

# Workshop: e-Waste Management – Issues & Challenges

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## Recycling of e-waste plastics - Stockholm Convention BAT/BEP Guidance to control PBDEs in plastic

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# Content of Presentation

- Amount of global WEEE plastic and challenge for the management
  - Challenge and risk of hazardous chemicals in circular economy
  - Contamination/dilution by global WEEE plastic recycling
  - Solution 1: Substitution of problematic additives
  - Solution 2: Separation of PBDE/BFR-containing plastic & management
  - Challenges of separation of WEEE plastic in India
  - Solution 3: Thermal treatment of WEEE plastic fraction
- Challenges/option treating WEEE plastic in incinerators & cement kilns.
- Some Conclusions

# Plastic share and volume in WEEE categories

- The average plastic share in WEEE is approximately 20%.
- WEEE by 2019 is about 50 million t/a including 10 mio t/a plastic.

WEEE Category/Product Category		Plastic share [in % by weight]	Annual plastic flow [in t/year]
1	Large household w/o cooling appliances	19%	500'500
1	Cooling and freezing appliances	28%	473'100
2	Small household appliances	37%	369'400
3	ICT equipment w/o screens	42%	317'600
3	Computer screens (CRT and flat)	20%	156'100
4	Consumer equipment w/o screens	24%	180'900
4	TV screens (CRT and flat)	20%	200'100
5	Lighting equipment – Lamps	3%	7'300
6	Electrical and electronic tools	11%	37'800

FR Industry state that the annual recycling potential for FR plastics is roughly 2.7 million tonnes, equaling a business potential of about 8 billion and a potential CO2 reduction of up to 8 million tonnes (EFRA, 2013; Plastic News, 2013).

10	Automatic dispensers	20%	3'500
<b>Total amount</b>		<b>Average of 20%</b>	<b>2'266'100</b>

# Plastic challenge in developing countries

- A large share of plastic fractions (currently) does not have a market.
- Or the plastic is recycled not in environmentally sound manner.



PS, HIPS, PA, PP



PVC and PE



HIPS, ABS, with BFRs



PVC and PE

Source: Haarmann & Gasser (2017)

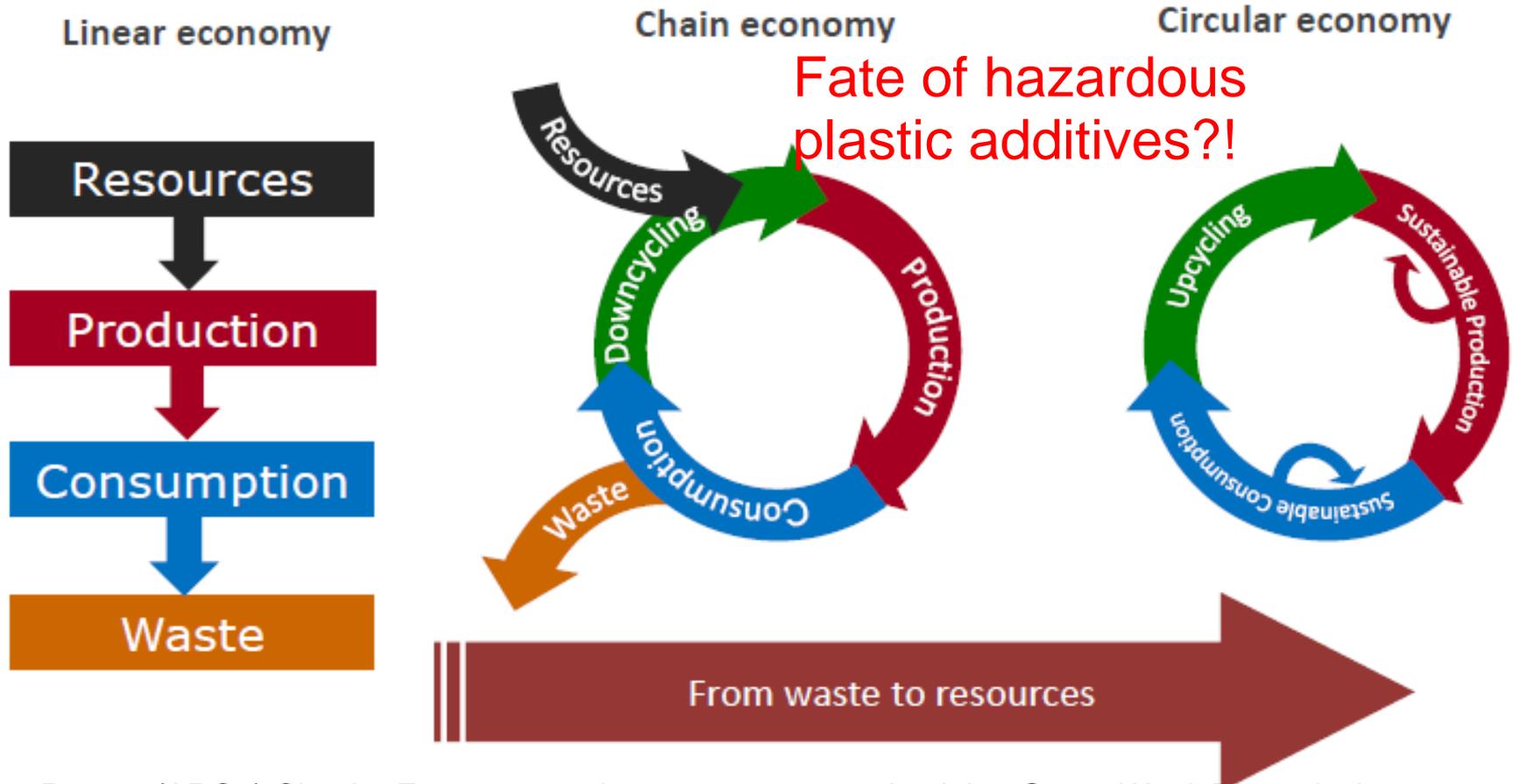


- For a circular economy all major plastic fraction need to be addressed!

# Toxic plastic additives challenging circular economy <sup>5</sup>

EU Circular Economy Strategy (Roadmap 04/2015).

UNIDO and GEF stresses the need for global circular economy.



Bonnet (ARC+) Circular Economy, saving resources, creating jobs, Green Week Brussels June 2014

For moving to a (more) Circular Economy, hazardous chemicals need to be controlled and phased out by non-toxic alternatives.

# PBDE/BFR contamination of recycled plastic!

- High levels of PBDE & PBDD/F in recycled plastic in sensitive uses!
- Risks to human health demonstrated.
- Challenge to control recycling in developing & emerging economies.
- Challenge with low POPs limit – 50 ppm PBDE would stop recycling.



*PBDE in carpet padding (DiGangi et al, OHC , 2011) PBDE in children toys China (Chen et al, ES&T 43, 4200, 2009) PBDE in thermo-cup Samsonek & Puype (2013) Food Add. & Contam. Prof. Miriam Diamond: Salad servers*

⇒ Need of a better life cycle management and control!  
 ⇒ Need of non-toxic alternatives for clean material cycles!!

# Need of non-toxic alternatives for circular economy!

## POP-BFR often substituted by other BFRs

When looking to substitution history of PBDEs we find that often **regrettable alternatives** were chosen which are now also listed as POPs or are of concern.

Polymer	Content [%]	POP-BFRs	Alternative introduced
High impact polystyrene	11–15	OctaBDE	DecaBDE, Br-polystyrene Ethane 1,2 bis(pentabromophenyl)
Epoxy resin	0-10	PentaBDE	TBBPA
Polyamides	13–16	OctaBDE	DecaBDE, Br-polystyrene
Polyolefins	5–8	OctaBDE	DecaBDE, propylene dibromo styrene
Polyurethanes	2-18	PentaBDE	Derivative tetrabromophthalate (TBPH) & 2,3,4,5-tertrabromobenzoate (TBB),
Polyesters	8–11	OctaBDE	Brominated polystyrene
Unsaturated polyesters	13–28	PentaBDE	TBBPA
Polycarbonate	4–6		Brominated polystyrene
Textiles	12–15	PentaBDE	DecaBDE, HBCD

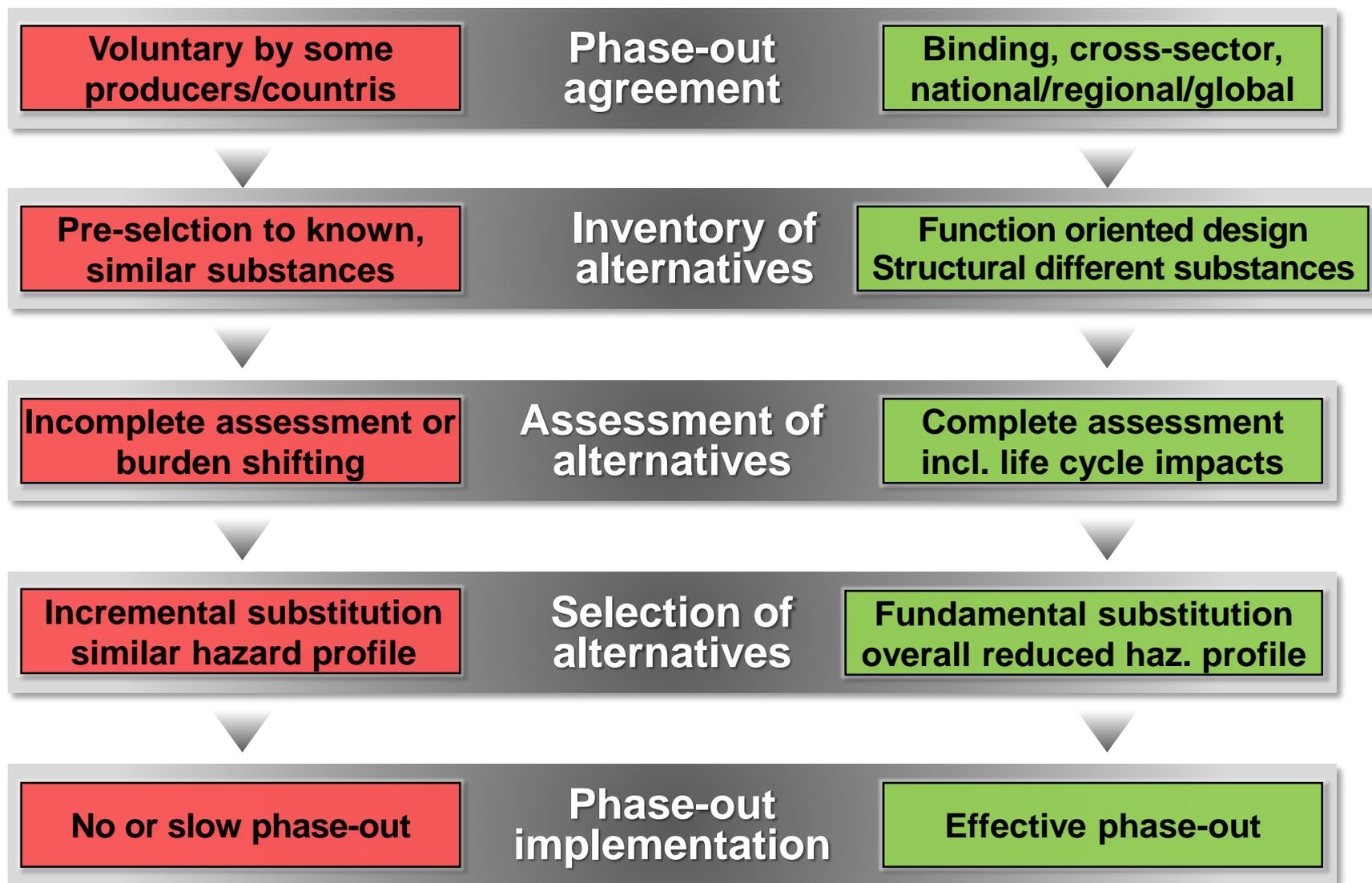
For DecaBDE industry voluntary phase-out was concluded with US EPA – however emerging economies continue production & many exemptions in Stockholm listing.

# Modifications in the substitution approach to achieve a successful phase-out and replacement of hazardous chemical additives

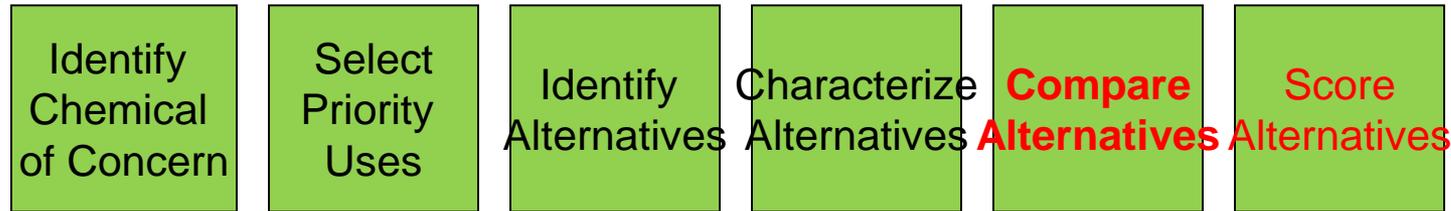
## Current practice

## additives

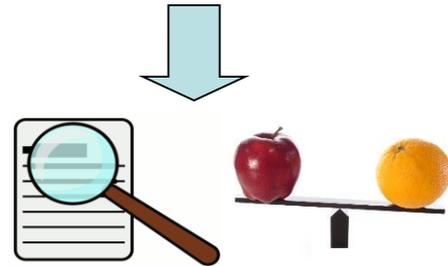
## Recommended practice



# Alternatives Assessment and Available Tools for chemical substitution



**Capacity building needed!**



Compare Alternatives

Compare hazard profiles

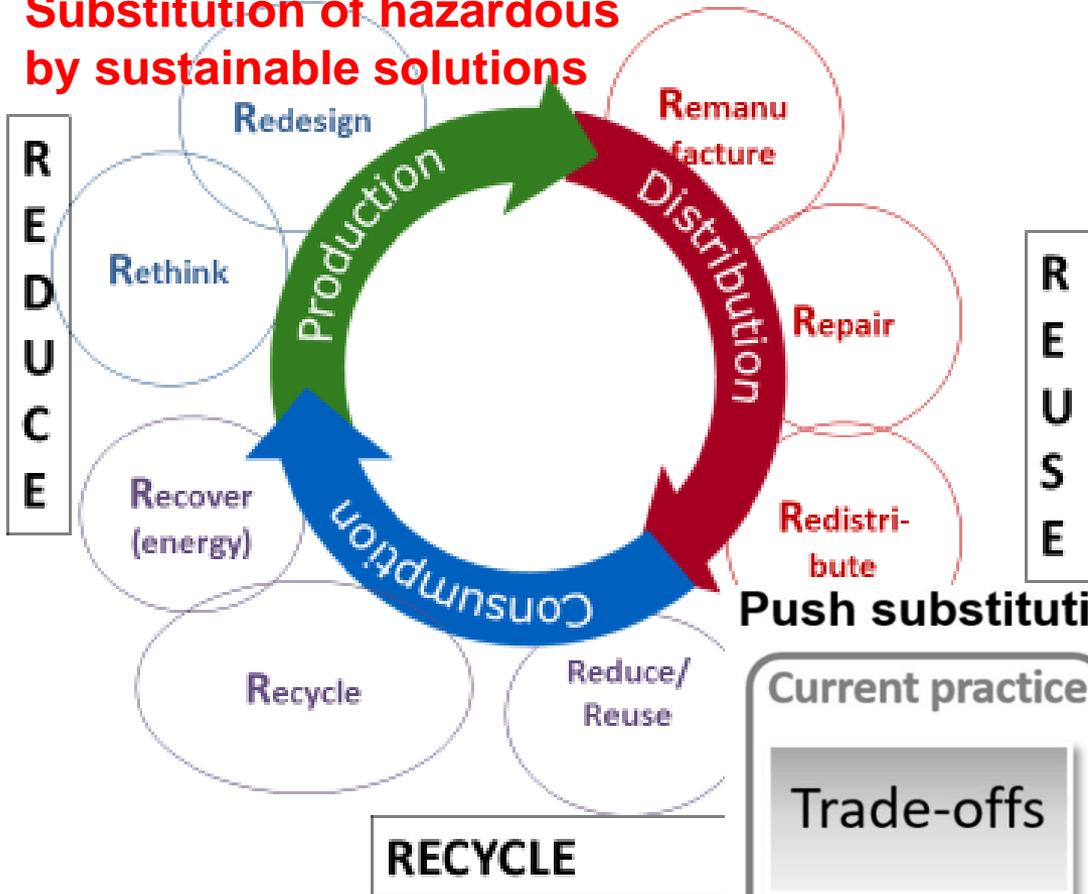
Use available screening tools

TURI's P2OASys  
 CPA's Green Screen  
 HBN's Pharos

GUIDE ON  
**SUSTAINABLE  
 CHEMICALS**

# Push substitution into the product design phase

Substitution of hazardous by sustainable solutions



Push substitution into product design processes

Current practice

Trade-offs

→ Performance needs to be combined with environmental sustainability during design

Qualitative

→ Qualitative metrics need to be replaced by quantitative life cycle-based metrics

Relative

→ Relative improvement needs to be increased to meet targets for sustainability

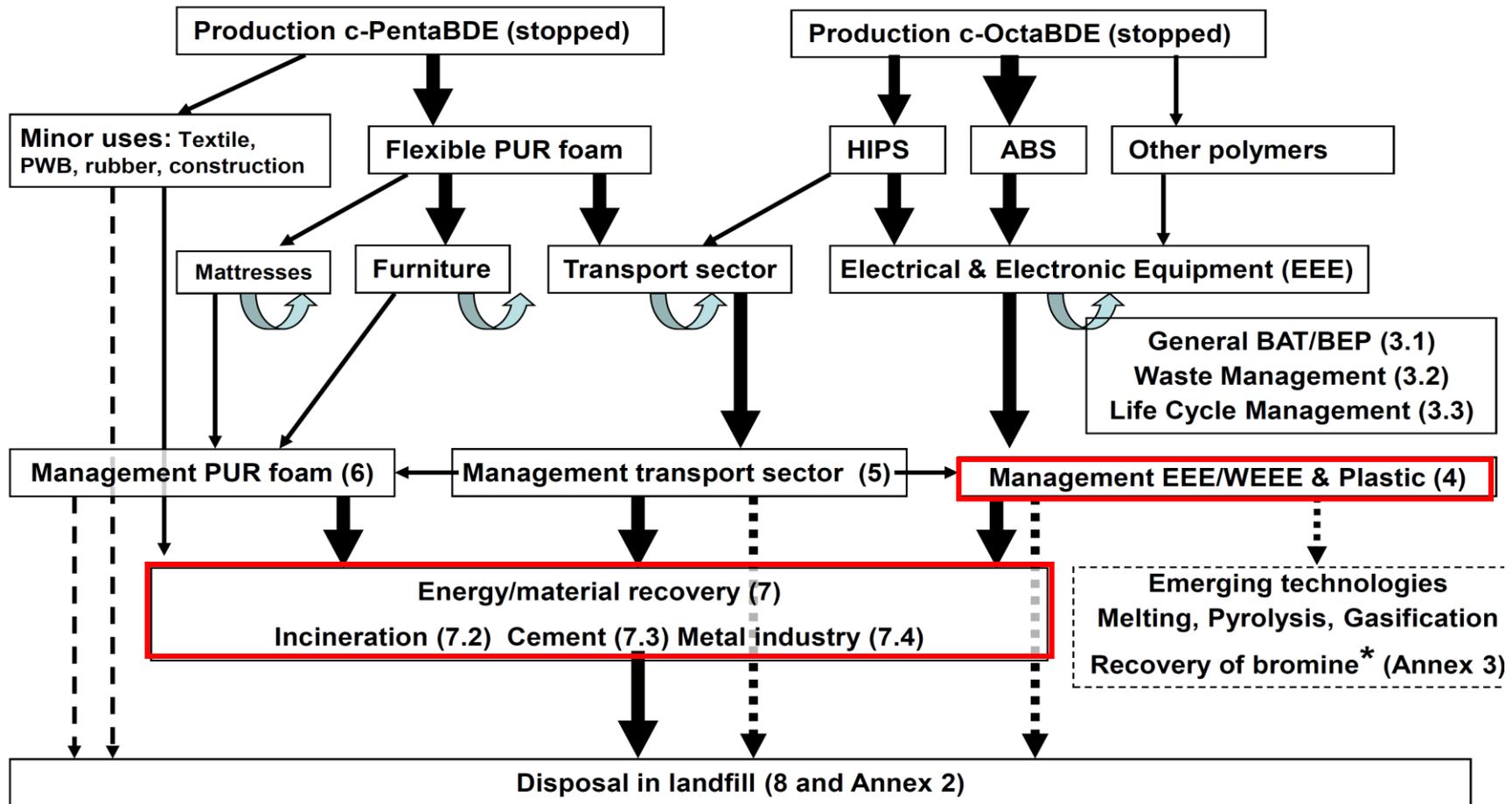
# PBDEs listed as POP in Stockholm Convention 2009 got an exemption for recycling – BAT/BEP need

- The allowance of reuse and recycling of articles containing POP-PBDEs results in the need to define Best Available Technology (BAT) and Best Environmental Practices (BEP) to carry out the recycling and the final disposal in an environmentally sound manner (ESM).
- The objective of this guidance document is to assist Parties in developing strategies for complying with the Convention obligations related to the recycling and waste disposal of articles containing POP-PBDEs, and implementing the recommendations of the COP.
- Technologies are evaluated and defined which can be considered as BAT/BEP to manage these material streams in an ESM and would be used for developing action plans and to prioritize areas for the management of POP-PBDE containing material flows.
- Labor intensive separation techniques possibly applied in developing countries are not well described yet in the guidance.

# Material flow of POP-PBDE-containing goods and PBDE BAT/BEP guidance structure

Production  
Use & Re-use  
Recycling  
Disposal

Material flow of POP-PBDE-containing goods



→ • The size of the arrow indicate major use or major flows of POP-PBDEs or POP-PBDE-containing materials.

..... → • Dashed arrows indicate non-preferred routes

↻ Reuse of Articles (e.g. cars, electronics, furniture).

\*Bromine recovery is not operated in full scale yet.

# Chapter 4. Specific BAT/BEP: POP-PBDE/bromine- containing plastic in WEEE

## Considering waste hierarchy the BAT/BEP guidance mention: Reuse/repair of electrical and electronic equipment (EEE)

- **Reuse & repair of EEE** is the **preferred option** for **EoL** management. **Reuse** extends the life span, **saves energy** for the manufacturing and **lowers the environmental impacts** of mining for raw materials.

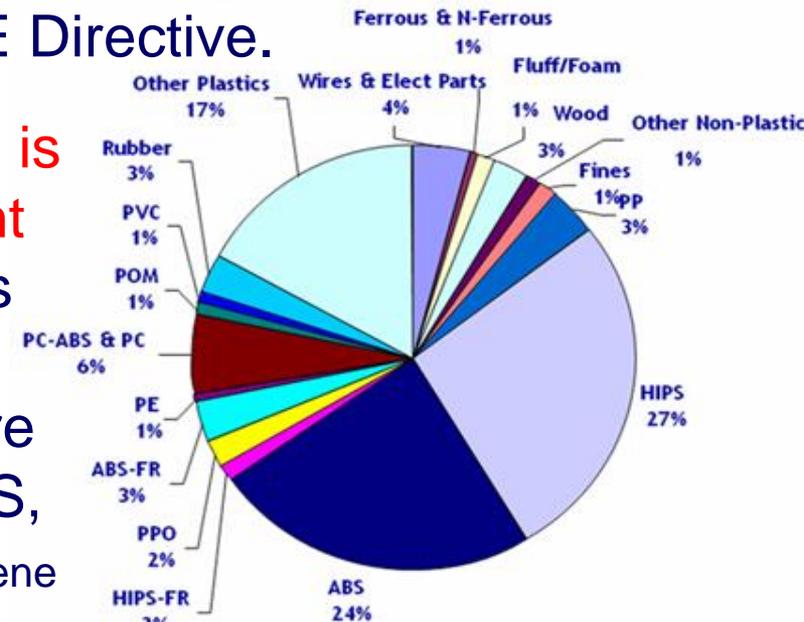
## Recovery of materials from waste EEE (WEEE)

- **The Stockholm Convention BAT/BEP guidance stresses the recycling and recovery of WEEE plastic considering the waste hierarchy and the elimination of PBDEs in the WEEE plastic.**
- The management of POP-PBDE in WEEE plastic should consider the recommendation of POP Review Committee & Conference of Parties to separate PBDE containing plastic using BAT/BEP approaches.
- With listing of DecaBDE without recycling exemption the separation is needed.

# Recycling/separation of POP-PBDE/bromine containing polymers in WEEE

- **The recovery of metals is the key driver of WEEE recycling!**
- Current WEEE recycling facilities are often not optimized for separation of PBDE/bromine containing polymers. In the EU, separation capacity for BFR plastic <30% although separation of BFR plastic is a requirement of the EU WEEE Directive.

- **The complex mixture of plastic in WEEE is difficult to separate and industry has tight specifications for materials and additives resulting in low recycling rates of polymers from WEEE.** However there are major plastic types as target plastic (ABS, ABS-PC, HIPS, and PP). (Acrylonitrile butadiene styrene; High Impact Polystyrene; PolyPropylene)

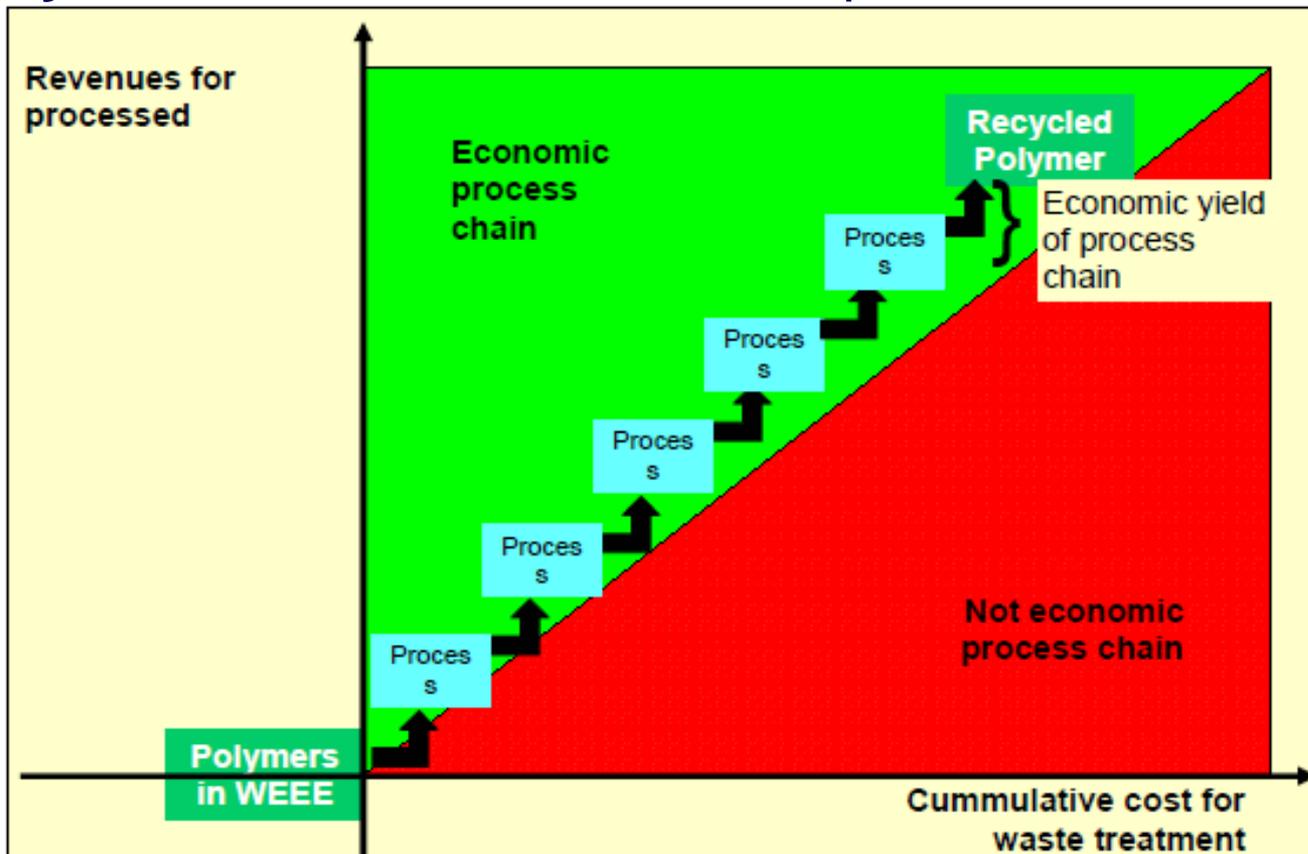


(Slijkhuis/MBA polymers, 2011)

- **Strategy:** to separate/produce valuable recyclates of major plastic types with a quality accepted by producers of new products and separation of PBDE/bromine as an integrative part of this recycling

# Production of plastic for recycling from WEEE including separation of PBDE/bromine

- A stepwise separation of WEEE plastic is needed for transformation into valuable plastic-for-recycling. Numbers of process/separation steps vary depending on process combinations used.
- The overall cost for **separation steps and technologies** need to be **covered by the final revenues** from the products.



# Separation and upgrading steps in the recycling of (WEEE) plastic: Combination of technologies



- Full scale plants to separate PBDE/bromine-containing polymers.

WEEE input	Separation techniques	Polymers Separated	Quality of separated polymers	PBDE/bromine Elimination (RoHS compliant products)	Development Stage*	Reference
Mixed polymer from WEEE (Austria, China)	Not disclosed	A) Low-bromine types of ABS, HIPS and PP	A) Good (Customer specify)	Yes bromine rich fraction incinerated	Industrial scale	MBA Polymer Patent
Small electronic equipment, White goods (Switzerland)	Includes XRT	bromine and PVC free polymers	Good	Yes	Industrial scale	(Gerig 2010)
WEEE polymers (UK)	Undisclosed	Low-bromine types of ABS and HIPS	Good	Yes	Industrial scale	(Morton 2007)
WEEE polymers (Germany)	Undisclosed (incl. S/F and Electrostatic)	Low-bromine types of PP, ABS and HIPS	Good	Yes	Industrial scale	(wersag 2011)
TV and computer casings (Sweden)	Manual, not disclosed	Low-bromine types of ABS and HIPS	Good	Yes	Industrial scale	(Retegan 2010)
Mixed polymer from WEEE (Germany)	Successive Grinding and XRT	bromine and PVC free polymers	Not approved yet	Yes	Industrial scale	(Adamec 2010)

# Moving towards more circular WEEE plastic management



- Growing supply
  - Land-filled/Incinerated
- ↓
- Self-replenishing
  - Sustainable and growing supply

- Mechanical 'mining' process
- ↓
- < 10% of energy
  - <10% of water consumption
  - Save about 1-3 tons CO2/ton

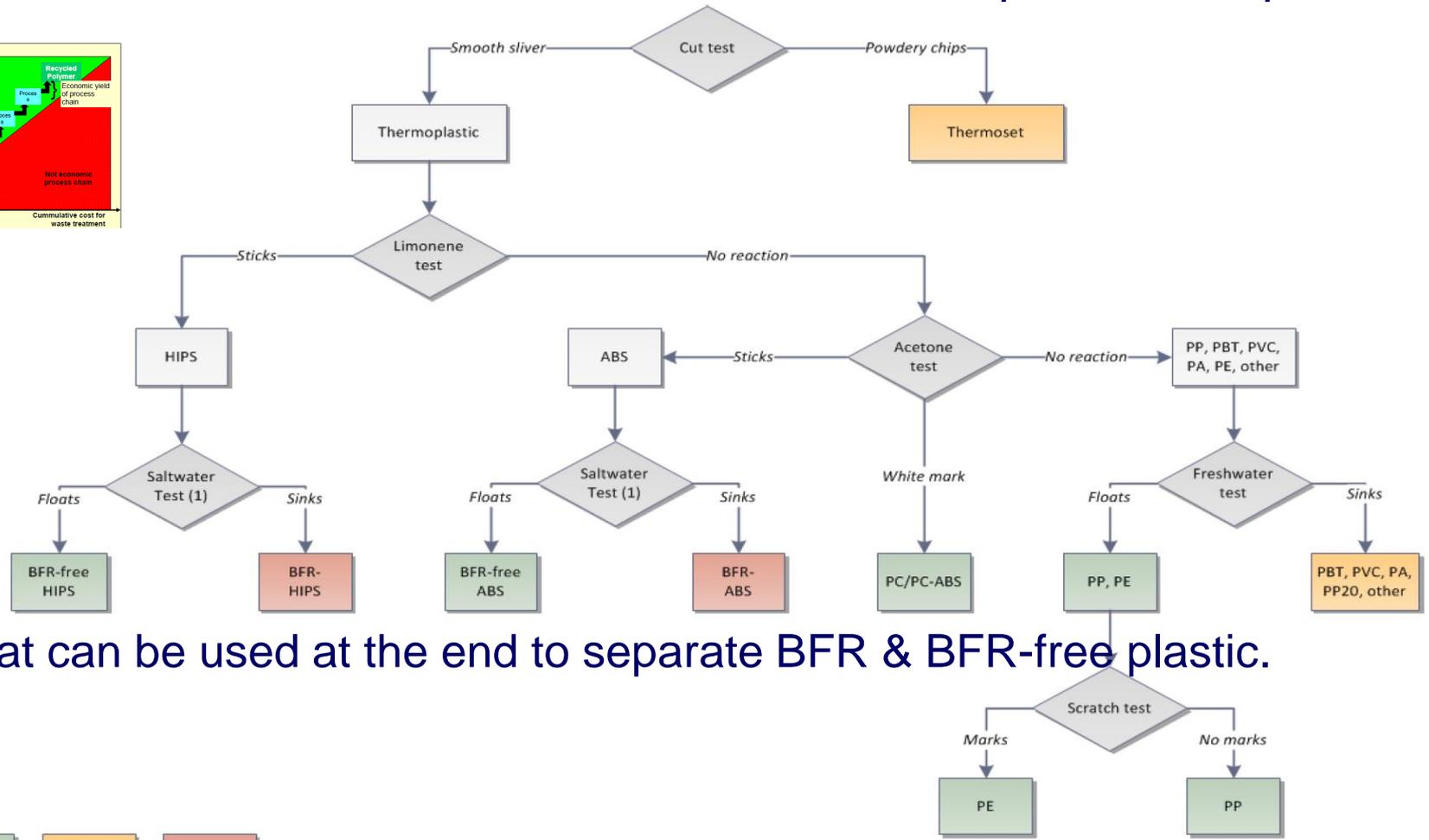
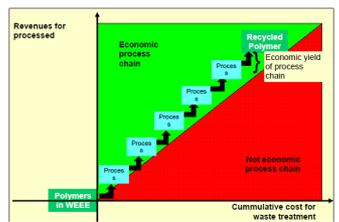
- "Green" products
  - Virgin-like quality possible
- ↓
- More sustainable business
  - PCR plastics

Back to plastic for EEE !



# Separation/upgrading steps in the recycling of (WEEE) plastic India: Combination of technologies

- Informal recyclers developed separation of plastic with simple tools.
- With these methods 10,000ds of tonnes of WEEE plastic is separated.



- Sink/float can be used at the end to separate BFR & BFR-free plastic.



Source: Haarman & Gasser (2017)

# Situation India – high plastic recovery without control<sup>21</sup>

- Swiss institutes (EMPA, WRF; Sustainable Recycling Industries SRI) have a project on assessment of WEEE plastic management in India.
- **WEEE plastic** is normally **recycled without separation of the BFRs**.
- If BFRs fraction is separated then for producing high BFR fractions for use in FR-plastic applications (V0; V1). But high load of POP-BFRs!

Haarman & Gasser (2016) Managing hazardous additives in WEEE plastic from the Indian informal sector. Report Sustainable Recycling Industries June 2016



- The remaining plastic waste from processing **WEEE plastic** is sold to **brick kilns as fuel**. No study on related releases and contamination.
- Another current practice is the use of **plastic in pyrolysis facilities**.
- **Research needs:** Assessment of the treatment of waste WEEE plastic in cement kiln, pyrolysis, incinerators and in brick production.

# Monitoring Dioxin in eggs around boilers burning plastic

- The burning of plastic waste in boilers of tofu factories in Indonesia is poisoning the food chain with Dioxin (PCDD/PCDF).
- The International POPs Elimination Network (IPEN) found, in an East Java village, that toxic dioxins in free range chicken eggs are 70 times above the level allowed by European safety standards. In Asia only eggs at Agent Orange contaminated sites in Vietnam were higher (90 times above EU level).



<https://www.bbc.com/news/science-environment-50392807>

<https://ipen.org/news/plastic-waste-poisons-indonesia%E2%80%99s-food-chain>

# Challenges of developing countries with waste incinerators

**Are incinerators a solution for ESM of waste from WEEE plastic recycling?**

**Important challenges associated with incineration in developing countries:**

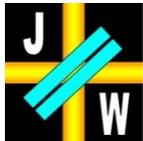
- Capital investment and operating costs of BAT incinerators are high;
- Increase in waste treatment cost may incentivize waste generators to seek alternatives to incineration, which is good if the alternative is for recycling, but not if it ends up in uncontrolled dumping or burning;
- There is a minimum requirement to the lower calorific value (7 MJ/kg). In low to middle income countries it may be a challenge to achieve this;
- Skilled staff is required for the operation and maintenance of the facility;
- The NIMBY syndrome also exists for WtE.

Source: ISWA Guidelines: Waste to Energy in Low and Middle Income countries. August, 2013

- The uptake of Waste-to-Energy (WtE) in India was not successful and the majority of plants have failed to sustain operations. As of 2012, only eight WtE plants had been installed in India. In 2017, only one WtE plant incinerating just MSW remains in operation in India (Nixon et al. 2017).
- Challenges to manage residues/ashes and control releases (Petrik & Bell 2017).

# Option/Challenges to use WEEE plastic waste as alternative fuels in cement kiln

- **The use of alternative fuels is only economical above a certain amount.** Replacement of 10 [%] of the heat consumption of the kiln can be considered a reasonable starting point for a change.
- The alternative fuel has to be available every hour, depending on the alternative fuel, between ca. 1.5 and 4.0 [t/h].
- Problem is that these quantities must be delivered from somewhere. Industrial countries have a **collection system for plastic or tires**. Developing countries **have waste plastic or used tires, but normally no collection and delivering system and a lack of quality control to deliver stable waste fractions.**



# Elements in plastic with problems in cement kilns

**Chlorine and Bromine** (present in some large plastic waste fraction (construction, E-waste, Car-shredder) :

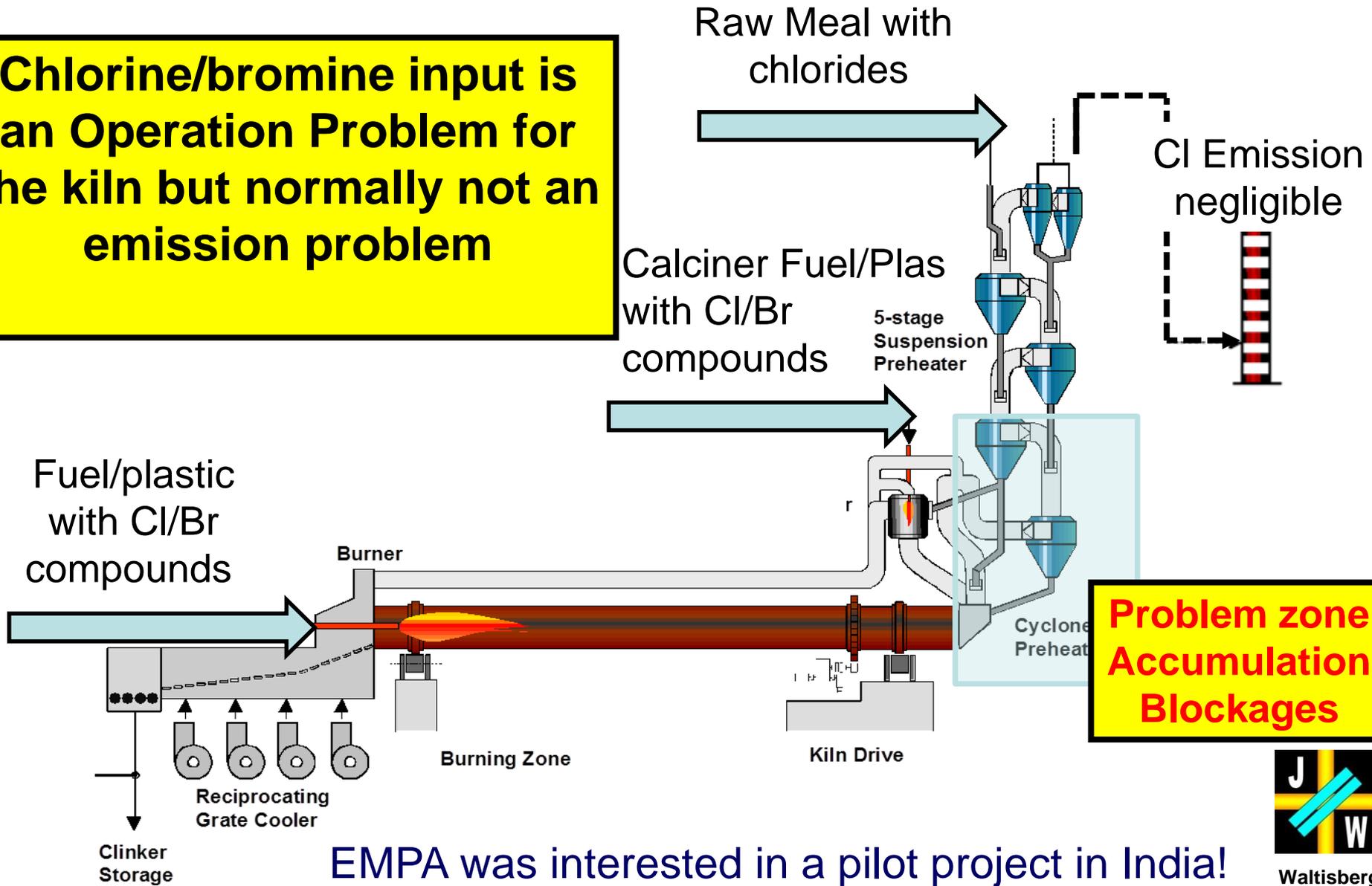
- Problem of clogging: Limit of **300 g/t total clinker input** restrict the use of alternative fuel (AFR) with chlorine. **The Cl/Br input via AFR must be limited; e.g. not more than 0.5 % in plastic or solvent.** Option of chlorine bypass!
- Increase risk of dioxin formation (can be controlled) and corrosion.
- The fate of bromine in cement kilns is not documented. Risk of release of brominated ODS or elemental bromine?. Assessment/research needed.

## **Phosphorus (P<sub>2</sub>O<sub>5</sub>)**

- Phosphorus from PFRs (or sewage sludge or animal meal),
- Lost in cement kiln – P is a valuable resource)
- Higher concentrations of P can cause a delayed setting time of cement.
- Loss of Strength in cement
- Maximum total input < 1 % P<sub>2</sub>O<sub>5</sub> in clinker

# The Chlorine(Bromine?) Problem

**Chlorine/bromine input is an Operation Problem for the kiln but normally not an emission problem**



EMPA was interested in a pilot project in India!



## Some Conclusions

- Important to control the recycling of WEEE plastic into sensitive uses such as toys and food contact materials.
- Two low POPs limit are currently in Basel Guidelines: 1000 mg/kg and 50 mg/kg. The latter would be a considerable challenge to reach in recycling.
- The separation of WEEE plastic by experienced informal sector in India can result in separated plastic types for the market. Further sink-float treatment produce “BFR free” and “BFR rich” fractions. Both are used.
- Technologies are available and in use to separate POP-BFRs from WEEE plastic and produce low POP-BFR plastic for recycling.
- Thermal treatment of WEEE plastic in non-BAT facilities result in environmental pollution and is a risk for contamination of food & humans.
- WEEE plastic can be thermally recovered in incinerators & cement kilns.
- Challenges of developing countries to operate BAT waste incinerators.
- Lack of projects of co-incineration of the waste WEEE plastic fraction.
- PBDEs are only one of hazardous chemicals in WEEE plastic. Other additives need to be considered for worker and consumer exposure.

# Thank you for your attention ! Questions? <sup>29</sup>

## More Information

Basel Convention: [www.basel.int](http://www.basel.int)

Rotterdam Convention: [www.pic.int](http://www.pic.int)

Stockholm Convention: <http://chm.pops.int/>

Montreal Protocol/Vienna Convention: <http://ozone.unep.org>

SAICM: [www.saicm.org/](http://www.saicm.org/) FAO: [www.fao.org/](http://www.fao.org/) WHO: [www.who.int/](http://www.who.int/)

POPs phase out & alternatives <http://poppub.bcrc.cn/>

OECD: <http://www.oecd.org/chemicalsafety/>

Science: [www.ipcp.ch](http://www.ipcp.ch); <http://greensciencepolicy.org/>

NGO: [www.ipen.org](http://www.ipen.org); [www.chemsec.org](http://www.chemsec.org); [www.ihipa.info](http://www.ihipa.info); [www.ban.org](http://www.ban.org)

**Better-world-links:** <http://www.betterworldlinks.org/>



Basel Convention

Rotterdam Convention

Stockholm Convention

Synergies

<http://synergies.pops.int/>

**SYNERGIES**

among the Basel, Rotterdam  
and Stockholm conventions

