INSTITUTE OF PLASMA PHYSICS
OF THE CZECH ACADEMY OF SCIENCES

SUSTAINABLE ELECTRONIC WASTE MANAGEMENT VIA THERMAL PLASMA PROCESSING: OPPORTUNITIES AND CHALLENGES

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The use of Plasma Chemical Technologies in the treatment of e-waste plastics as a possible irreversible destructive technology for this type of waste

Plasma chemical technologies: Gasification and Pyrolysis

WASTE TO VALUE.

- Elements present in mixed plastics from e-waste and their outputs after pyrolysis and gasification.
- Hydrogen and carbon nanoparticles production

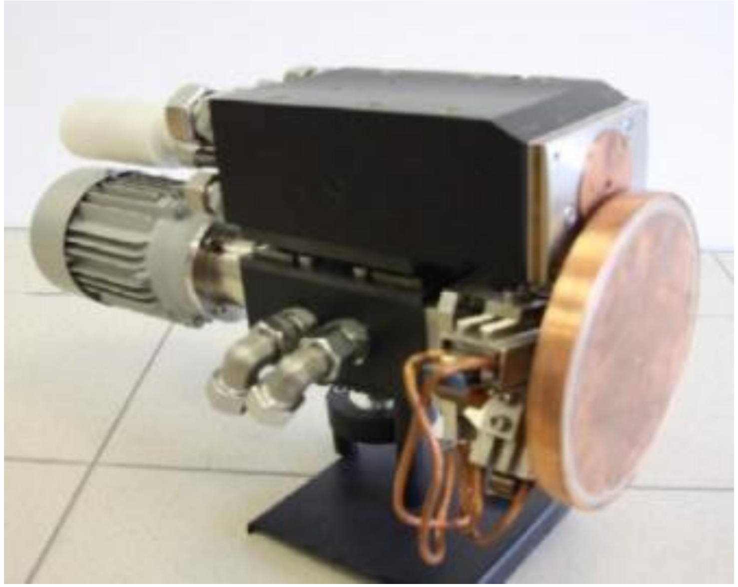
THERMAL PLASMA TREATMENT

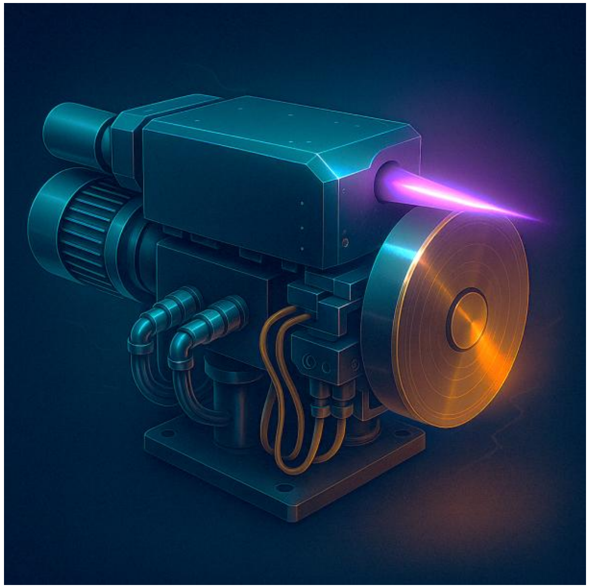
Plasma properties
- Transport of energy and temperature control – **enthalpy, density**
- Transfer of energy to material – **thermal conductivity, radiation properties**
- Reaction of plasma gas with products of material destruction

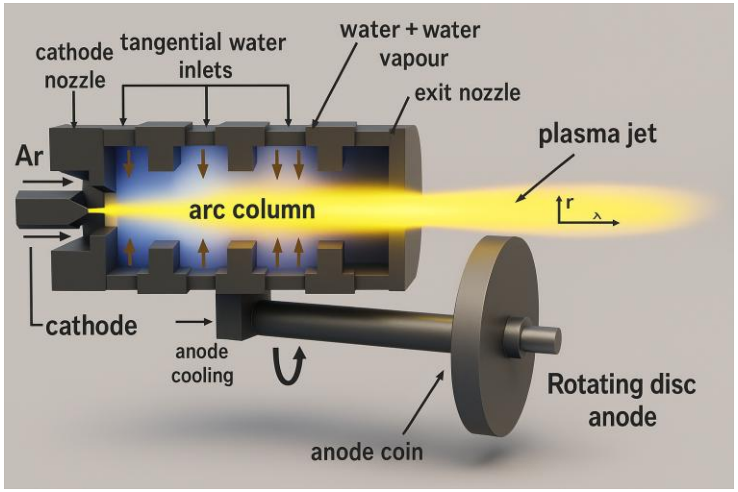
Role of plasma
- Transport of energy for endothermic reactions of material decomposition to the reactor
- Control of temperature in the reactor volume
- Supply of **gasifying agents (H_2O, CO_2)** for control of composition of reaction products

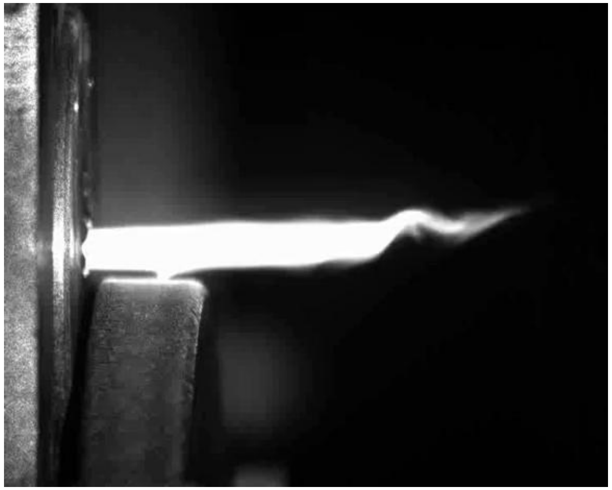
Advantages of thermal plasma treatment
- It reaches higher temperatures than conventional reactors (**up to 1600 °C**)
- **High energy density, high thermal transfer rate**
- Lower plasma gas input compared with the gas flow of classical burner
- **Better control of reaction gases composition**
- Rapid heating and reactor start-up and shut-down
- Smaller installation size
- Decoupling of heat generation from oxygen supply

Water stabilized plasma torch

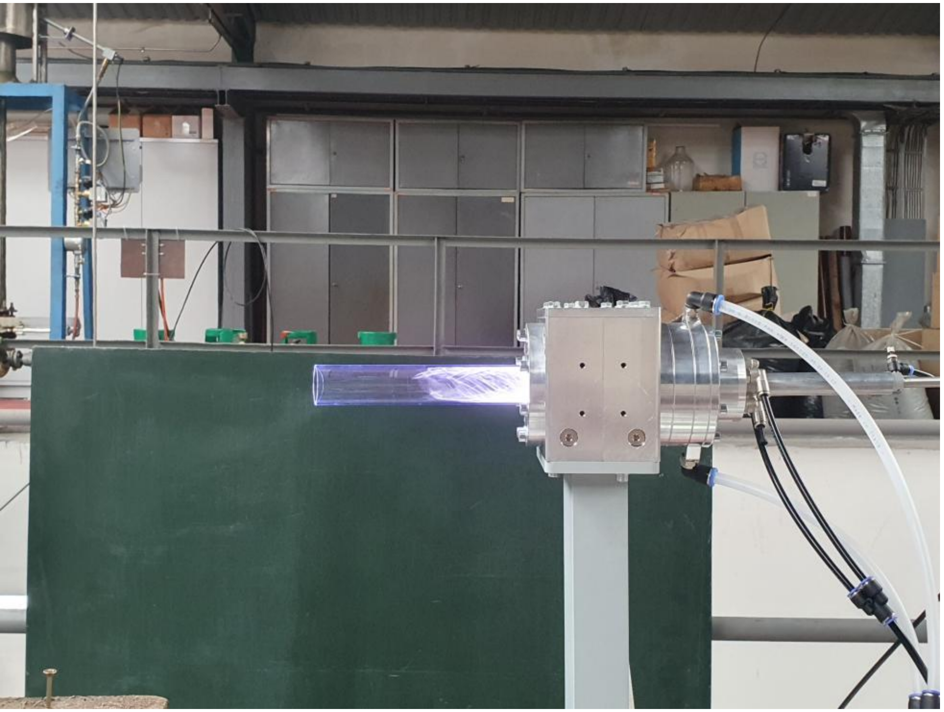




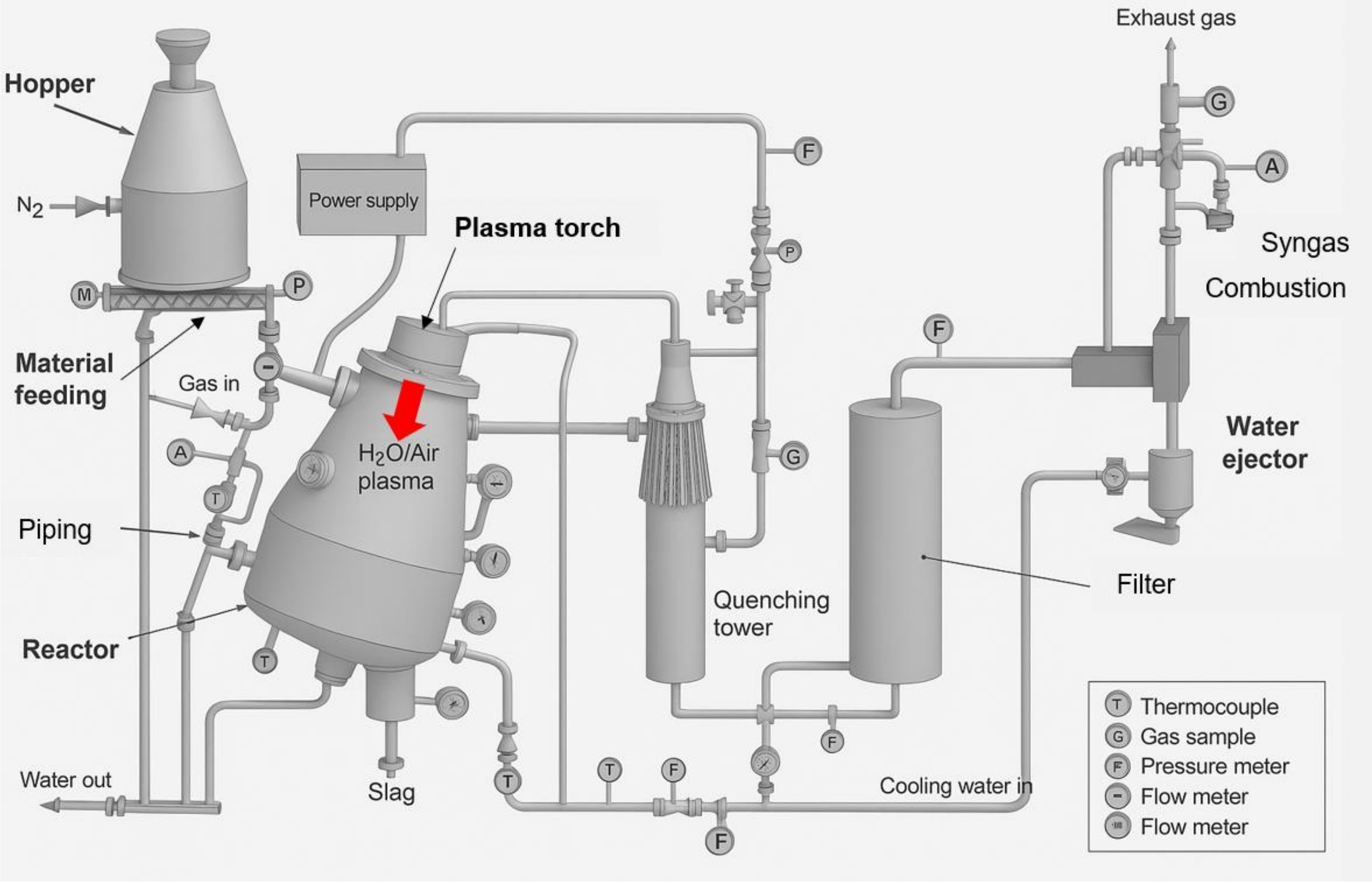




Microwave plasma torch



Reactor and auxiliary



- **High enthalpy steam plasma** provides optimal conditions for gasification and pyrolysis processes.
- **The process can be used as energy storage**. Electrical energy is transferred to plasma energy and stored in products (syngas, hydrogen, carbon). It could be used with power sources and non-stable electricity production (**POWER2X**).
- **Decrease the amount of pollutants** entering to the recyclates.

PLASTICS

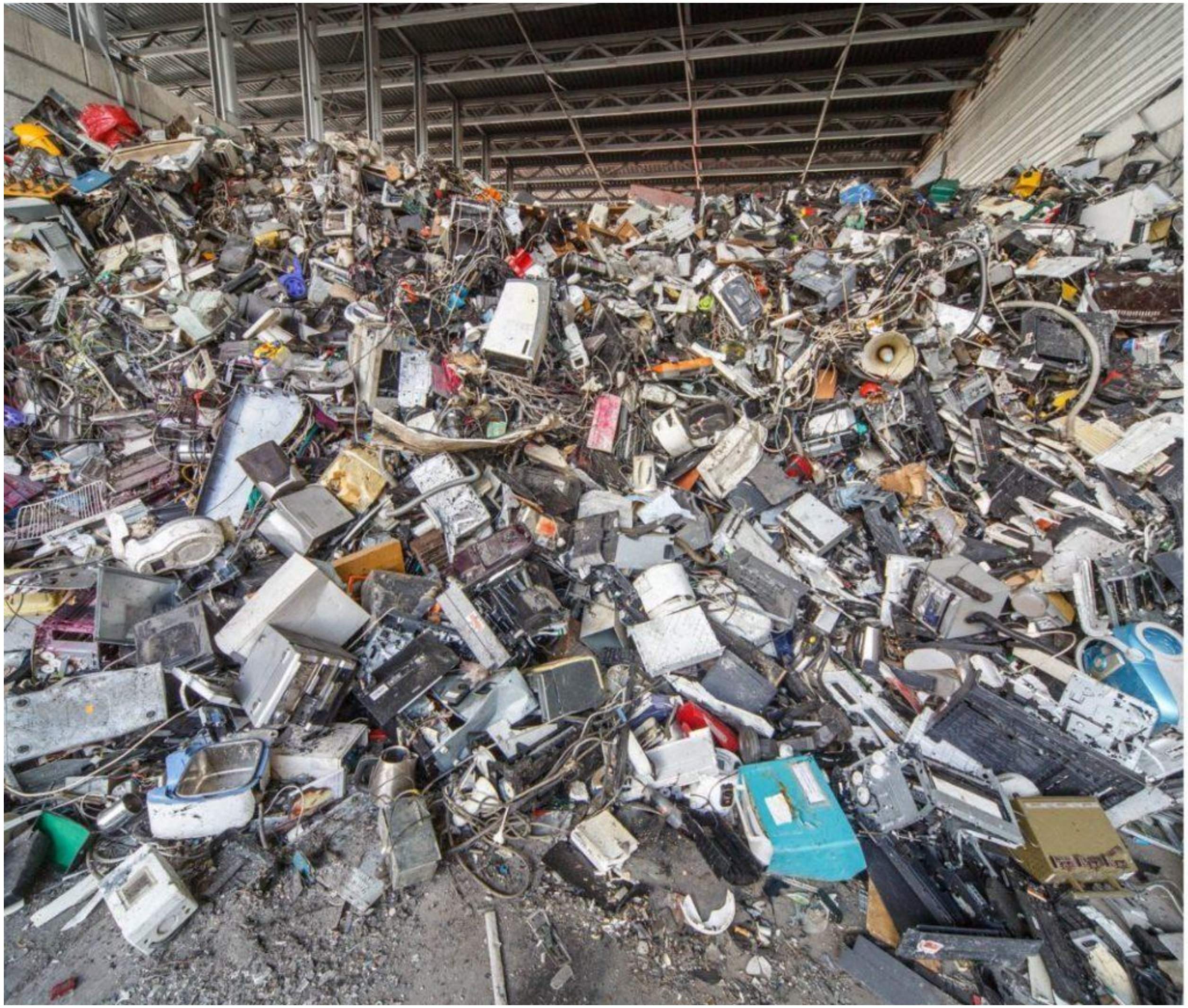
- Polymer type
- Additives

- Mechanical Recycling
- Recyclates
- Chemical Recycling
- Cement kiln

- Substances of high-concern
- Elemental pollutants
- POPs

- Global Plastic Treaty
- Global Conventions

VISITING ASEKOL



PLASGAS

6.25 kg Input material (0.1-1.5 mm)
0.94 kg Output material
(cyclone, bag filter, and reactor)

0.4 m³ of H_2 /kg of WEEE (Gasification)
1.2 m³ of H_2 /kg of WEEE (Pyrolysis)

TECHNIQUES

- Handheld XRF
- XRF
- Inductively Coupled Plasma Mass Spectrometry (ICP-MS)
- Ultimate and proximate analysis
- X-Ray Diffraction (XRD)
- Scanning Electron Microscopy (SEM)

E-WASTE MIXED PLASTICS

Elements in high-concern additives	Ag	Al	As	B	Ba	Bi	Br	Ca	Cd	Cl	Co	Cr	Cu	F	Fe	Hg	I	K	Li	Mg	Mn	Mo	Na	Ni	P	Pb	S	Sb	Si	Sn	Ti	V	Zn								**33**
Elements measured by the techniques	Ag	Al	As	B	Ba	Bi	Br	Ca	Cd	Cl	Co	Cr	Cu	F	Fe		I	K	Li	Mg	Mn	Mo	Na	Ni	P	Pb	S	Sb	Si	Sn	Ti	V	Zn	La	Pd	Sr	Te	Y	Zr	Pt	**39**
ICP - MS	Ag	Al	As	B	Ba	Bi	Br	Ca	Cd	Cl	Co	Cr	Cu		Fe			K	Li	Mg	Mn	Mo	Na	Ni	P	Pb		Sb		Sn	Ti	V	Zn	La	Pd	Sr	Te	Y	Zr		**34**
Ult - Prox		Al		B	Ba		Br	Ca	Cd	Cl	Co	Cr	Cu	F	Fe			K		Mg	Mn		Na	Ni	P	Pb	S	Sb	Si	Sn	Ti		Zn			Sr			Zr		**27**
Handheld XRF	Ag	Al	As		Ba		Br	Ca	Cd	Cl	Co	Cr	Cu		Fe		I		Li	Mg	Mn	Mo		Ni	P	Pb	S	Sb	Si	Sn	Ti		Zn								**26**
XRF			As		Ba		Br	Ca	Cd	Cl		Cr	Cu		Fe						Mn			Ni	P	Pb			Si		Ti	V	Zn			Sr					**18**
SEM	Ag	Al						Ca		Cl			Cu		Fe			K		Mg			Na				S		Si		Ti								Zr	Pt	**14**

Group 1
>20.000 ppm

Group 2
>10.000 ppm

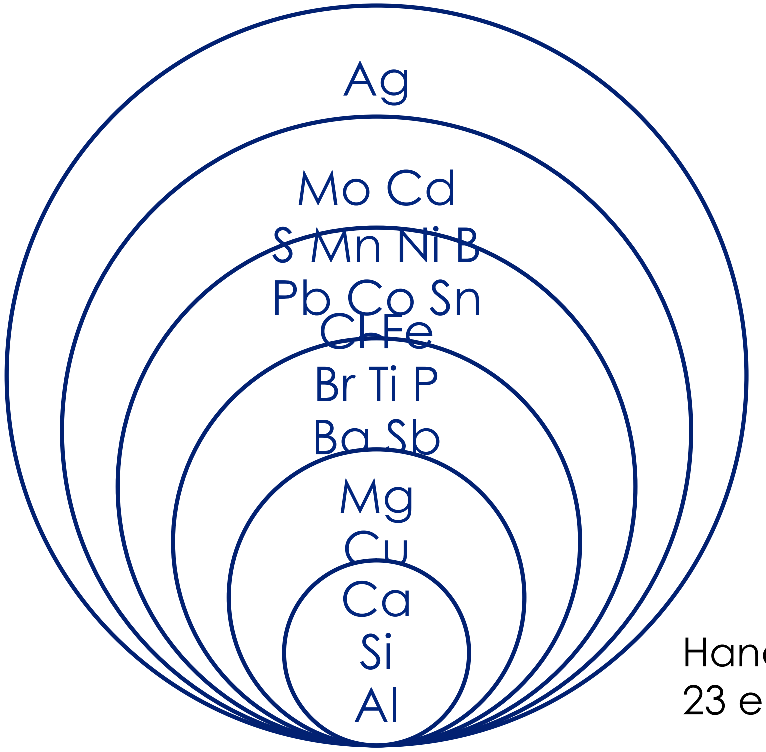
Group 3
>1.000 ppm

Group 4
>100 ppm

Group 5
>10 ppm

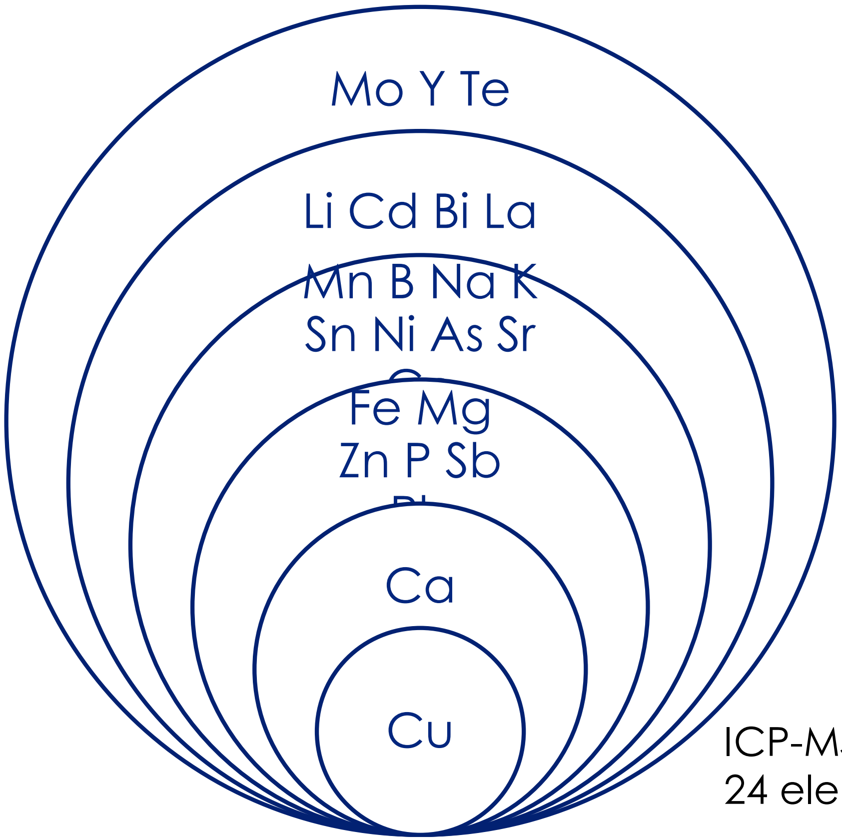
Group 6
>1 ppm

Elements with Combined Standard Uncertainty < 50%

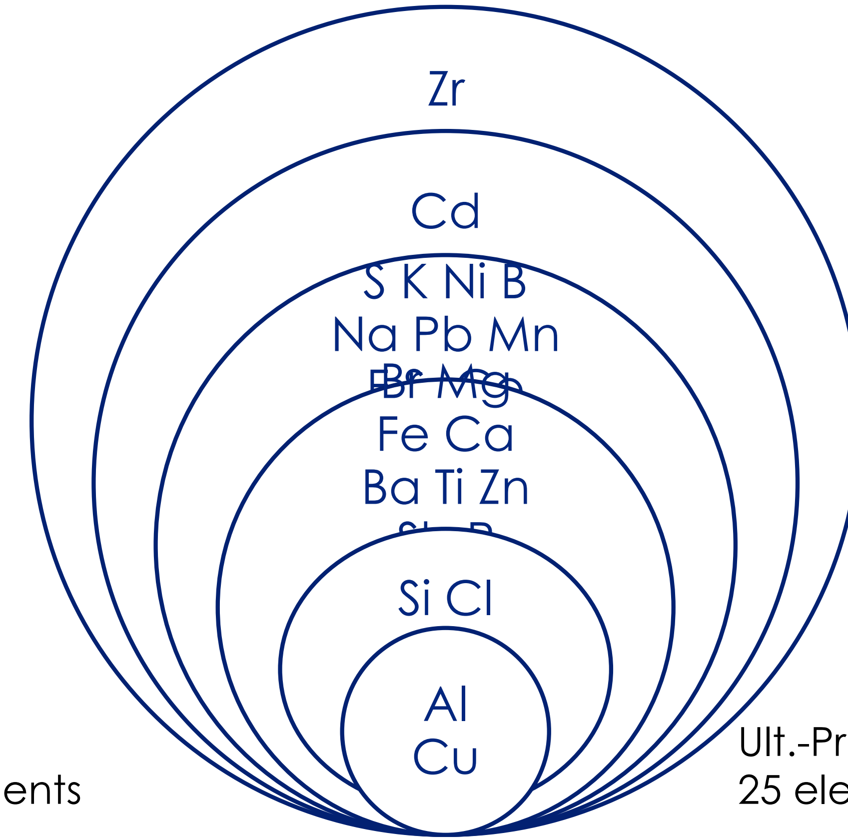


Handheld XRF
23 elements

ELEMENTS CONCENTRATIONS



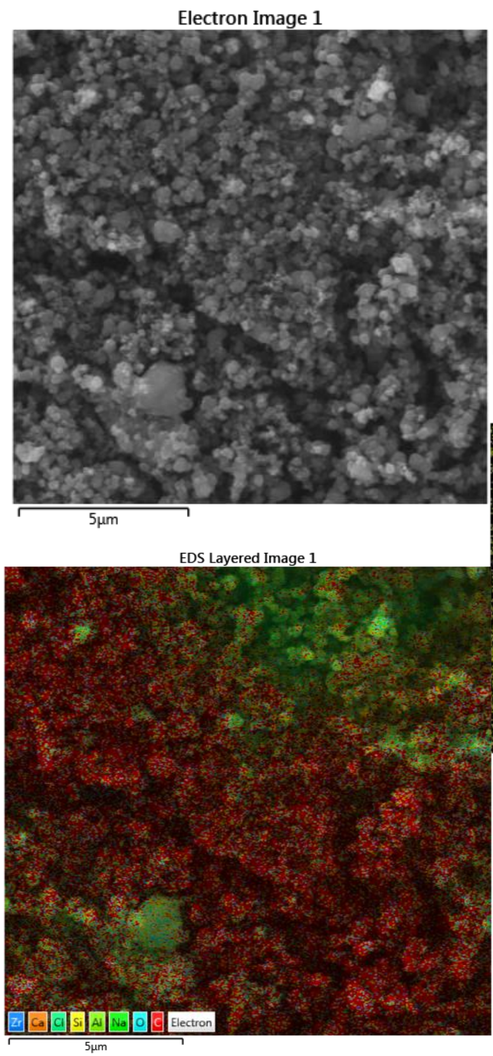
ICP-MS
24 elements

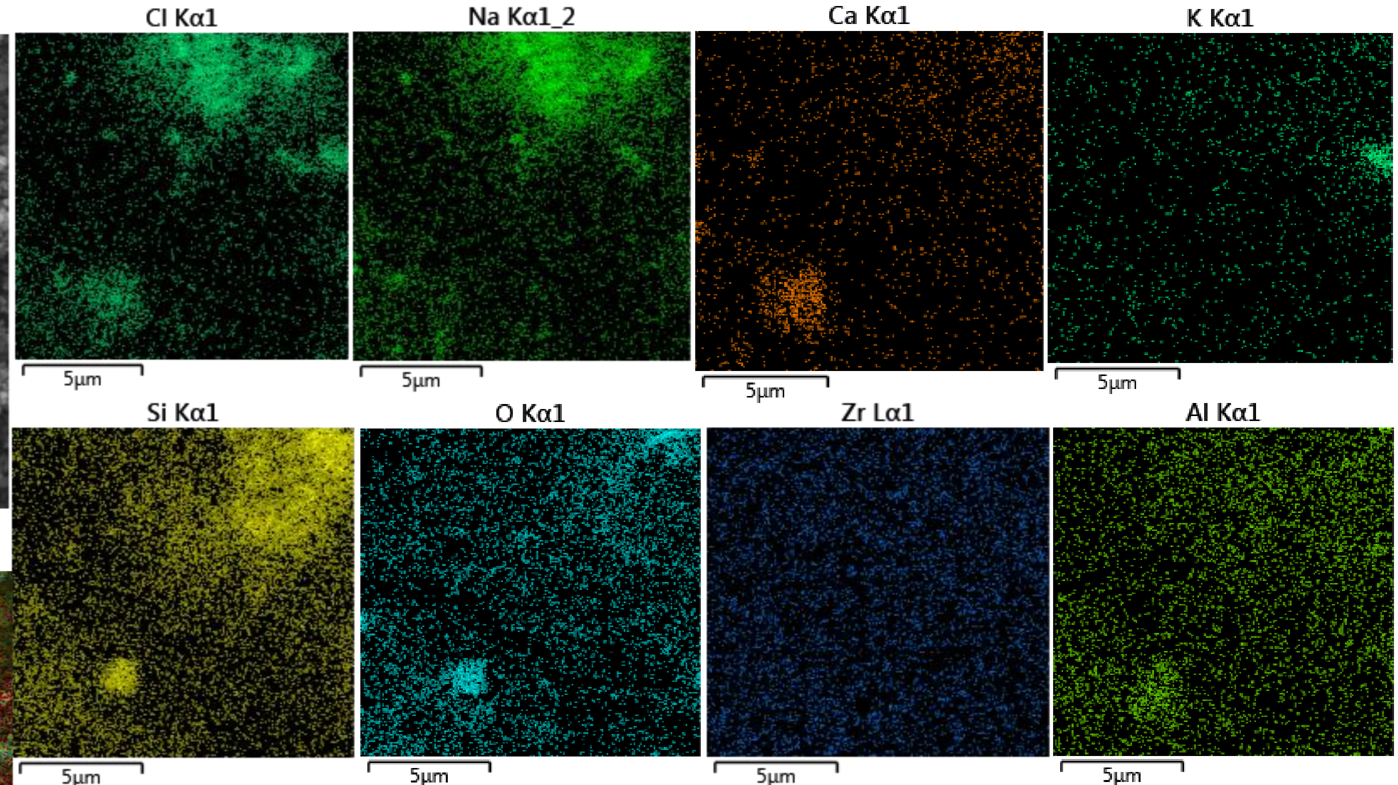


Ult.-Prox.
25 elements

Elements found	Elem. of high concern additives	Elemental pollutants and POP elem.	CRM EU	Valuable metals
Al	Al	Al	Al	Al
Ba	Ba			
Br		Br		
Ca				
Cd	Cd	Cd		
Cl		Cl		
Cu	Cu	Cu	Cu	Cu
Fe		Fe		Fe
Mg		Mg	Mg	
Ni	Ni	Ni	Ni	Ni
P	P			
Pb	Pb	Pb		Pb
S				
Si				
Ti		Ti		
Zn	Zn	Zn		Zn
Sr		Sr		

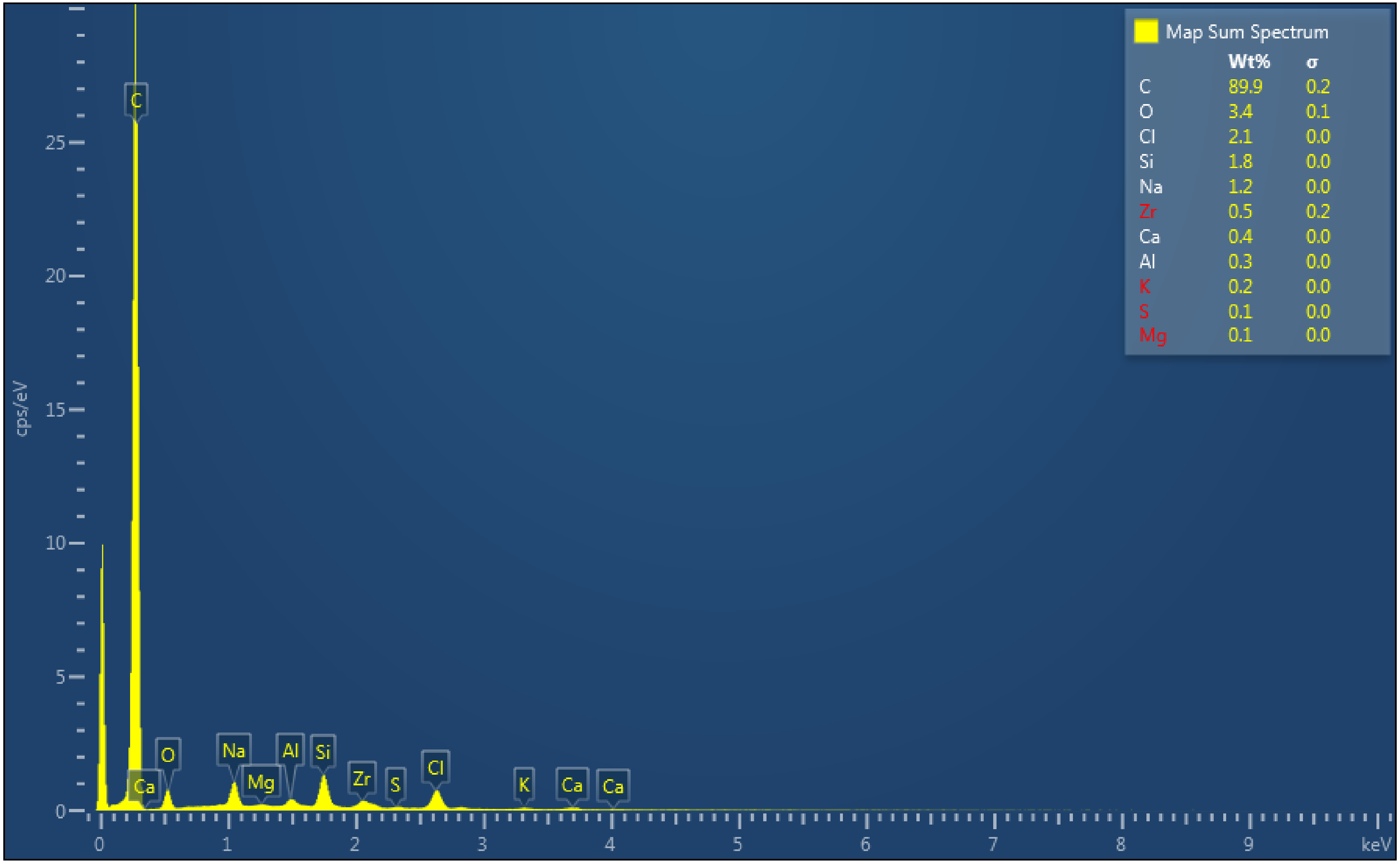
ELEMENTS FOUND IN E-WASTE MIXED PLASTICS





Bag filter

ELEMENTS FOUND IN E-WASTE MIXED PLASTICS



POROSITY AND SURFACE AREA

Cyclone pyrolysis				Sample out cyclone	
Pore Volume	0.0320 cc/g			0.1336 cc/g	
Surface Area	13.9242 m^2/g			46.4067 m^2/g	
Lower Confidence Limit	0.8068 nm			0.8068 nm	
Mode (Half Pore Width)	1.3845 nm			1.4483 nm	
Fitting Error	0,69%			1,75%	
Notes Desorption data (augmented)					
Cyclone gasification				Sample out cyclone	
Pore Volume	0.0456 cc/g			0.0496 cc/g	
Surface Area	22.2520 m^2/g			19.2754 m^2/g	
Lower Confidence Limit	0.8068 nm			0.8068 nm	
Mode (Half Pore Width)	1.3845 nm			1.3845 nm	
Fitting Error	0,65%			0,89%	
Notes Desorption data (augmented)					
Bag filter					
Pore Volume	0.0456 cc/g				
Surface Area	17.7075 m^2/g				
Lower Confidence Limit	0.8068 nm				
Mode (Half Pore Width)	1.3845 nm				
Fitting Error	0,68%				
Notes Desorption data (augmented)					

MATERIAL PHASES

Pyrolysis	%	%	%	AVER.	S. DEV	% RDS
NaCl	75	74	68	72	3,9	5%
Graphite	11	12	18	14	3,4	25%
TiO2	6	5	6	5	0,5	10%
CaCO3	8	10	9	9	0,9	10%
Gasification	%	%	%			
NaCl	36	33	33	34	2,0	6%
Graphite	23	28	28	26	3,1	12%
TiO2	17	15	14	15	1,8	11%
CaCO3	23	24	24	24	0,5	2%
ZnSe		1				
Bag Filter	%	%	%			
NaCl	61	71	67	66	5,0	8%
Graphite	20	5	9	11	7,7	69%
TiO2	5	8	9	7	1,8	25%
CaCO3	14	16	15	15	1,2	8%

MATERIAL PHASES

Reaktor	%	%	%			
NaCl	3	3	2	3	0,5	18%
Graphite	3	6	7	5	2,1	40%
CaCO3	8	7	9	8	0,8	10%
CaAl2Si2O8	34	32	37	35	2,4	7%
Al2O3	30	32	29	31	1,3	4%
Si	5	5	3	4	1,1	26%
Fe	1	3	2	2	1,1	64%
SiO2 (high temp phase)	7	7	7	7	0,1	1%
SiO2	5	2	1	3	1,8	69%
SiO2	3	3	2	3	0,7	24%

EXAPMPLE OF POLYPROPYLENE TREATMENT

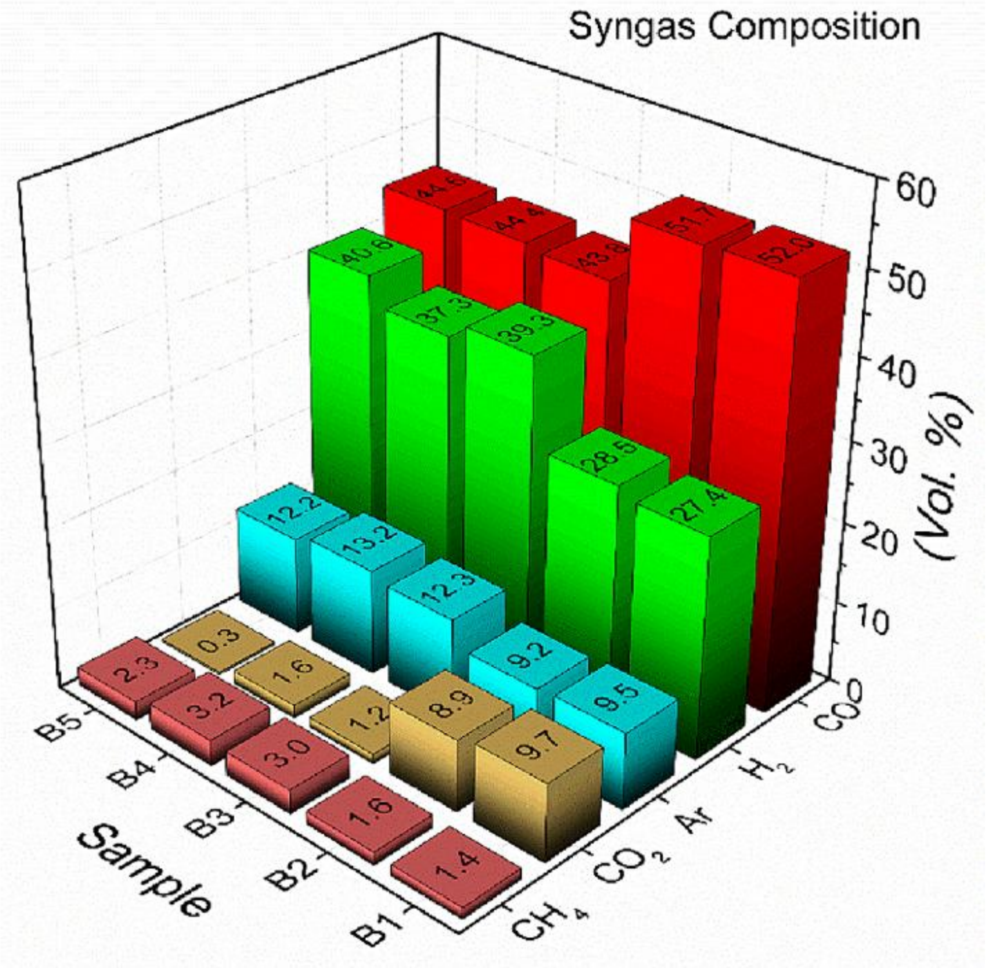
Reaction name	Reaction	Reaction enthalpy
Dry reforming	$C_nH_m + n\ CO_2 \leftrightarrow m/2\ H_2 + 2n\ CO$	Endothermic
Steam reforming	$C_nH_m + n\ H_2O \leftrightarrow (n + m/2)\ H_2 + n\ CO$	Endothermic
Cracking	$C_nH_m \leftrightarrow n\,C + \frac{m}{2}H_2$	Endothermic
Boudouard reaction	$C + CO_2 \leftrightarrow 2CO$	$+172.52$ KJ mol^{-1}
Water-gas reaction	$C + H_2O \leftrightarrow H_2 + CO$	$+131.2$ KJ mol^{-1}
Water-gas shift reaction	$CO + H_2O \leftrightarrow CO_2 + H_2$	-41.18 KJ mol^{-1}

EXAPMPLE OF POLYPROPYLENE TREATMENT

Operating parameters of the experiment.

Case	PP feedrate (kg/h)	Input of CO_2 (L/min)	Power of the Plasma Torch (kW)	Input H_2O Plasma Torch (g/min)	Argon Plasma Torch (L/min)	Calibrating argon (tracer) (L/min)
B1	6.0	180	110	25	5.0	40
B2	6.0	180	110	25	5.0	40
B3	6.0	76	88	25	5.0	40
B4	6.0	76	88	25	5.0	40
B5	6.0	76	95	25	5.0	40

EXAPMPLE OF POLYPROPYLENE TREATMENT



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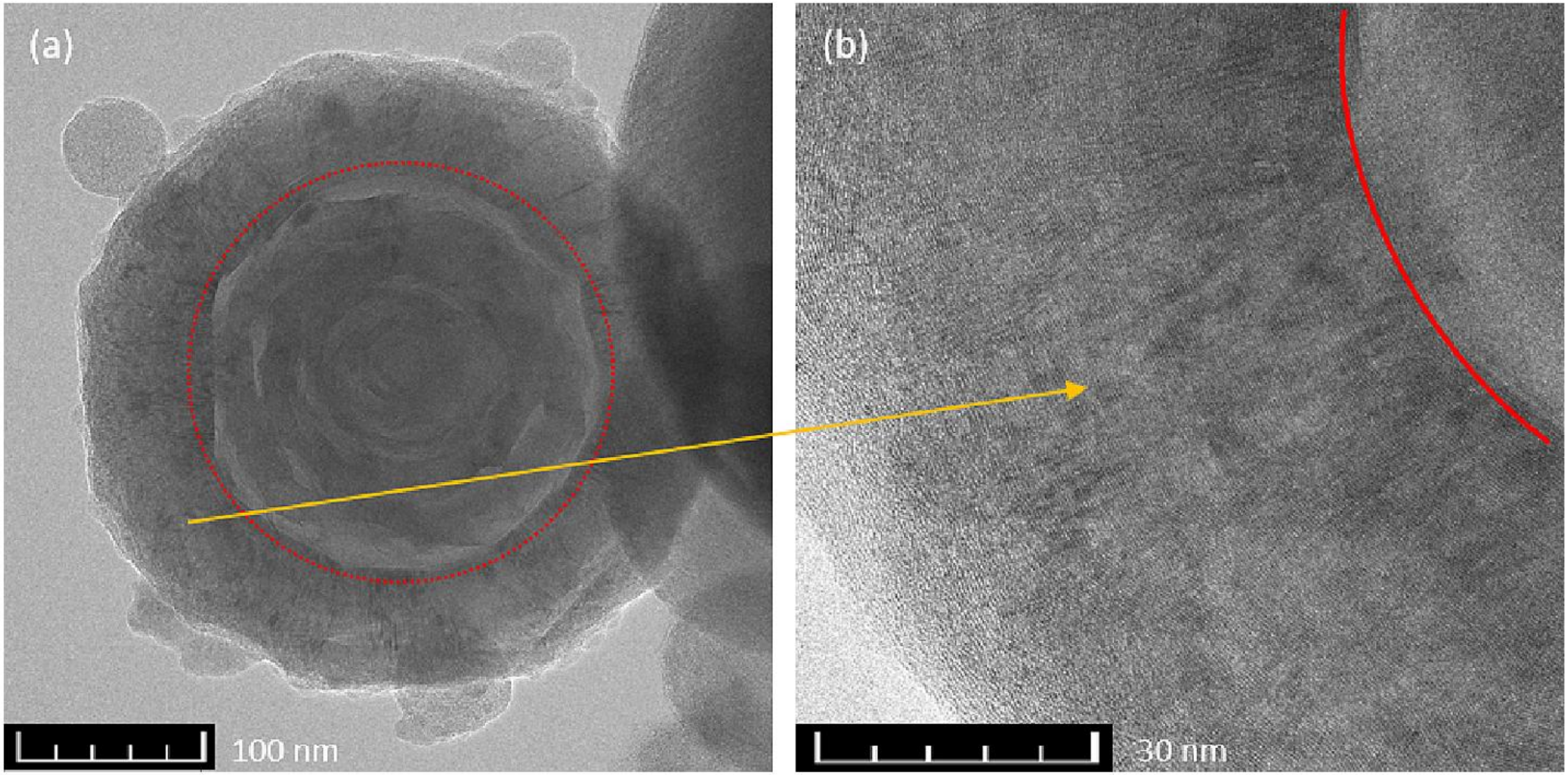

SUMMARY

- Plastic waste is a growing stream that, when treated by plasma chemical technologies, can potentially be a **source of hydrogen**, **a reservoir of elemental pollutants**, and a generator of **spherical carbon nanoparticles**.

- Plasma chemical technologies do not compete with mechanical recycling and could **complement plastic waste management** by treating polluted fractions.

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