Point of Use Abatement Tool Selection and Evaluation

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Abstract

This report evaluates the benefits of utilizing point of use gas stream abatement tools in compound semiconductor manufacturing (and related industries). Point of use (POU) gas abatement equipment includes various sorts of scrubber and filtration equipment. These technologies include burners, water scrubbers, particulate scrubbers, and dry scrubbers. There are also hybrid tools that combine the features of several of the previously mentioned technologies such as combination burner and water scrubber systems.

In this report we examine the origins of point-of-use abatement and the motivations that are driving the growth of this mode of process emission treatment including the economic, EHS, and regulatory advantages. Point of use abatement equipment offers a number of advantages for both and existing manufacturing facilities. First, these devices offer economic benefits by reducing the total loading on end of line (EOL) equipment. This reduces the capital and operating costs associated with EOL systems. In addition, employing POU equipment can yield large increases in DRE due to the fact that POU tools can be specialized for a given process, while EOL tools by their very nature, must be general in scope. Finally, POU tools can increase plant safety and reduce facility maintenance by intercepting corrosive, particulate laden, flammable, and toxic gas streams immediately following the reactor so these streams do not have to be transported large distances to EOL abatement equipment.

We provide an overview of the decision matrix that an engineer should employ when choosing point of use abatement equipment for various processes. Two simultaneous challenges must be met in the CS field. First, tool effluent streams are often complex and care should be taken when choosing abatement to ensure that the selected POU device meets all of the air quality challenges. As various technologies for air quality control have varying efficiency for different types of contaminants, one must ensure capacity exists for meeting all challenges present in the process. At the same time it must be recognized that while a given abatement tool may be particularly effective for abating the gases of interest, if care is not taken during the selection process then the abatement tool may create new hazards such as unwanted reaction byproducts or through the creation of new environmental challenges such as water contamination.

Finally, we discuss how to evaluate the environmental, health, and safety performance of a point of use abatement tool. Topics discussed include the selection of appropriate metrology equipment for a given experiment, design of experiment for measuring performance, and evaluation of experimental data. We discuss how to properly calculate destruction and removal efficiency (DRE) by calculating dilution factors, verifying the true inlet and outlet gas flows, and evaluating the quality of the data used in the determination of DRE.

Section 1: Motivation for the Use of Point of Use Abatement

The earliest point of use abatement systems (POU) were designed to provide emergency abatement for difficult to scrub gases that provided unusual safety hazards. These gases could create catastrophic damage if they leaked form, or reacted within, the facility ducting. Hence, local scrubbers were developed to abate these gases as close to the point of origin as possible in order to minimize risk. Examples of these gases include silane (SiH_4), phosphine (PH_3), and arsine (AsH_3).

Another driving factor in the development of point-of -use technology was the desire to off-load abatement from central scrubbing systems. Many facilities have found that their end-of-line (EOL) scrubbing systems are nearly 100 percent utilized while the increasing complexity and larger flow rates in modern processes requires additional abatement capacity. Since adding additional end-of-line scrubbing capacity is very expensive and requires extensive permitting, the desire to reduce the loading on EOL systems is a major reason for increasing point-of-use scrubbing. POU scrubbers can actually meet new abatement requirements and reduce the loading on EOL systems.

Finally, point-of-use abatement can be directed toward process specific gas abatement and thereby increase DRE on those gases. In addition, POU abatement enables the EHS engineer to more closely track waste discharge and capture in order to demonstrate compliance with environmental regulations.

As an example of the benefits mentioned in the preceding paragraphs we will consider the ramifications of utilizing only a central scrubber for the abatement of an MOCVD process vs. the benefits of utilizing a POU system on MOCVD in addition to a central system.

First, let’s assume a generic MOCVD system using arsine and phosphine gas in a hydrogen carrier. The first problem we will encounter with the EOL only solution is that arsine and phosphine gas will be transported in house ducting for long distances. A leak of these highly toxic gases in the house ducting would, at a minimum, require a facility evacuation and resultant loss of production until the leak was repaired and the environment sanitized. The leak of phosphine and hydrogen could also cause a fire and significant property damage. In addition to the foregoing, this leak would invite regulatory scrutiny for the creation a work-place hazard.

The second problem from the use of an EOL only solution would be the deposition of flammable phosphates and toxic arsenic compounds in the ducting and on any blowers or ancillary equipment involved in moving the gas stream.

Finally, the EOL system would create several compliance problems. First, it would most likely have less than adequate destruction and removal efficiency (DRE) on the hydride gases (which are regulated to very low levels). Moreover, the toxic arsenic would contaminate solid waste from a burner or water used in a wet scrubber and create a very large new hazardous waste stream.

In contrast to the EOL only solution, with a point-of-use fixed bed adsorption system on an MOCVD process running arsine, phosphine, and hydrogen the facility engineer will be able to do the following:

A. Remove the highly dangerous arsine and phosphine molecules immediately after the reactor. This prevents the need to transport the hazardous stream through house ducting for long distances and greatly reduces the risk of facility shut down or damage and the potential injury or death to employees associated with those ducting runs

B. Provide redundancy in abatement so that the loss of the EOL system does not result in a release to the environment (and the regulatory and community relations nightmare associated with such an excursion).

C. Enable destruction and capture of toxic gases to the point where releases are not detectable at the scrubber discharge. In addition, this solution enhances compliance by capturing the toxins locally so that the EHS engineer can completely close the mass balance on the regulated substances for compliance purposes.

D. Greatly reduce the loading on EOL systems thereby increasing EOL capacity and enabling the factory to add or modify processes without extensive delays and expense for permit modification.

E. In many regulatory environments POU equipment is considered part of the process tool to which it is attached. This, in turn, lowers the facility's potential to emit (PTE). Lowering PTE can yield significant regulatory and community relations advantages.

Given the foregoing, it should be clear that POU scrubbers could offer many benefits to a compound semiconductor manufacturing facility. Next, we will examine the considerations that should be addressed when choosing the appropriate POU technology for various processes.

Section 2: Selection of Point of Use Abatement

When selecting abatement for a factory the axiom "caveat emptor" certainly applies. That is, the buyer must beware. In an ideal world the facility or EHS engineer could rely upon external consultants and vendors for an honest and accurate assessment of abatement tool application. However, very few external vendors or consultants know a facility as well as the engineers working at the facility. Also, the level of expertise available for analyzing a waste stream varies wildly from vendor to vendor. And finally, the engineer must realize that vendors will often slant an appraisal of technology so that the suggested product mix matches that vendor's offering. This of course, is not in the consumer's best interest and a proper education in selecting and evaluating abatement tools is required to make an informed purchase.

Following is a summary of questions an engineer must consider when selecting any abatement device.

A. What are the correct and most efficient technologies to abate the waste stream?
B. If more than one technology can abate the discharge stream then which POU abatement system can provide the most efficient and economical methods to scrub the gas stream?
C. Is a custom design POU abatement system necessary for the process?
D. Are the facilities available to support the assigned POU system being considered? If not, will budget be available to modify the facility?
E. Can the system abate the waste stream form the reactors to acceptable levels?
F. Will the abatement system be the source of new waste streams such as NOx, metal contaminated water, unburnt hydrocarbon, or contaminated ash?

G. Can the abatement system handle particulate generated in the reactor?
Will the abatement systems intrude upon or impede production?

The first task that should be undertaken in the selection of POU equipment is developing a complete profile of the processes to be abated. This includes all gases used in the reactor and any possible changes to the recipe in the future. A common mistake when characterizing a process for abatement is to only consider certain key gases while excluding inerts or gases that are not priorities for point of use abatement. There are number of reasons why complete characterization is required. First, the information is required to determine concentration and total gas loading – key parameters in POU design and rating. Second, the gases that enter a reactor are often not the same as the gases that leave a reactor. The chemical reactions, high temperatures and any plasma used in the reactor ensure that the reactor discharge is quite different from the feedstock to the reactor.

Point-of-use abatement systems generally utilize one or more of the following air pollution control methods: thermal destruction, chemical reaction, adsorption, and absorption. Common scrubber implementation of these technologies include the following components:

- Burners
- Chemical reaction beds
- Dry adsorption beds
- Wet scrubbers

Within each of the aforementioned technologies there are many permutations and a detailed breakdown of all these is beyond the scope of this paper. However, we will lay out a basic hierarchy for the decision making process so that the engineer can identify a basic strategy and can then supplement his or her knowledge of that technology to better decision.

Perhaps the most important point that the engineer should remember when evaluating a scrubber is this. Mass in always equals mass out. If some molecule enters the scrubber it will either be captured in the scrubber or transformed into another species or transferred to another media. The facility manager must be able to identify which of these has occurred and be able to demonstrate the same to regulatory officials. This consideration is of great importance for a number of reasons. First, if metals or highly toxic substances are used the engineer must recognize whether a given technology will safely remove these materials and enable the engineer to track them without creating a new, dangerous, and expensive to treat waste stream. This performance must be verifiable to regulators and other key stakeholders.

There is no “best” POU technology. The technology employed should appropriate to the task at hand. All of the basic scrubber types can provide high efficiencies on some processes while providing poor efficiencies on others. The technology effectiveness matrix shown in Table 1 gives a general breakdown of scrubber application. When examining the table remember that it is a general guideline and that a detailed study must be made when applying the solution to a specific abatement challenge. In the matrix shown in Table 1 the rating is assigned on the basis of tool uptime and efficiency. However, the table also considers whether the application of the assigned technology creates a new waste challenge that is unacceptable. For example, a thermal wet system may have high destruction efficiency for a metal organic. However, in the process of abating the gas stream heavy metals would transfer to the water and this is not acceptable.

Also, Table 1 implicitly considers the required standard of abatement on certain gases. For example, if the required standard for abatement (from a regulatory and safety standpoint) is not met by a given technology then a rating of poor is assigned – even if the nominal DRE is very high.

	Dry Scrubbing	Wet Scrubbing	Thermal	Combination Thermal Wet	Plasma	Heated Catalyst	Combination Heated Catalyst Wet
Challenge Gas Type							
VOC	E	P	E	E	E	E	E
Hydride	E	P	M	P	P	M	M
Flammable	E	P	E	E	E	E	E
Pyrophoric	E	P	E	E	E	E	E
Corrosive	E	E	P	E	P	P	E
Toxic	E	P	M	M	M	M	M
Metalorganic	E	P	P	P	P	M	P
NOx	E	P	P	M	P	E	E
PFC	P	P	M	P	E	E	E
Fouling	M	M	E	E	P	P	M

Table 1: Technology effectiveness matrix for application of common POU tools by application. E indicates excellent, M indicates moderate, and P indicates poor. For cases in which an abatement tool will generate an unacceptable transfer of toxin to another media a poor rating is assigned (for example, if a water scrubbing stage results in the transfer of a heavy metal from a gas to the discharge water a rating of poor is assigned regardless of the removal efficiency in the gas abatement section).

As the engineer chooses an appropriate abatement technology for a given process in a given facility they should do a stepwise consideration of effectiveness and facility capacity to arrive at one or two appropriate technologies to investigate closely. An example of the decision tree employed in applying an abatement technology in a manufacturing facility is shown in Figure 1.

The general principles to be considered when invoking the decision process as shown in Figure 1 include the following:

A. The technology must exhibit safety and the effectiveness required by law when abating a given process stream.
B. If a water scrubber (thermal-wet or standalone water) is part of the solution the facility must have water and the capability to treat contaminated wastewater from the scrubber.
C. If a water scrubber (thermal-wet or standalone water) is part of the solution the process must not transfer any regulated toxics, organics, or heavy metals to the water. For example, wet scrubbing of arsenic bearing gases would be proscribed.
D. If burning is part of the solution the material must be able to be combusted to the limits required for safety and regulatory compliance. In addition, no toxic materials can be discharged to the air or to any ash residue. For example, burning of mercurous compounds would be proscribed.
E. Often abatement technologies transfer a waste from one media to another (for example, from air to water). The facility must have the ability to successfully handle any new waste stream created.

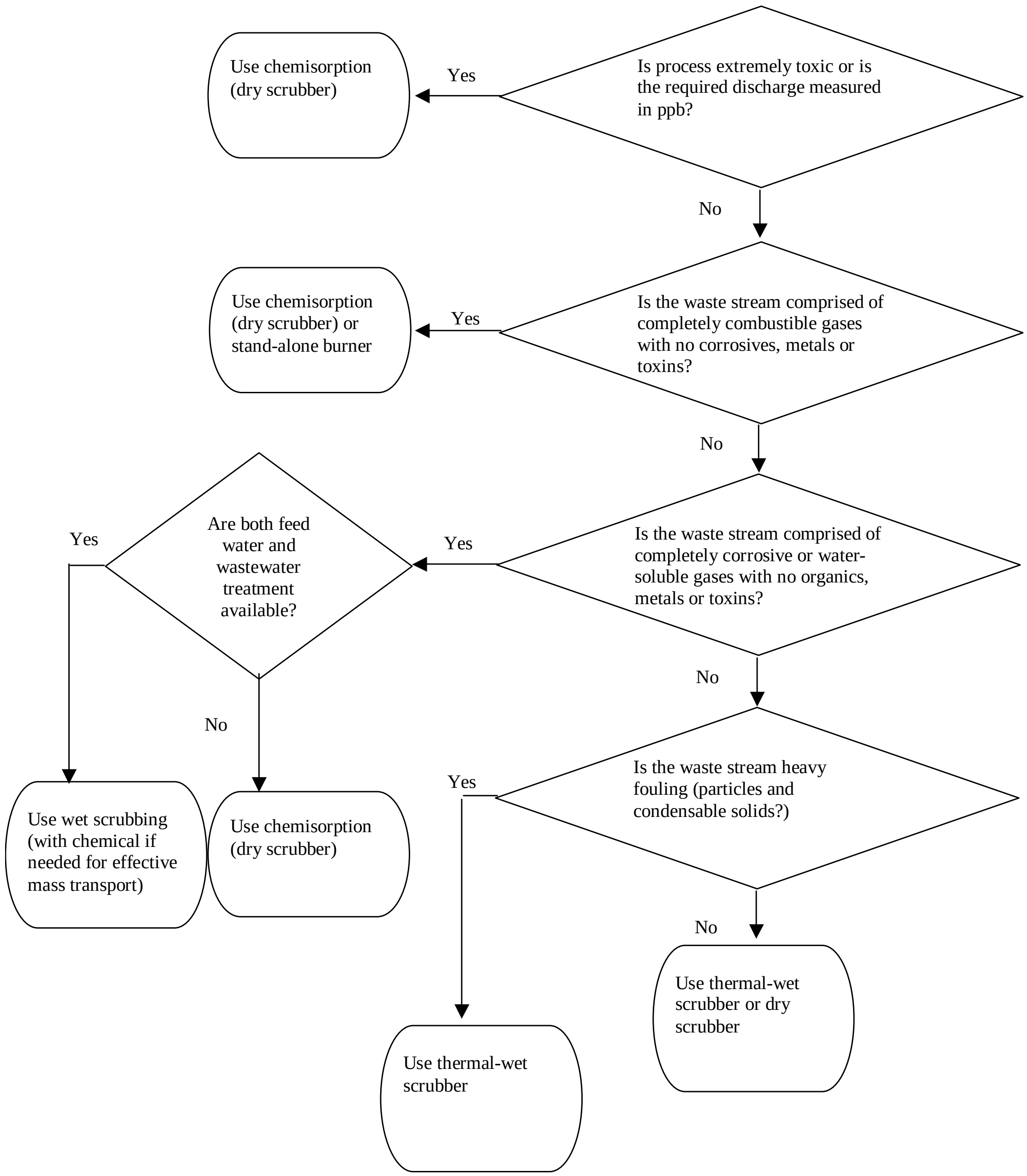

Figure 1: Example of an effective decision matrix for selecting an effective POU technology for a given process with consideration for facility capability.

Section 3: Evaluating the Environmental, Health, and Safety Performance of a Point of Use Abatement Tool.

The metrics used to evaluate a POU abatement tool are really the same criteria used in selecting an abatement tool. These include:

- Effectiveness as abating the waste stream
- Impact on process or facilities
- Performance as measured by mean time between failure (MTBF) and mean time between intervention (MTBI)
- Safety history (burns, shocks, spills, etc.)
- Cost of Ownership (including waste water treatment, solids disposal, utilities, air loading, etc.)

The engineer should consider all of the foregoing when measuring POU tool effectiveness. In this discussion we will concentrate on the measurement of tool performance with regard to measuring destruction and removal efficiency (DRE).

For purposes of daily operations the scrubber owner has a number of options. Chemical cells or tapes can provide effective performance monitoring for many, but not all, gases. These devices can be installed in the ductwork or often are supplied as part of the POU tool package. For flammable gases flame detectors are often a good choice. When PFCs are involved the facility generally must use narrow band IR, NDIR, or in situ mass spec.

The facility should employ a more rigorous gas testing procedure shortly after installing abatement and regular intervals for the following reasons.

- To ensure the tools meet performance guarantees made by the scrubber manufacturer
- To ensure the tools are properly installed
- To ensure no health or safety risks exist at the outlet of the scrubber
- To verify compliance with regulatory guidelines
- To develop quantitative data for annual emission reporting

When performing emission testing care should be taken when selecting the metrology equipment used. For those gases that respond well to FTIR this technology is an excellent tool as it is fast, accurate, and provides permanent evidence of data through saved interferograms. Organics, most acid gases, and many PFCs are well suited to FTIR.

For binary gases such as fluorine, chlorine, and bromine, FTIR is not a suitable technology. In this case mass spectroscopy is a good choice for measurement within the manufacturing facility.

Most good testing processes will utilize both FTIR and mass spec as these two technologies can collectively identify and quantify almost all components in the waste stream. When implementing a testing program a solid design of experiment should developed that ensures that the metrology equipment is properly calibrated before and after the test. This is usually done by means of a multipoint test using inert gases to determine actual and diluent flow rates and multiple runs of gases of interest across the range they are likely to be found at the tool discharge.

After properly calibrating the metrology equipment testing should be accomplished across the range of possible operating conditions on the process tool. In addition, the scrubber operating parameters should be varied across the range of parameters in which it may be operated during normal processing. For example, if a burner uses multiple flame temperatures or fuel to air mixtures then performance should be tested under all of these possible modes.

At the conclusion of testing a report should be assembled detailing the following.

- DRE of all gases of interest
- Maximum and average concentration out of all gases of interest
- Percent of concentration reduction due to dilution as opposed to destruction or capture
- New waste products generated by the scrubber (e.g. NO or NO2)
- Proof of baselining and calibration of metrology instruments

When measuring scrubber exhaust the most important concern is that the scrubber should abate all gases to acceptable safe concentration limits regardless of DRE. For example, even if DRE is very high it is still not acceptable to have discharge of a toxic gas above IDLH or known regulatory standards. For example, if an inlet stream bearing 2% fluorine in total flow of 50 liters were fed to a scrubber that diluted the stream at a 2:1 ratio and removed fluorine with an dilution effectiveness of 99.9 % the outlet concentration of fluorine would be 20 ppm – an unacceptably high concentration for this dangerous gas.

Another important concern when evaluating scrubber performance is dilution. Most scrubbers use air or nitrogen as part of the treatment process and these gases will affect the concentrations at the discharge of the scrubber. This is perfectly acceptable as long as the scrubber still effectively abates the gases without regards to aid from dilution. The user must understand that dilution is not socially acceptable nor is it acceptable from an EHS perspective. Furthermore, dilution for the purpose of evading compliance is not a defensible regulatory position and will inevitably lead to compliance issues. Remember, measuring abatement tool performance is simply a mass balance. The engineer should account for all gases entering the scrubber and all gases leaving the scrubber. Only those moles removed from the gas stream count towards DRE as shown in the equations below.

DRE = (Moles of species out - Moles of species in) ÷ Moles of species in

DRE = ((Outlet concentration x DF) – Inlet concentration)) ÷ Inlet concentration

Where

DF (dilution factor) = Total flow out ÷ Total flow in

The dilution factor accounts for the addition of air, nitrogen, and oxygen in the scrubber. In to calculate true performance these gases must be measured before, during, and after the testing.

Testing itself may be accomplished real time or through the use of samples collected in bags at discreet points in time. There are benefits to both methods and the appropriate EPA protocol should be employed regardless of which method is chosen.

Section 4: Summary

The keys to selecting and measuring the performance of a POU scrubber can be summed up in the following points.

- The abatement tool should not impede the performance of the process tools any more than is absolutely necessary
- The abatement tool must perform its primary function and abate the gases of interest
- The abatement tool should be reliable and have good uptime on the process of interest
- The abatement tool must be selected with consideration to available resources and facilities
- Performance of the tool should be measurable and should be verifiable for regulatory purposes

Of course, it must be recognized that abatement science is a highly specialized field and the facility engineer should rely upon experts from the consulting and scrubber manufacturing industry for advice before spending large sums of money and purchasing devices that are key to the health and safety of the workers in a facility and the surrounding community. The purpose of this document is to give the buyer of abatement tools a background from which to develop questions and evaluate information and suggestions presented with regards to the selection of the scrubbers. By applying the same diligence and engineering standards to abatement tool selection as to process tool selection the engineer can ensue that her facility has the highest EHS compliance with minimum cost and risk.