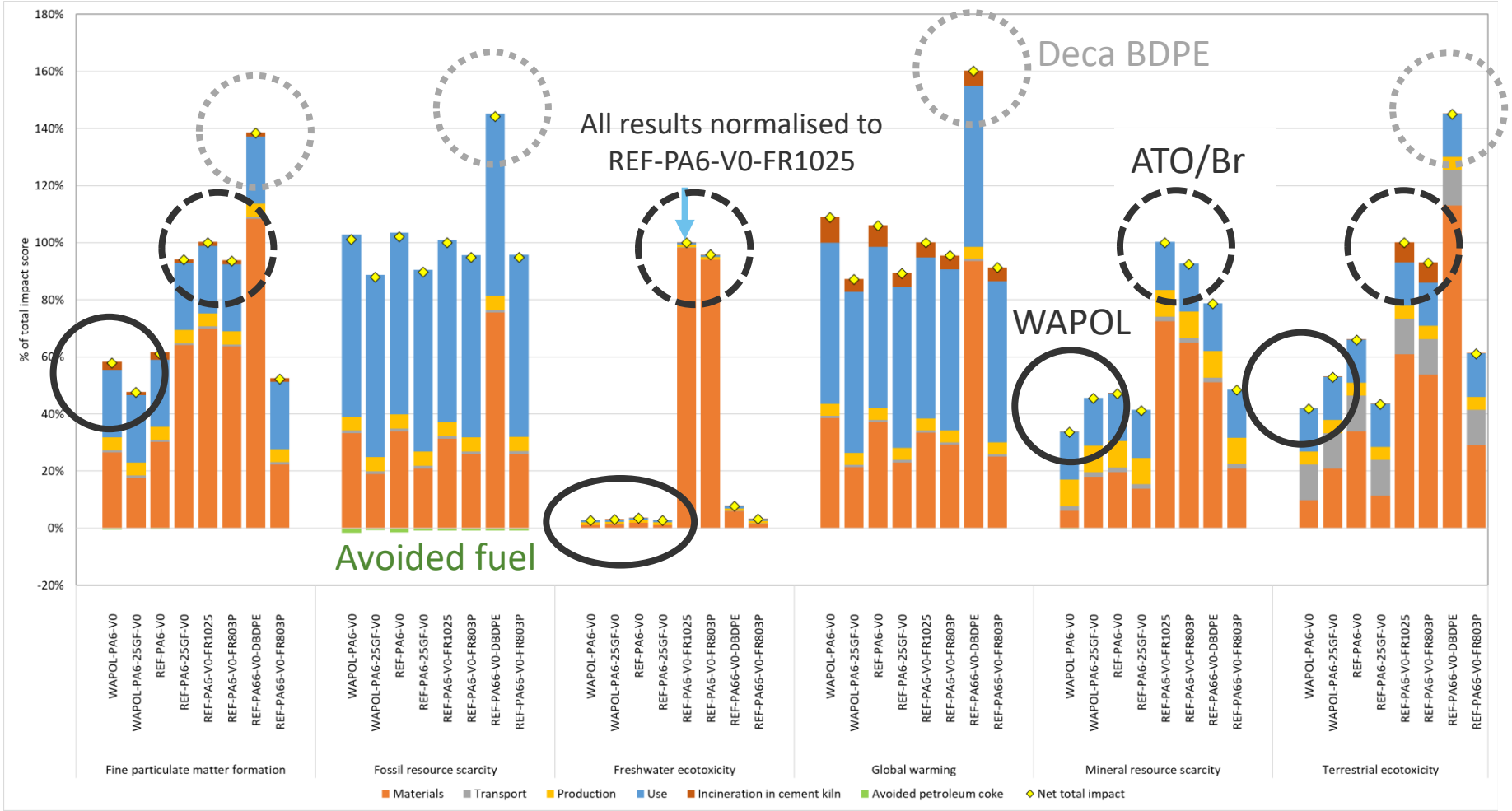
LCA Results- Incineration (in cement kiln, energy recovery)



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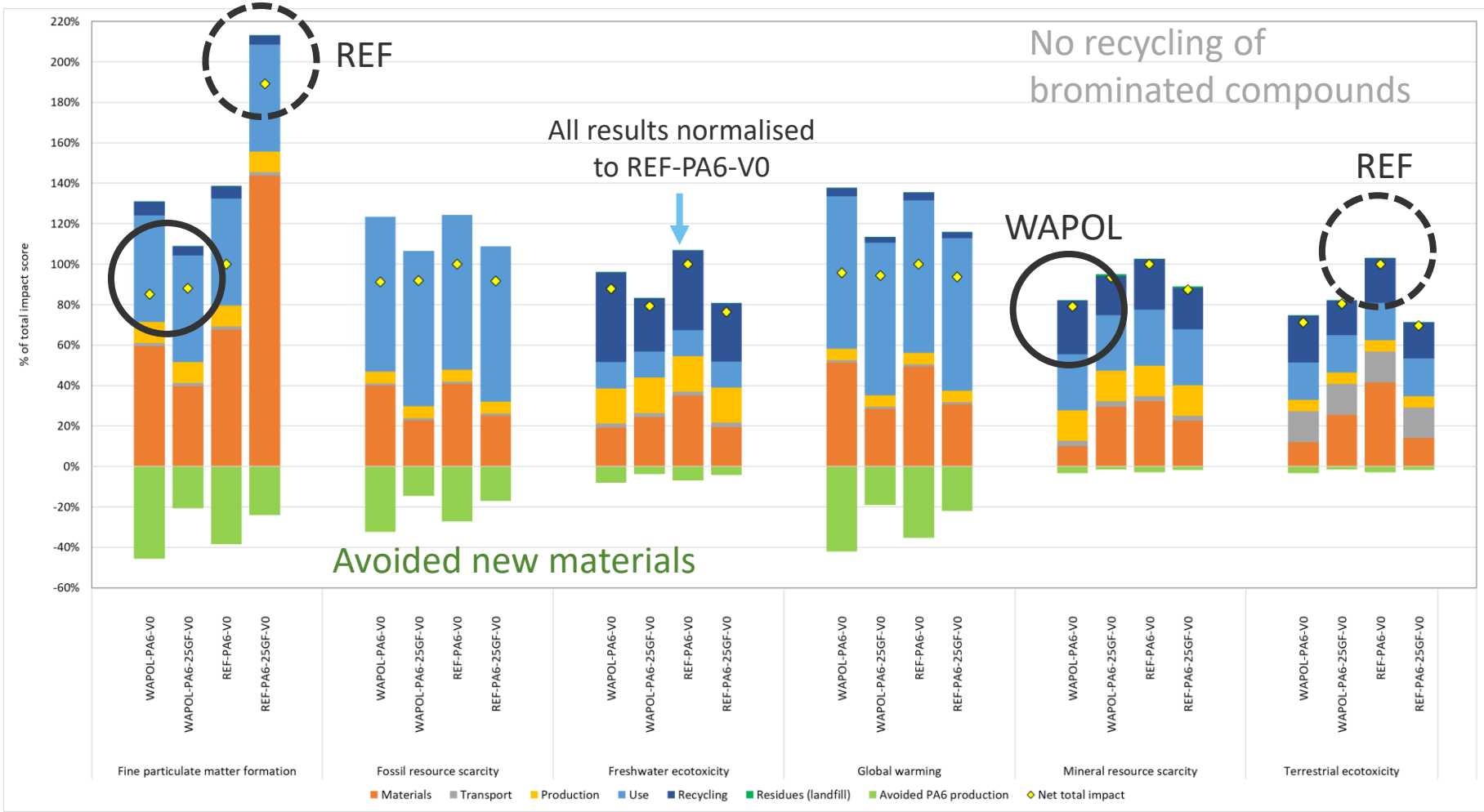
LCA Results- Recycling as End-of-Life Scenario



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Overall conclusions

- The End-of-Life scenario has the only effect on the LCA results
  - The compounds have a large effect on the End-of-Life results

- Either WAPOL-PA6-V0 or WAPOL-PA6-25GF-V0 has the lowest or nearly lowest environmental impact in all impact categories

- REF-PA6-25GF-V0 has the lowest or nearly lowest environmental impact in some categories

- ***The WAPOL compounds <u>generally</u> have slightly better environmental impacts and costs than the REF compounds***

Q & A session

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