SECOND INTERNATIONAL
SLAG VALORISATION SYMPOSIUM
THE TRANSITION TO SUSTAINABLE MATERIALS MANAGEMENT

ADVANCED PLASMA POWER

Tetronics

Thermal Plasma processing in the production of value added products from municipal solid waste (MSW) derived sources

Chris Chapman, Richard Taylor, David Deegan

HT centre

SMART-PRO²

Overview

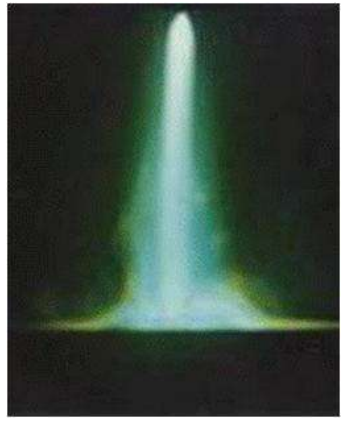
- Context
- Background to plasma environmental processing
- Use of plasma in the treatment of MSW derived materials
  - Gasplasma® process for treating refuse derived waste
  - Treatment of APC residues from EfW facility
- Applications testing of vitrified material
- Fabrication of higher added value products

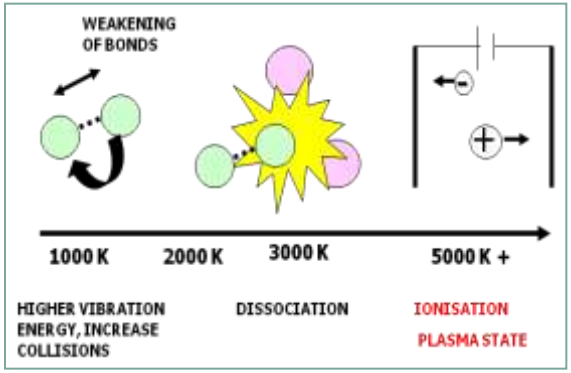
Context:
The drivers that promote slag valorisation technologies

- Disposal of Municipal Solids Wastes (MSW) and other wastes are an increasing challenge
- EU regulations: restrict landfill, cross boundary movement and promote recovery of materials/energy
- Sustainable solutions are required:
  - Achieve more efficient use of resources, recover and utilise secondary materials
  - Improve energy utilisation, lower carbon footprint and reduce overall environmental impact
- Fiscal policy in place: discourage landfill, promote renewable power generation using ATT

Background to Plasma environmental processing (1)

- Thermal plasma: high temperature (>5000K), intense UV radiation
- Plasma is an ionised (electrically charged) gas - referred to as 4th state of matter
- Features when applied to environmental treatment:
  - High melting/reaction rates
  - High flexibility on wide range of wastes
  - Energy input readily controllable and independent of process chemistry
  - Low gas volumes - reducing size and cost of gas cleaning





Background to Plasma environmental processing (2)

- Environmental treatment of waste forms
  - Efficient melting of ashes and other inorganic waste forms, immobilisation of the heavy metals
  - Close control of process chemistry permitting recovery of valuable metal species
  - Rapid destruction of complex organic molecules into simple gaseous species (i.e. H_2, CO, H_2O, CO_2)
- Inorganic waste treatment
  - Steel plant wastes, MSW incinerator residues, asbestos containing materials, aluminium residues
- Organic wastes
  - MSW, C&I , wood residues, oily residues, ASR wastes

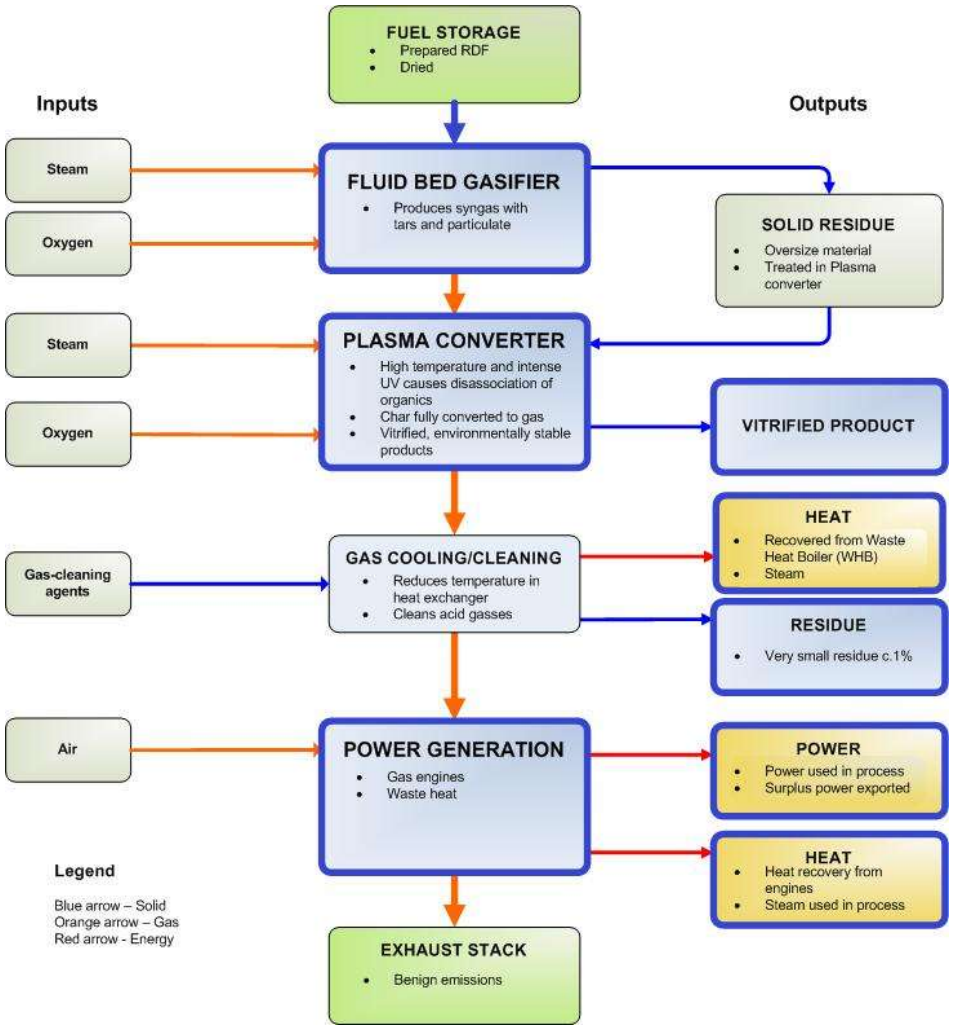
Plasma processing of MSW derived materials

- Market considerations
  - Global generation of MSW: 1.7 - 2.2 billion tpa
  - EU 27 generation of MSW: 266 million tpa
  - Air Pollution Control (APC) residues are classified as a hazardous waste (absolute entry) under EWC (19 01 07). Around 1.9 million tpa generated within EU 27

- Gasplasma treatment of Refuse Derived Fuel (RDF)
  - 2-stage continuous process for production of high quality syngas for use in a gas engine or gas turbine
  - Production of a vitrified calcium alumina silicate slag

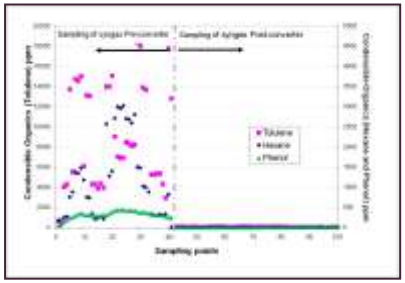
- Vitrification of APC material
  - Production of slag; recovery of HCl in separate stage

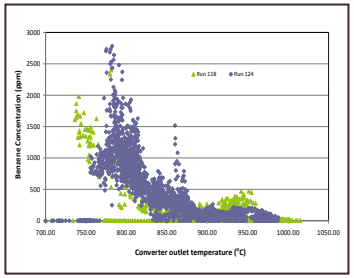
Plasma processing of MSW derived materials (2): Gasplasma® Process



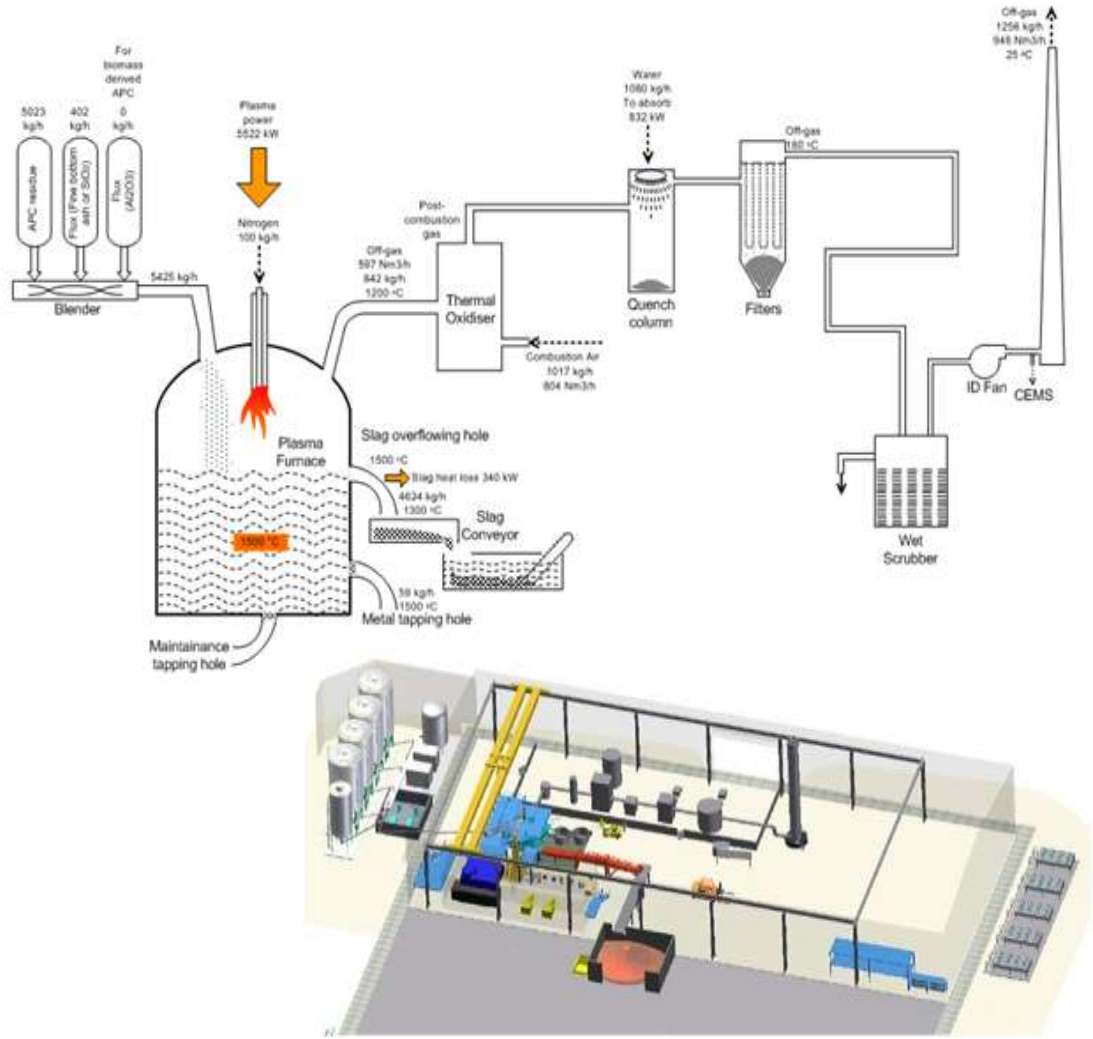
Converts RDF feedstock into:

- Converts 98% of the waste fuel
  - Very clean hydrogen-rich gas
  - Recyclable aggregate
- Minimal emissions/low environmental impact
- Low Carbon impact
- Potential CHP Energy efficiencies of >70%
- Syngas used in gas turbine or engine
- Exporting up to 82% of electricity generated





Plasma processing of MSW derived materials (3): APC Residues



Plasma treatment of APC Residue:

- Provides near zero waste solution in the treatment of a problematic waste stream
- Vitrification of the inorganic fraction to recover a dense, environmentally stable slag – a product that may be used in a range of building applications
- Recovery of chloride species as HCl
- Commercial plants operational in Japan for mixed IBA/ APC ashes
- Extensive proving of APC ash has been carried out at Swindon demonstration plant

Plasma processing, Gasplasma®: Materials, methods and products

RDF Feed and Slag Chemistry

Characteristics	Component
Proximate analysis, %(w/w)	
Fixed carbon	11.6
Volatile matter	64.8
Ash	12.1
Moisture	11.5
Ultimate analysis, %(w/w)	
Carbon	43.0
Hydrogen	5.6
Oxygen	26.6
Nitrogen	0.61
Sulphur	0.25
Chlorine	0.34
GCV, MJ/kg (dry basis)	21.0
Bulk slag analysis, %(w/w)	
Silica	33.3
Calcia	26.6
Alumina	13.8
Iron oxide	15.3
Soda &Potash	5.6
Others	5.4

Demonstration plant in Swindon:

- Maximum capacity :100 kg/h
- Slag is intermittently tapped every 24 hours at temperature of ~1350-1500ºC
- Clean syngas used to generate power in a gas engine
- Around 1400 operating hours
- Vitrified slag is (CaO-Al_2O_3 FeO-SiO_2)
- Also contains significant levels of soda and potash

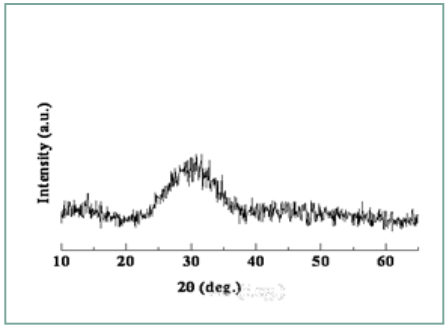
Plasma processing, APC treatment: Materials, methods and products

APC Feed and Slag Chemistry

Chemical species	As-received APC residues (wt%)	APC residue derived glass (wt%)
Na_2O	3.8	0.4
MgO	0.7	1.2
Al_2O_3	2.2	21.3
SiO_2	4.2	37.7
P_2O_5	0.6	0.35
K_2O	4.2	0.1
CaO	51.9	34.1
TiO_2	0.9	1.3
Mn_3O_4	-	0.2
Cr_2O_3	0.07	<0.05
Fe_2O_3	0.8	0.9
ZrO_2	0.02	0.05
ZnO	1.3	<0.05
SrO	0.08	0.06
BaO	0.03	0.06
S	-	0.13
Cl^-	22.3	2.2

Demonstration plant in Swindon:

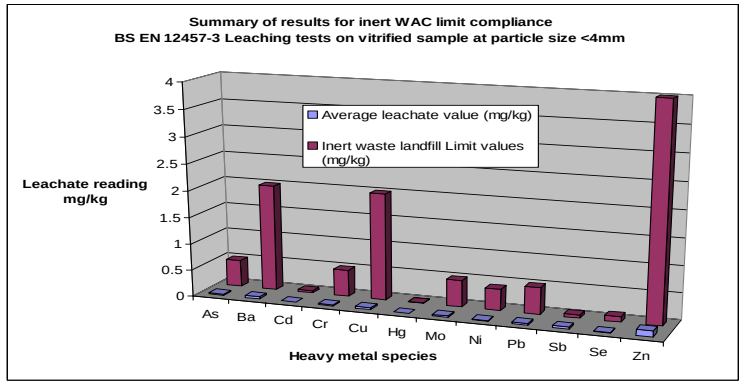
- APC is high in lime and chloride
- Alumina and silica flux additions are made to the feed so that the slag composition falls within the anorthite phase
- Material fed at a rate of 80 kg/h and periodically tapped at temperature of ~1350-1500°C
- Vitrified slag is $CaO\text{-}Al_2O_3\text{-}SiO_2$

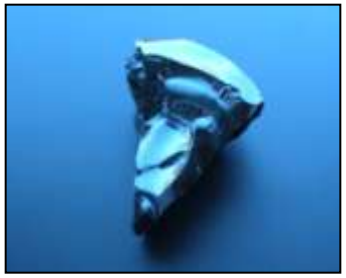


Leachate testing of feed and vitrified material

Elements	Gasplasma® RDF derived glass	APC derived glass	Leachable metals/ions in APC residues	Inert Landfill WAC
As	0,025	<0,007	0,005-4	0,5
Ba	0,040	0,053	10-45	20
Cd	<0,0055	<0,0025	<0,5	0,040
Cr	<0,02	<0,016	0,5-2,5	0,5
Cu	0,035	0,076	1,3-3	2
Hg	<0,0017	0,0031	0,04-0,7	0,01
Mo	<0,025	0,012	1-4	0,5
Ni	0,010	0,023	0,2-45	0,4
Pb	<0,03	<0,007	300-700	0,5
Sb	0,014	0,06	<0,001-0,02	0,060
Zn	0,120	0,020	40-85	4,000
Cl	<20	0,2	140.000-170.000	800,0
SO_4	<50	<50	1200-7000	1000,0
TDS*	268,0	592,0	-	4000,0

< Indicates below the lower limit
*Total dissolved solids
L/S=10

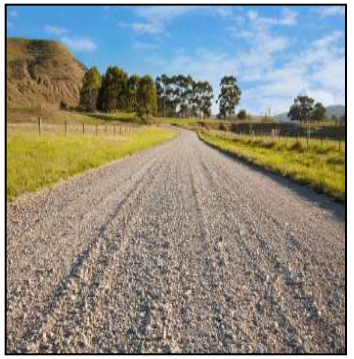




Leachate testing to BS EN 12457-3
Vitrified glass is extremely leach resistant

Applications testing of vitrified material

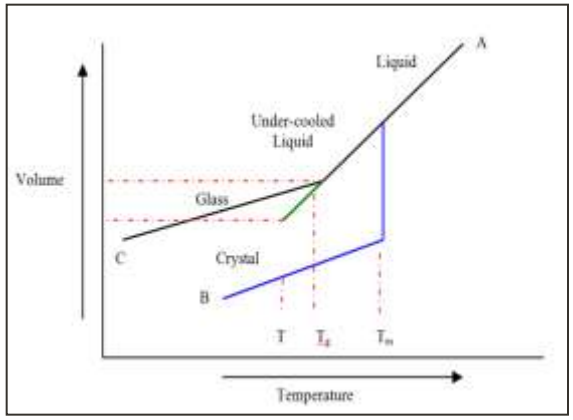
Application test	Purpose of test	Result	Interpretation
Los Angeles test (BS EN 1097-2)	This is a mechanical testing proceedure to demonstrate that the material exhibits acceptable resistance to fragmentation	27%	The material is categorised as LA20 which indicates that there is some minor fragmentation under high loadings, most likely due to the fracturing of the sharp edges on individual particles, whilst the majority of the particles remained intact. The LA coefficient falls well within the range for use as an unbound pipe bedding material where a value of less than 50 is required.
Water soluble sulphate (BS EN 1744-1)	This test measures the level of leachable sulphates in the material that may chemically react with adjacent building materials such as concrete	0%	The vitrified product is categorised as AS0.2 and is virtually inert with respect to sulphate leaching
Magnesium sulphate (BS EN 1367-2)	This test provides a measure of the weathering properties of the aggregate	1%	The materials is categorised as MS18, which indicates that it exhibits extremely high resistance to weathering
Water absorption test (BS EN 1097-6)	This gives a measure as to the materials susceptability to frost heave	0,6%	The material is categorized as WA24 which indicates that the material has low water absorption properties and is not prone to break down under freeze -thaw cycling conditions



Mechanically strong
Is compliant with application testing

Accepted by EA as a product – not a waste

Production of glass ceramic tiles



Glass ceramic production

Made by controlled crystallisation of glass

- Create high density of nuclei
- Crystal growth phase

Produces a fine grained material with good mechanical and chemical leach properties

Methods used:

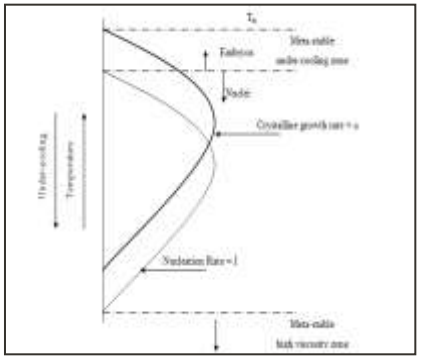
Conventional nucleation and growth

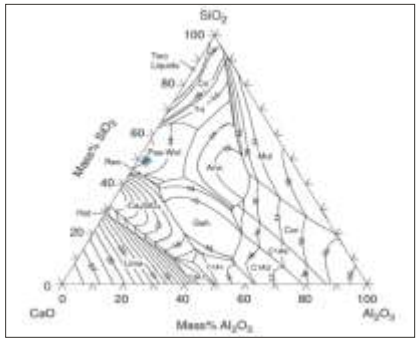
Peturgic method

Powder sintering

Sintering testing conducted at Imperial College:

- APC material obtained from UK EfW facility
- In vitrification trials blended feed: 69.8wt% APC, 21.9wt% SiO_2, 8.3wt% Al_2O_3
- Molten material quenched in water, fritted sample had particle size of ~5 mm.
- Plasma vitrified APC material and cullet glass (CG) separately milled to <250 µm
- Three compositions prepared:
  - i)100% APC
  - ii) 50% APC: 50% CG
  - iii) 100% CG
- 5 wt% bentonite binder was added to each batch, addition of 20% water added mixed in laboratory mixer
- Granulated spheres sieved at 1.18 mm
- Pressed in a rectangular die at 250 kg/cm^2
- Heated at rate of 10^{o}C /min and then soaked for 1 hour.





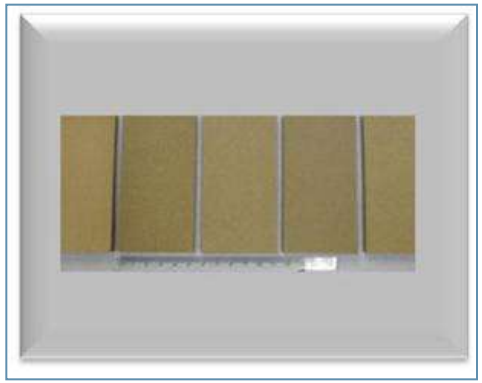
Properties of the sintered products

Properties	100APC			50:50 APC:CG	Floor tile standard[a]	Wall tile standard[a]	Multi purpose floor tiles[a]	Multi purpose wall tiles[a]	Wall tiles[b]	Floor tiles[b]	vitrified tile[b]	Porcelain tiles[c]
Firing temperature (^{o}C)	900	1000	1100	900	1200	1170	1200	1170	1060	1175	1175	1220
Density (g/cm^3)	2,4	2,4	2,4	2,2	-	-	-	-	-	-	-	2,42
Water absorption (%)	5,3	5,6	5,7	6	2,0	14,5	1,2	11,0	14,2	4,0	0,2	0,08
Linear shrinkage (%)	4,0	4,45	4,7	2,7	6,0	-0,2	5,0	0,6	0,9	4,0	5,8	-
Young's modulus (GPa)	95,5±4	90,3±3	86,6±3	62,1±6	-	-	-	-	-	38,7	-	-
Flexural strength (MPa)	60,6 ±2	61,1±1	58,3±1	31,2±7	48,32	27,33	46,53	30,0	1,62	-	60,0	61,0
Hardness (Hv) (GPa)	5,45±0,1	-	4,23±0,9	4,47±0,9	-	-	-	-	-		-	7,3

[a] Kara *et al.*,JECS (2006) (negative sign means expansion)
[b] Ghosh *et al.*,Industrial ceramics (2006)
(floor and wall tile – 90: 10 % pyrophyllite: clay;
synthetic vitrified tile – 50 : 50% pyrophyllite: clay)
[c] Carbajal *et al.* JECS (2007)

100 APC :100 wt% APC residues derived glass
50:50-APC:CG : 50wt% and 50 wt% mixed APC derived and cullet glass

Summary of 100 APC sintered tiles
Optimum properties at low firing temp (900^{o}C)
Density (g/cm^3): 2.4
Water Absorption (%):
Strength (MPa): ~60
Hardness (GPa): 5.45
Compare favourably with commercial tiles



Conclusion

- In the Gasplasma® process treating RDF from MSW:
  - Conversion to power and recovery of a vitrified product of low leaching potential
- The vitrified product from MSW conversion to power has properties suitable for use in aggregate applications and added value products:
  - low mechanical fragmentation, low sulphate leaching, good weathering and high frost resistance
- Air Pollution control (APC) residues used to produce saleable environmental products:
  - Properties of the APC derived glass-ceramic tiles compare favourably with typical commercial ceramic tiles

Thank You: Questions?

Chris Chapman, Chief Technical Officer

Advanced Plasma Power Ltd.

Unit B3

Marston Gate

South Marston Business Park

Swindon, Wiltshire

SN3 4DE

UNITED KINGDOM

www.advancedplasmapower.com

Tel: +44 (0)1793 238 550