Fly Ash Reclamation and Beneficiation Using a Triboelectric Belt Separator

L. Baker, A. Gupta, and F Hrach

ST Equipment & Technology LLC, 101 Hampton Avenue, Needham MA 02494 USA

CONFERENCE: WOCA 2019

KEYWORDS: Electrostatic, Beneficiation, Fly Ash, Landfilled, Ponded

ABSTRACT

Tribo-electrostatic separation has been used for the commercial beneficiation of coal combustion fly ash to produce a low carbon product for use as a cement replacement in concrete for over twenty years. With 24 separators installed in 17 locations across the world, ST Equipment & Technology LLC's (STET) patented electrostatic separator has been used to produce over 17.5 Million tons of low carbon product that has been recycled for use in concrete or cement production.

Commercial tribo-electrostatic beneficiation of fly ash has been performed primarily on dry "fresh" ash. Reductions in the quantity of dry fly ash generation and requirements to empty historical ash landfills and ponds has created the need to develop a process to reclaim and beneficiate landfilled or ponded ash.

The authors have determined the effect of moisture exposure on separation efficiency of multiple ash samples that have been reclaimed from landfills and ponds at the pilot-scale. Test results have demonstrated that concrete performance for the low carbon fly ash product produced using tribo-electrostatic separation is equivalent for reclaimed fly ash and "fresh" fly ash produced from the same source.

A technical and economic evaluation of tribo-electrostatic separation and combustion-based processes for beneficiation of reclaimed fly ash was performed. This study confirmed that the tribo-electric process is significantly lower total cost of operation and generates significantly lower air emissions than combustion-based processes for beneficiation of reclaimed fly ash.

INTRODUCTION

The American Coal Ash Association (ACAA) annual survey of production and use of coal fly ash reports that between 2000 and 2017, over 1.1 billion short tons of fly ash have been produced by coal-fired utility boilers in the United States.[1] Of this amount, approximately 460 million tons have been beneficially used, mostly for cement and concrete production. However, the remaining 640 million tons are primarily found in landfills or filled ponded impoundments. While utilization rates for freshly generated fly ash have increased considerably over recent years, with current rates above 60%, approximately 14 million tons of fly ash continue to be disposed of annually. While utilization rates in Europe have been reported higher than in the US, considerable volumes of fly ash have still been stored in landfills and impoundments in some European countries.

Recently, interest in recovering this disposed material has increased, partially due to the demand for high-quality fly ash for concrete and cement production during a period of reduced production as coal-fired power generation has decreased in Europe and North America. Concerns about the long-term environmental impact of such impoundments are also prompting utilities to find beneficial use applications for this stored ash.

LAND FILLED ASH QUALITY AND REQUIRED BENEFICIATION

While some of this stored fly ash may be suitable for beneficial use as initially excavated, the vast majority will require some processing to meet quality standards for cement or concrete production. Since the material has been typically wetted to enable handling and compaction while avoiding airborne dust generation, drying and deagglomeration is a necessary requirement. A greater challenge is assuring the chemical composition of the ash meets specifications, most notably the carbon content measured as loss-on-ignition (LOI). As fly ash utilization has increased in the last 20+ years, most "in-spec" ash has been beneficially used, and the off-quality ash disposed. Thus, LOI reduction will be a requirement for utilizing the vast majority of fly ash recoverable from utility impoundments.

LOI REDUCTION BY TRIBOELECTRIC SEPARATION

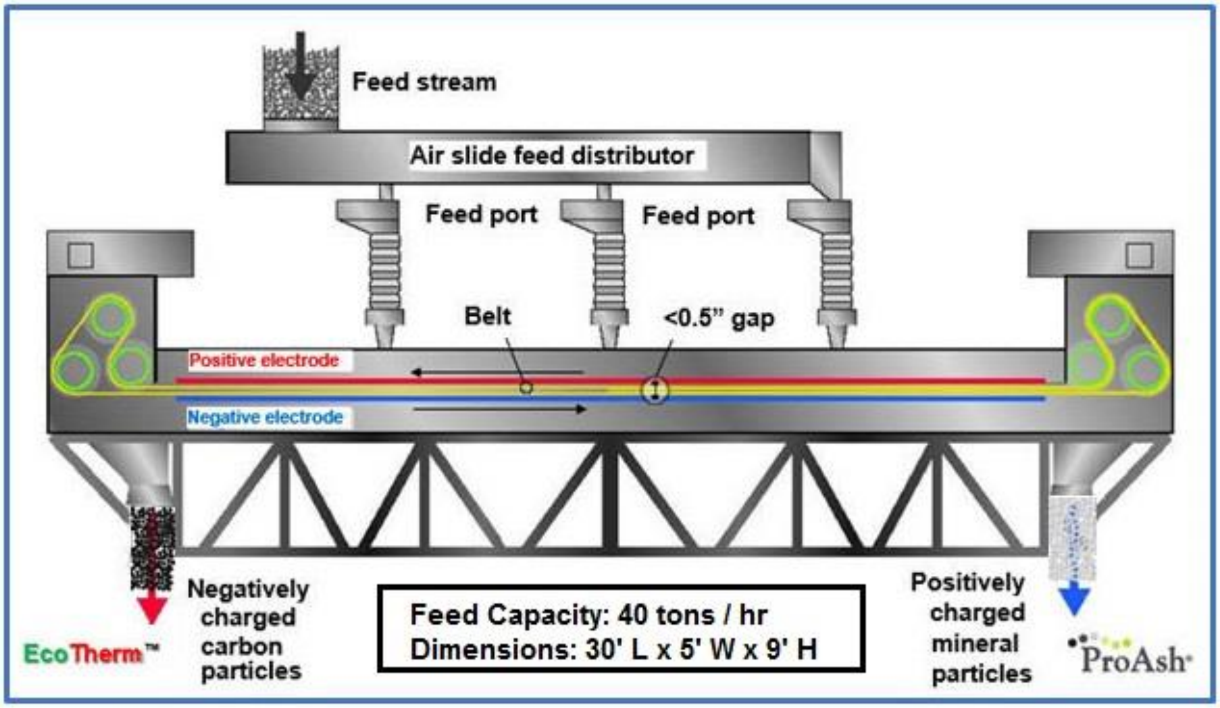
While other researchers have used combustion techniques and flotation processes for LOI reduction of recovered landfilled and ponded fly ash, STET has found that its unique tribo-electrostatic belt separation system, long used for beneficiation of freshly generated fly ash, is also effective on recovered ash after suitable drying and deagglomeration.

STET researchers have tested the tribo-electrostatic separation behavior of dried landfilled ash from several fly ash landfills in the Americas and Europe. This recovered ash separated very similarly to freshly generated ash with one surprising difference: the particle charging was reversed from that of fresh ash with the carbon charging negative in relation to the mineral.[2] Other researchers of electrostatic separation of fly ash carbon have also observed this phenomena.[3,4,5] The polarity of the STET tribo-electrostatic separator can easily be adjusted to allow rejection of negatively charged carbon from dried landfilled fly ash sources. No special modifications to the separator design or controls are necessary to accommodate this phenomena.

TECHNOLOGY OVERVIEW – FLY ASH CARBON SEPARATION

In the STET carbon separator (Figure 1), material is fed into the thin gap between two parallel planar electrodes. The particles are triboelectrically charged by interparticle contact. The positively charged carbon and the negatively charged mineral (in freshly generated ash that has not been wetted and dried) are attracted to opposite electrodes. The particles are then swept up by a continuous moving belt and conveyed in opposite directions. The belt moves the particles adjacent to each electrode toward opposite ends of the separator. The high belt speed also enables very high throughputs, up to 40 tons per hour on a single separator. The small gap, high voltage field, counter current flow, vigorous particle-particle agitation and self-cleaning action of the belt on the electrodes are the critical features of the STET separator. By controlling various process parameters, such as belt speed, feed point, and feed rate, the STET process produces low LOI fly ash at carbon contents of less than 1.5 to 4.5% from feed fly ashes ranging in LOI from 4% to over 25%.

Fig. 1 STET Separator processing dried, landfilled fly ash



The separator design is relatively simple and compact. A machine designed to process 40 tons per hour feed is approximately 30 ft. (9 m.) long, 5 ft. (1.5 m.) wide, and 9 ft., m (2.75 m.) high. The belt and associated rollers are the only moving parts. The electrodes are stationary and composed of an appropriately durable material. The belt is made of non-conductive plastic. The separator's power consumption is about 1 kilowatt-hour per tonne of material processed with most of the power consumed by two motors driving the belt.

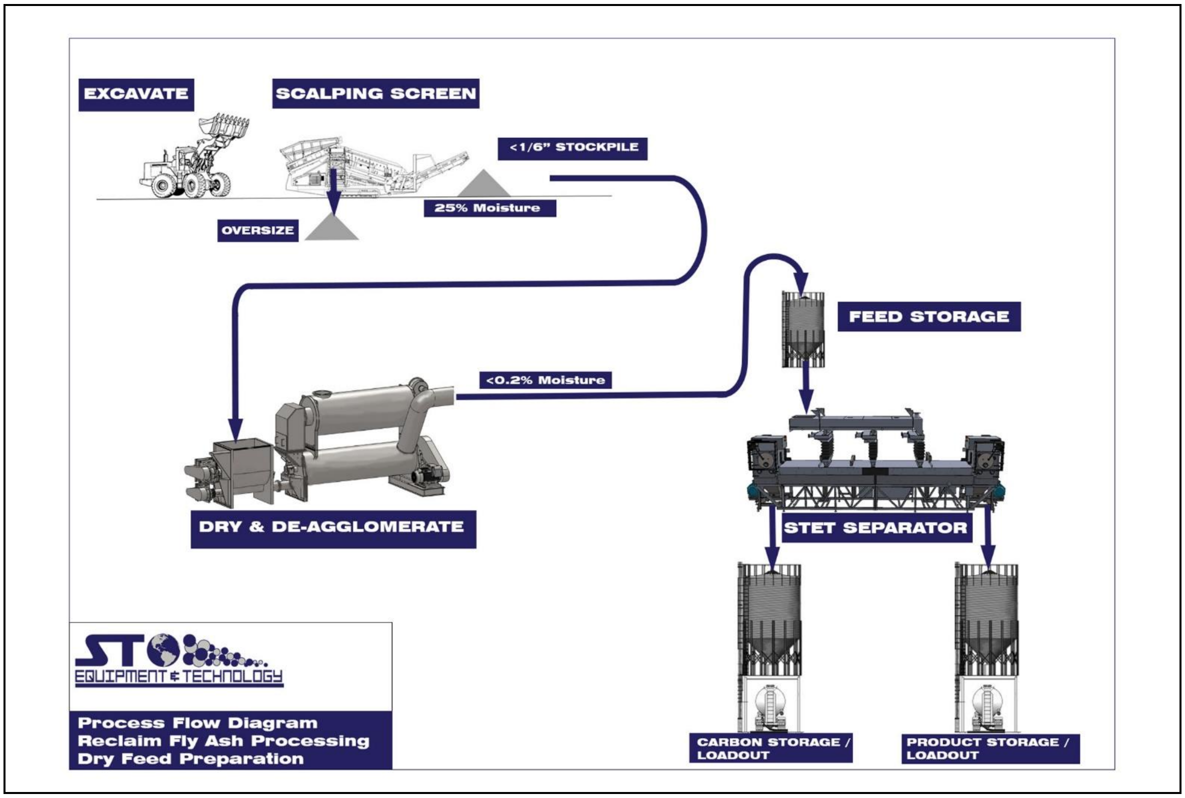
The process is entirely dry, requires no additional materials other than the fly ash and produces no waste water or air emissions. The recovered materials consist of fly ash reduced in carbon content to levels suitable for use as a pozzolanic admixture in concrete, and a high carbon fraction useful as fuel. Utilization of both product streams provides a 100% solution to fly ash disposal problems.

PROASH® RECOVERED FROM LANDFILLS AND PONDS

Seven (7) sources of ash were obtained from landfills and ponds: sample A from a power plant located in the United Kingdom and samples B, C, D and E from ash landfills and ponds the United States, and samples F and G from a source in France. All these samples consisted of ash from the combustion of bituminous coal by large utility boilers. Due to the intermingling of material in the landfills, no further information is available concerning specific coal source or combustion conditions.

The reclaimed fly ash moisture for each sample varied between 15% and 27% water as is typical for landfilled or dewatered pond material. The samples also contained varying amounts of large >1/8 inch (~3 mm) material. To prepare the samples for carbon separation, the large debris was removed by mechanical dry screening and the samples then dried and deagglomerated prior to carbon beneficiation. Several methods for drying/deagglomeration have been evaluated at the pilot-scale in order to optimize the overall process. STET has selected an industrially proven, feed processing system that offers simultaneous drying and deagglomeration necessary for effective electrostatic separation. A general process flow sheet is presented in Figure 2.

Figure 2: Process flow sheet



CARBON SEPARATION

Carbon reduction trials using the STET triboelectric belt separator resulted in very good recovery of low LOI products from all seven landfilled and ponded fly ash sources. The reverse charging of the carbon as discussed above did not degrade the separation in any way as compared to processing fresh ash.

The properties of the low LOI fly ash recovered using the STET process for both freshly collected ash from the boiler and ash recovered from the landfill is summarized in Table 1. The results show that the product quality for ProAsh® produced from landfilled material is equivalent to product produced from fresh fly ash sources.

Table 1: Properties of feed and recovered ProAsh®.

Feed Sample to Separator	LOI	ProAsh® LOI	ProAsh® Fineness, % +325 mesh	ProAsh® Mass Yield
Fresh A	10.2 %	3.6 %	23 %	84 %
Landfill A	11.1 %	3.6 %	20 %	80 %
Fresh B	5.3 %	2.0 %	13 %	86 %
Landfill B	7.1 %	2.0 %	15 %	65 %
Fresh C	4.7%	2.6%	16%	82%
Pond C	5.7%	2.5%	23%	72 %

Landfill D	10.8 %	3.0 %	25 %	80 %
Landfill E	6.1%	3.0%	20 %	91%
Landfill F	6.5%	3.0%	24 %	81%
Landfill G	8.4%	3.0%	34 %	80%

PERFORMANCE IN CONCRETE

The properties of the ProAsh® generated from the reclaimed landfill and pond material were compared to that of ProAsh® produced from fresh fly ash generated by the utility boilers from the same location. The processed reclaimed ash meets all the specifications of ASTM C618, AASHTO M250, and EN450 standards. The following table summarizes the chemistry for samples from two of the sources showing the insignificant difference between the fresh and reclaimed material.

Table 2: Ash Chemistry of low LOI product ash (wt% as oxides for major elements)

Material Source	**LOI**	**SiO2**	**Al2O3**	**Fe2O3**	**CaO**	**K2O**	**Na2O**	**SO3**
Fresh B	2.0	51.6	24.7	9.9	2.2	2.2	0.3	0.09
Landfill B	2.0	50.4	25.0	9.3	3.0	2.4	0.2	0.11
Fresh C	2.6	47.7	23.4	10.8	5.6	1.9	1.1	0.03
Pond C	2.5	48.5	26.5	11.5	1.8	2.4	0.2	0.02
Landfill D	3.0	49.8	25.7	16.6	1.6	1.25	0.1	0.03
Landfill E	3.0	63.0	21.3	6.5	0.7	2.4	0.5	0.05
Landfill F	3.0	52.5	25.9	6.7	4.5	2.0	0.8	0.6
Landfill G	2.9	53.9	28.2	5.2	1.7	4.2	0.8	0.1

Strength development of a 20% substitution of the low LOI fly ash in a mortar containing 600 lb cementitious/ yd^3 (See Table 3 below) showed the ProAsh® product derived from landfilled ash yielded mortars with strength comparable to mortars produced using ProAsh® from fresh fly ash produced at the same location. The end product of the beneficiated reclaimed ash meets specifications for use in the concrete and cement industry.

Table 3: Compressive strength of mortar cylinders.

	Fresh Ash		**Reclaimed STET process ash**	
Fly Ash Source	7 day (psi)	28 day (psi)	7 day (psi)	28 day (psi)
B	3948	5185	4254	5855
C	3860	5680	3750	5610
E			4040	4950

PROCESS ECONOMICS

The availability of low cost natural gas greatly enhances the economics of drying processes, including the drying of wetted fly ash from landfills and dewatered ash from ponds. Table 4 summarizes the energy costs for drying and deagglomerating feed ash for the STET separation process in the USA for 15%, 20%, and 25% moisture contents. The incremental costs for drying fly ash for STET tribo-electrostatic separation processing are relatively low.

Table 4: Drying costs on basis of dried mass.

Moisture content	**Fuel cost/ton dry feed**	**Power cost/ton dry feed**	**Total Energy Cost for feed Prep**
	Nat. gas @ $3.50/MMBTU	Electricity @ $0.10/kWh	
15 %	$2.25	$3.06	$5.31
20 %	$3.20	$3.06	$6.26
25 %	$4.30	$3.06	$7.36

A technical and economic evaluation of tribo-electrostatic separation and combustion-based processes for beneficiation of reclaimed fly ash was performed. This comparison assumed a hypothetical installation designed to produce 300 ktpy of concrete quality fly ash product using (1) two STET model F42 tribo-electric fly ash separation systems, compared to (2) a combustion-based system (SEFA STAR or Boral CBO). Feed preparation and product ash storage and loadout was included for each facility. Table 5 lists the design/input cost assumptions used in the evaluation and Table 6 summarizes the results of the economic comparison.

Table 5: Technology Comparison Basis

	Triboelectric Separation	**Combustion-based Process**
	Two STET F42 Separators	SEFA STAR III or equivalent
Product Ash Rate (kstpy)	300	300
Feed LOI	6%-10% (8% average)	
Feed Moisture	15%-25% (20% average)	
Feed particle size	Feed meets ASTM C618 fineness spec met after screening to 6 mesh	
Feed Chemistry	Meets ASTM C618 class F after screening No contamination from scrubber by-products	
Utilities-Natural Gas	$3.50/MMBTU	
Utilities-Electricity	$0.10/kWh	
Fluegas treatment -sulfur sorbent	Not needed	$150/ton delivered
Emissions	Nat gas dryer plus PM	NOx, SOx, CO, metals from fly ash carbon combustion and PM

Table 6 – Technology Cost Comparison

	Tribo-electrostatic Separation	**Combustion-based Process**
	Two STET F42 Separators	SEFA STAR III or Boral CBO
CAPEX (relative %)	100%	188%-192%
OPEX ($/ton product ash- relative %)	100%	90%
Total Cost of Operation (TCO)* for 10 yrs (relative %)	100%	130-135%

*TCO over 10 years was calculated from capital and operating cost assuming an 8% discount rate.

This study confirmed that the tribo-electric process is significantly lower cost and generates significantly lower air emissions than combustion-based processes for beneficiation of reclaimed fly ash. Since the only additional air emission source to the standard STET process installation is a natural gas-fired dryer, permitting is relatively simple.

STET has initiated design and equipment procurement for a new installation at a US utility site to demonstrate the utilization of the STET separation technology for reclaim and processing of landfilled and ponded fly ash sources.

STET ASH PROCESSING FACILITIES

STET's separation process has been used commercial since 1995 for fly ash beneficiation and has generated over 17.5 million tons of high quality fly ash for concrete production. Controlled low LOI fly ash ProAsh®, is currently produced with STET's technology at elevenlocations throughout the U.S., Canada, the U.K., Poland, Republic of Korea, Japan, and the Philippines. ProAsh® fly ash has been approved for use by over twenty state highway authorities in the USA. ProAsh® has also been certified under Canadian Standards Association and EN 450:2005 quality standards in Europe. Ash processing facilities currently using STET technology are listed in Table 7.

Table 7. Fly Ash Processing facilities using STET separation technology

Utility / Power Station	Location	Start of Commercial operations	Facility Details
Duke Energy – Roxboro Station	North Carolina USA	Sept. 1997	2 Separators
Talen Energy - Brandon Shores Station	Maryland USA	April 1999	2 Separators 35,000 ton storage dome. Ecotherm™ Return
New Brunswick Power Company Belledune Station	New Brunswick, Canada	April 2005	1 Separator Coal/Petcoke Blends Ecotherm™ Return
Talen Energy Brunner Island Station	Pennsylvania USA	December 2006	2 Separators 40,000 Ton storage dome
Tampa Electric Co. Big Bend Station	Florida USA	April 2008	3 Separators, double pass 25,000 Ton storage dome Ammonia Removal
RWE npower Aberthaw Station	Wales UK	September 2008	1 Separator Ammonia Removal Ecotherm™ Return
ZGP (Lafarge Cement Poland / Ciech Janikosoda JV)	Poland	March 2010	1 Separator
KOSEP Yeongheung Units 5&6	South Korea	September 2014	1 Separator Ecotherm™ Return
Taiheiyo Cement Co. Chichibu plant	Japan	February 2018	1 Separator
ZSPS (Lafarge Cement Poland/PGNiG Termika JV)	Poland	June 2018	1 Separator Ecotherm™ Return
Armstrong Fly Ash/Eagle Cement	Philippines	December 2018	1 Separator
KOEN Samcheonpo Power Plant	South Korea	Scheduled 2019	1 Separator Ecotherm™ Return

RECOVERED FUEL VALUE OF HIGH-CARBON FLY ASH

In addition to the low carbon product for use in concrete, brand named ProAsh®, the STET separation process also recovers otherwise wasted unburned carbon in the form of carbon-rich fly ash, branded EcoTherm™. EcoTherm™ has significant fuel value and can easily be returned to the electric power plant using the STET EcoTherm™ Return system to reduce the coal use at the plant. When EcoTherm™ is burned in the utility boiler, the energy from combustion is converted to high pressure / high temperature steam and then to electricity at the same efficiency as coal,. The conversion of the recovered thermal energy to electricity in ST Equipment &Technology LLC EcoTherm™ Return system is two to three times higher than that of the competitive technology where the energy is recovered as low-grade heat in the form of hot water which is circulated to the boiler feed water system. EcoTherm™ is also used as a source of alumina in cement kilns, displacing the more expensive bauxite which is usually transported long distances. Utilizing the high carbon EcoTherm™ ash either at a power plant or a cement kiln, maximizes the energy recovery from the delivered coal, reducing the need to mine and transport additional fuel to the facilities.

STET's Talen Energy Brandon Shores, NBP Belledune, RWEnpower Aberthaw, and the two facilities in South Korea all include EcoTherm™ Return systems.

CONCLUSIONS

ST Equipment & Technology (STET) offers a commercially proven processing technology for reducing the carbon (LOI) content of freshly generated dry fly ash. This proven tribo-electrostatic separation device has been used for the commercial beneficiation of coal combustion fly ash to produce a low carbon product for use as a cement replacement in concrete for over twenty years. Recent work by STET has demonstrated that this same commercially proven technology is suitable for processing recovered fly ash from ponds and landfills.

After suitable scalping of large material, drying, and deagglomeration, fly ash recovered from utility plant landfills and ponds can be reduced in carbon content using the commercialized STET triboelectric belt separator. The quality of the fly ash product, ProAsh® using the STET system on reclaimed landfill material is equivalent to ProAsh® produced from fresh feed fly ash. The ProAsh® product is very well suited and proven in concrete production. The recovery and beneficiation of landfilled and ponded ash will provide a continuing supply of high quality ash for concrete producers in spite of the reduced production of "fresh" ash as coal-fired utilities reduce generation. Additionally, power plants that need to remove ash from landfills or ponds to meet changing environmental regulations will be able to utilize the process to alter a waste product liability into a valuable raw material for cement and concrete producers.

The STET separation process with feed pre-processing equipment for drying and deagglomerating landfilled fly ash is an attractive option for ash beneficiation with significantly lower total cost and lower emissions compared to other combustion systems.

REFERENCES

[1] American Coal Ash Association, CCP Production and Use Statistics, https://www.acaa-usa.org/publications/productionusereports.aspx

[2] ST internal report, August 1995.

[3] Li,T.X,. Schaefer, J.L., Ban, H., Neathery, J.K., and Stencel, J.M. *Dry Beneficiation Processing of Combustion Fly Ash,* Proceedings of the DOE Conference on Unburned Carbon on Utility Fly Ash, May 19 20, Pittsburgh, PA, 1998.

[4] Baltrus, J.P., Diehl, J.R., Soong, Y., Sands, W. *Triboelectrostatic separation of fly ash and charge reversal,* Fuel 81, (2002) pp.757-762.

[5] Cangialosi, F., Notarnicola, M., Liberti, L, Stencel, J. *The role of weathering on fly ash charge distribution during triboelectrostatic beneficiation,* Journal of Hazardous Materials, 164 (2009) pp.683-688.

AUTHORS

Lewis Baker is the Senior Project Manager for ST Equipment & Technology (STET) based in the United Kingdom

Abhishek Gupta is Manager, Process Engineer based at the Separation Technologies pilot plant and lab facility, STET Technical Center, 101 Hampton Ave, Needham MA 02494 +1-781-972-2300

Frank Hrach is Vice President of Process Engineering based at the Separation Technologies pilot plant and lab facility, STET Technical Center, 101 Hampton Ave, Needham MA 02494 +1-781-972-2300