Results of the ISMI ESH Technology Center Greenhouse Gas Facility Survey

International SEMATECH Manufacturing Initiative
Technology Transfer #09065012A-TR

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Abstract: This report from the International SEMATECH Manufacturing Initiative (ISMI) ESH Technology Center (ESHT001) presents the results and analysis of a greenhouse gas facility survey of ISMI and Semiconductor Industry Association (SIA) members. The purpose was to gather facility-specific data on the impact on fab operations of Environmental Protection Agency's proposed Mandatory Greenhouse Gas (GHG) Reporting Rule published in the Federal Register on April 10, 2009. Results of other surveys in this series are in Technology Transfers #09065014A-TR and #09065015A-TR.

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1 EXECUTIVE SUMMARY

In support of the industry's response to the U.S. Environmental Protection Agency (EPA) proposed rule Mandatory Reporting of Greenhouse Gases, the International SEMATECH Manufacturing Initiative (ISMI) and the Semiconductor Industry Association (SIA) developed and sent to their members a series of surveys to collect technical data on greenhouse gases (GHGs). The first survey gathered facility-specific data on the impact of the proposed rule on semiconductor manufacturing facilities.

Twenty-one responses were received from companies representing 58% of total U.S. silicon area production capacity. Survey respondents included 25 of the EPA's estimated 29 large fabs.

Results showed that the industry is not currently collecting significant portions of the data required by the proposed rule. The rule also requires that the industry spend large amounts of money and devote significant resources to track process GHG emissions. The final year compliance costs will be 26X to 44X greater than estimated by the EPA, and it is not clear whether the required data will be more accurate than what is already being generated.

2 BACKGROUND

The EPA's Mandatory Reporting of Greenhouse Gases was published in the Federal Register on April 10, 2009, beginning the 60-day comment period. The preamble explains the EPA's basis for the proposed rule. Subpart I outlines specific requirements for semiconductor manufacturing facilities. After reviewing the preamble and proposed rule, semiconductor industry members felt strongly that accurate data reflecting industry practice and assessing the cost impact of the rule must be collected and analyzed by a third party. ISMI's Environment, Safety, and Health Technology Center was asked to develop surveys, collect survey responses, and complete data analysis for ISMI and SIA members. Data analysis has been completed independent of the SIA to preserve respondent confidentiality.

3 SURVEY OVERVIEW

The survey consisted of the following parts:

- Background: Brief overview of the proposed rule and its requirements.
- Definitions of the terms used in the rule and survey.
- Part 1: General Facility Information
- Part 2: Information to Scope the Size and Cost of Fluorinated GHG and Nitrous Oxide (N_2O) Emissions Characterization Efforts—Data was used to estimate the potential scope and cost impact of process and point-of-use (POU) abatement emissions characterization that would be required of the industry under the proposed rule.
- Part 3: Information on Perfluorocompound (PFC) and N_2O Gas Distribution and Measurement of Gas Usage—Data was used to determine the way process GHGs are distributed in semiconductor fabrication lines (fabs), and methods by which gas consumption is currently tracked and the installation and operational costs to comply with the gas consumption measurement requirements of the rule.

- Part 4: Combustion Related Emissions
- Part 5: Recordkeeping and Reporting Requirements

The report compares the proposed requirements with industry practice in estimating GHG consumption, characterizing GHG POU abatement, and estimating GHG emissions. Recordkeeping and reporting practices are also summarized; however, N_2O and combustion-related emissions are not addressed.

4 SURVEY RESPONSES

Twenty-one responses were received from the U.S., representing 12 companies and 32 fabs. The respondents make up 58% of total U.S. production capacity based on silicon area (*World Fab Watch*, February 2009) and represent one-third of the EPA's estimated 91[1] semiconductor fabs that must report under the proposed rule. Under the proposed rule, large fabs (i.e., annual production capacity ≥10,500 m^2 silicon) have more stringent reporting requirements than other fabs (annual production capacity <10,500 m^2 silicon but ≥1,080 m^2 silicon); 71% of respondents were large facilities and the remaining 29% were not considered large but will still be required to report. The large facility respondents represent 9 companies, 17 facilities, and 25 fabs or 86% of the EPA's estimated 29 large U.S. fabs.

Responses were also received from four facilities located outside the U.S.; however, the survey results discussed herein are for U.S. respondents only.

4.1 Estimating Gas Consumption

4.1.1 Proposed Rule Requirements and Implications

The proposed rule requires the subject semiconductor facilities to

- Monitor changes in container mass and inventories using weigh scales with ±1% full scale accuracy or better

  or

- Monitor the mass flow of pure gas into the system using flowmeters with ±1% full scale accuracy or better (April 10, 2009 FR, p.16649).

Scales and flowmeters must be calibrated using suitable National Institute of Standards and Technology (NIST)-traceable standards and suitable methods published by a standards organization or, alternatively, calibration procedures specified by the manufacturer. The scales and flowmeters must be recalibrated at least annually or at a frequency specified by the manufacturer, whichever is more frequent (April 10, 2009 FR, p.16650).

Because emissions must be estimated by process type (CVD or etch), gas consumption must be tracked using Tier 2b methods at a minimum. Large facilities may be required to track consumption at the process equipment level. If flowmeters (e.g., MFCs) are used, software modifications or additional software to total the gas flow is required.

[1] Clarified with D. Ottinger on May 27, 2009, that EPA compliance estimates are based on number of fabs, not facilities. EPA estimates the rule will apply to 91 fabs and 29 fabs are large fabs under the rule.

4.1.2 Survey Questions

The additional required resources to track gas consumption according to the proposed rule will vary among fabs based on existing infrastructure (e.g., process gas distribution systems and gas consumption monitoring methods).

Figure 1 shows the survey questions asked to determine gas supply infrastructure and the expected cost to comply with the proposed rule's gas consumption monitoring requirements.

1. How are CVD and etch gases distributed within your facility (check all that apply):

- ☐ **Individual gas cylinders feed individual process chambers**
- ☐ **Cylinders feed multiple like process chambers (etch-only or CVD-only)**
- ☐ **Bulk distribution systems feed multiple process types and chambers**
- ☐ **Other (please describe)**

2. Please indicate how gas consumption is monitored at your facility (check all that apply):

- ☐ **Estimated based on purchases and assuming a heel factor**
- ☐ **Measured by weighing cylinders before and after each cylinder change on scale with 1% accuracy/precision or better**
- ☐ **Measured with mass flow controllers with 1% accuracy/precision or better**
- ☐ **Measured by weighing cylinders before and after each cylinder change on scale with less than 1% accuracy/precision**
- ☐ **Measured with mass flow controllers with less than 1% accuracy/precision**
- ☐ **Other (please describe)**

3. What is or would be the additional cost to your facility (installation costs), for compliance with the gas consumption measurement requirements of the proposed rule (include cost of scales, distribution modifications, MFCs, data collection systems, etc.). Please provide answer in $US Dollars.

4. What is or would be the additional cost to your facility (operating costs), for compliance with the gas consumption measurement requirements of the proposed rule? (e.g. calibration by NIST or manufacturer recommended procedure, software/hardware maintenance, general preventive maintenance, data collection and analysis costs) Please provide answer in $US Dollars.

5. Provide any additional comments regarding installation and/or operating costs.

Figure 1 Survey Questions to Determine Gas Supply Infrastructure and Compliance Cost of Gas Consumption Monitoring Requirements

4.1.3 Survey Results and Analysis

Respondents use a variety of methods to distribute gases to process equipment; 11 of 21 use more than one method within their fab(s). Two respondents use only individual gas cylinders to feed individual process chambers; neither gathers gas consumption data by process but, instead, estimates consumption based on gas purchases, assuming a 10% heel as described in the 2006 Intergovernmental Panel on Climate Change (IPCC) guideline (IPCC2006, Vol.3, 6.16). Eight respondents use only bulk distribution systems or large cylinders to feed multiple process types

and chambers; seven of these respondents estimate gas consumption based on gas purchases and assumed heel factor.

As seen in Figure 2, 81% of respondents monitor gas consumption by tracking purchases and assuming a heel factor; 24% use scales with ±1% accuracy to track some gas consumption. None of the respondents use mass flow controllers (MFCs) with ±1% accuracy as required by the proposed rule.

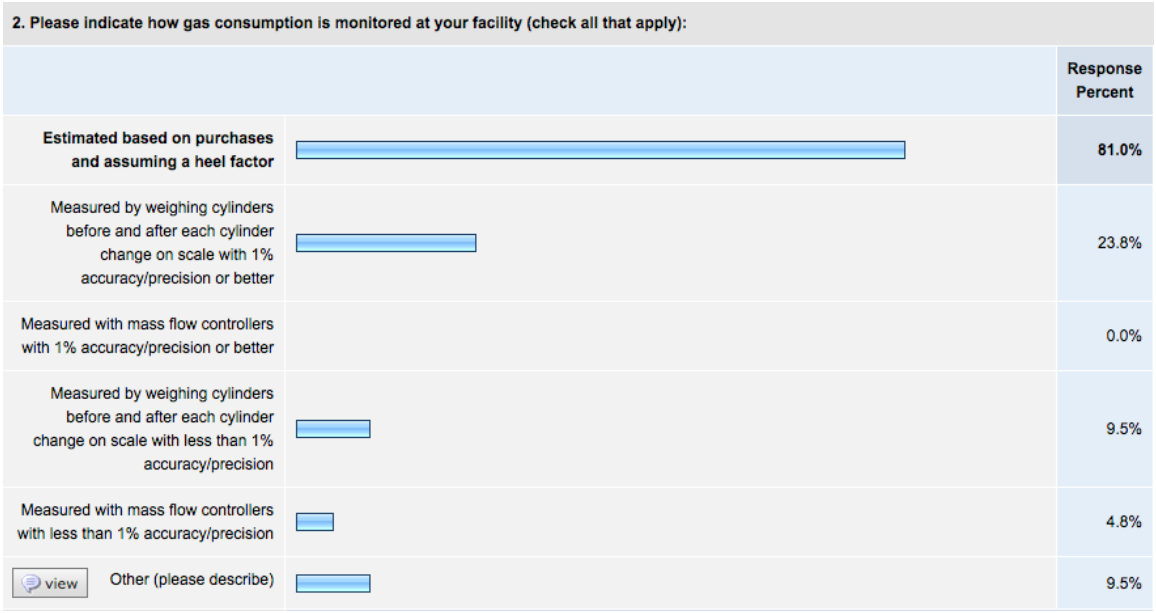

Figure 2 Gas Consumption Monitoring

The survey revealed several EPA misperceptions about the industry and its gas consumption tracking.

EPA Statement	Industry Practice
"Information on gas consumption by process is often gathered as business as usual…" (p16498).	62% of respondents have some bulk gas distribution feeding multiple tools and process types; 67% have some cylinders feeding multiple chambers and processes. For these respondents, consumption is not tracked by process.
"…electronics manufacturers commonly track fluorinated GHG consumption using flow metering systems calibrated to ±1 percent or better accuracy" (p16498).	80% estimate consumption based on purchases and assumed heel factor. 25% track by weighing some cylinders to ±1% accuracy. One respondent measures some usage with MFCs. None use MFCs with ±1% accuracy.

Although the industry uses MFCs within process equipment, they regulate gas flow rates and do not track gas consumption, which would require new or modified software. Additionally, respondents indicated that, although newer (<5 year old) process equipment may contain digital MFCs with ±1% full scale accuracy, much of the current installed base of process equipment is equipped with analog MFCs. These analog MFCs are not accurate to ±1% full scale and do not provide the digital output required by most control systems.

Survey respondents provided additional comments about how they currently track gas usage[2]:

- Scales are adjusted to zero without the cylinder on them. Using our cylinders weights (40 and 200lbs), scales are spanned to >60% full scale. The weights are verified themselves against the dock shipping scale (which is in the company cal program).
- The true weight of the gas is listed on the incoming cylinder spec. When the cylinder pressure reaches the fixed changeout pressure, it is changed. At this fixed pressure, the remaining quantity in the cylinder is known (PV = nRT) and is provided by the gas supplier.
- From a gas supplier supporting a respondent facility: We… do not calibrate our scales in the classical sense. We routinely conduct a performance verification during every cylinder change where we track the cylinder depletion using mass or scales. Historically, the term calibrate would refer to a quantitative method of generating a multipoint or 2-point calibration curve in which a know[n] mass or volume material is measured against a know[n] instrumental or equipment response. The equipment response is then adjusted to reflect the known values for the calibration curve. For the case of a scale a two point zero and span calibration reflects a linear relationship between mass and mV or mA output. Early in 2001 the ISO movement also required standards traceability, certifications, tamper proofing and records keeping. We do not have the manpower, facilities, or equipment to fully comply with the ISO requirements. As a result, we provide performance verifications and not calibrations. Our method of performance verification is very similar to calibration however it will not include requirement associated with tracking. certifications, tamper proofing or records keeping. We do use a 2-point, zero and span process in which we zero the scale by manually adjusting the zero potentiometer and span the scale by placing a know[n] traceable mass on the scale usually 25 lbs. and adjust the span potentiometer to read the correct value. Equipments … which require a true "calibration" are periodically certified by a 3rd party supplier of that service.

Respondents also expressed concern about implementing the gas consumption tracking requirements under the proposed rule. MFC manufacturers suggest that MFCs with ±1% accuracy be removed and shipped back to the manufacturer for annual calibration, requiring process equipment to be shut down and spare MFCs to be stocked. Respondents indicated that newer tools regulate flow with digital MFCs but that software changes are required to allow total consumption to be tracked. For older process equipment, some were able to estimate the cost of installing MFCs on each gas line at each tool and a data tracking system; others said they could not retrofit older equipment because of insufficient space.

Additionally, respondents indicated the following problems with the gas consumption tracking requirements[3]:

- Gas supplier indicates ±1% accuracy can't be achieved. Could probably get ±2% accuracy with new controllers, valves and monitoring systems.

[2] Responses are quotes from the survey with company names omitted.
[3] Responses are quotes from the survey with company names omitted.

- The gas systems engineer is not really sure if we can get that accuracy [±1%]... We have one MFC that is capable of ±2% precision/accuracy.
- Calibration would require evacuating the gas lines and purging all PFCs directly to the environment and would shut down all tools connected to the bulk system, significantly impacting production in our factories.
- If this is included in final rule, there is not enough time to implement changes to begin measuring at this level by Jan 1st to comply with 2010 adoption. Gas supplier indicates ±1% accuracy can't be achieved.
- Scales are basically of no value for cylinders with non-liquid gases.
- Review of a sample of PFC gas distribution systems indicated that 40%–50% of existing systems would need to be modified to segregate gas usage by process and platform for Tier 3 emissions inventory. Cost is for purchase and installation of additional gas distribution infrastructure only, and does not include cost of scales, or of equipment down time and lost production. It is likely that the systems could not be satisfactorily reconfigured, even at this high cost, due to the space constraints of the pre-existing fab layout.
- Most MFCs are calibrated to a Nitrogen standard – it was estimated that 95%+ of MFCs in our factories. You would have to have a correction factor for each MFC in each GHG. This is not done and characterizing this for each individual MFC if possible would be a multi-year and continual process as MFCs are recalibrated and replaced on an ongoing basis.
- Facility wide mass balance similar to acceptable EPA emissions inventory practices and air permit inventory requirements would be less costly.

4.1.4 Basis for Process GHG Consumption Cost Estimates

Survey respondents were given the requirements of the proposed rule for GHG consumption tracking and asked to estimate installation and annual operational costs. They reviewed their current fab infrastructure and identified requirements for scales or MFCs. Most also included the cost to modify equipment software or to install a gas consumption tracking system. Respondents did not include the costs associated with production downtime to make the required modifications. Twenty respondents provided installation costs estimates; 15 provided annual operational cost estimates.

Nineteen respondents provided descriptions of the basis for their cost estimates.

Method used by 1 respondent

- "Installation cost estimate includes
  - New and spare MFCs to be purchased
  - Labor cost to install new MFCs
  - Labor and material costs for wiring from the MFCs to hardware
  - Hardware to collect gas consumption data

- Contingency money for the unexpected operating cost estimate includes
  - Outsourced calibration services
  - Labor to install/reinstall MFCs for calibration."

Method used by 1 respondent

- "Cost estimate is to replace ~500 MFCs that do not have +/-1% accuracy on process tools, install system to communicate and maintain all tracking data, and develop a PFC-specific software program to manage data. Estimate ~$1400/MFC plus 1 hour to install. $400,000 to install tracking system; $15,000 to install PFC-specific software program to manage data. Vendor has been located who performs calibrations. Rate for this service is $480 per MFC."

Method used by 1 respondent

- "Measuring gas usage with flow meters and data management system: $600K to $1200K. Assumes replacement of 50%–100% of MFCs would be required to comply with proposed rule. (Does not include any cost for equipment downtime or lost production.) Assumes $250K–$400K data management expense. Measuring gas usage by weighing cylinders: up to $1500K. Review of a sample of PFC gas distribution systems indicated that 40%–50% of existing systems would need to be modified to segregate gas usage by process and platform for Tier 3 emissions inventory. Cost is for purchase and installation of additional gas distribution infrastructure only, and does not include cost of scales, or of equipment down time and lost production. It is likely that the systems could not be satisfactorily reconfigured, even at this high cost, due to the space constraints of the pre-existing fab layout."

Method used by 3 respondents

- Basis for estimate
  - "Replace any existing MFCs that are not rated for ±1% accuracy with new
  - Purchase a supply of backup MFCs (estimated to be 50% of the current inventory) that can be installed while others are being calibrated throughout the year
  - Process data and prepare reports
  - Hire one full-time employee whose sole job function is the calibration of MFCs at each of our facilities
  - Wage data estimated based on rates referenced by EPA
  - Develop software queries to totalize flows from existing monitoring data."

Method used by 1 respondent

- Basis for estimate
  - "Replace any existing MFCs that are not rated for ±1% accuracy with new

  - Purchase a supply of backup MFCs (estimated to be 50% of the current inventory) that can be installed while others are being calibrated throughout the year
  - Process data and prepare reports
  - Develop software queries to totalize flows from existing monitoring data. Assume annual calibrations will be done by nearby facility."

Method used by 3 respondents

- "Estimate to install scales under all cylinders: 1 cylinder x (scale + programming/labor) = $1,835.00. Total conversion (70 cylinders) = $128,450 plus initial calibration costs and need to add some spare scales...total ~$150K if we stay with the 40 and 200 lb weight scenario. We would add a few extra scales for rotations. NOTE: Scales are basically of no value for cylinders with non-liquid gases. That is where we use the pressure transducers."

Method used by 1 respondent

- "We estimated our costs based on what it would take to install flow meters with a ±1% accuracy. Our cost estimate is based on installing flow meters on each HFC line, feeding each tool. The data comes from vendor quotes for equipment and labor. The estimate includes the cost of the meter, the labor costs to install the meter, and costs to install hardware and software to track the flow meters. This estimate did not include any annual costs to maintain the equipment. Nor did the estimate include any costs associated with down time of Fab tools."

Method used by 3 respondents

- "$1000 to $1500 per MFC operating cost is an estimate with the majority of the cost in providing MFCs capable of accuracy continuously in compliance. Cost data assumes a third party is needed to calibrate MFCs."

Method used by 1 respondent

- "Assume tool MFCs required at $1000 per MFC and that centralized data system costs $25,000. Cost data assumes a third party is needed to calibrate MFCs."

Method used by 1 respondent

- "MFCs have to be shipped out for calibration. Estimate basis:
  - $2,000 per MFC (purchase, install, and miscellaneous materials) with no digital output for tracking
  - $6,000 per MFC (purchase, install, and miscellaneous materials) with digital output for tracking
  - From $364,000 to $1,032,000. Assume $700,000 is good estimate."

Method used by 1 respondent

- "Estimate provided by our gas management company. Company says upgrades can get to a bulk gas accuracy of 2–3%. These upgrades will cost $143,000/fab and $50,000/year/site. These are only costs to improve bulk gas measurements as technology to measure at a tool level currently does not exist."

Method used by 1 respondent

- "Mass flow meters would be the least expensive option. MFMs would be installed on PFC sticks that go to each tool. MFMs will then be ethernetted together to a new central computer. Cost of tool downtime to install MFMs not accounted for. Maintenance costs assume MFMs are sent offsite annually for calibration. Spare MFMs are required to allow swaps for calibration."

Method used by 1 respondent

- "The fab was not designed to and cannot provide the data necessary to comply with this regulation. Processes have not been characterized for gas use and emissions. Rule requires massive renovation of gas distribution system, new hardware and software to monitor MFCs, and replacement of existing MFCs."

4.1.5 Estimated Cost for an Average Fab to Comply with Gas Consumption Tracking Requirements

The cost for an average fab to comply with the gas consumption tracking requirements was calculated by summing the estimated cost responses and dividing by the number of fabs represented by the total. When respondents provided a cost range, the minimum value of the range was used so that the calculated average cost represents an estimated minimum average cost. The average cost to install infrastructure to comply with the gas consumption tracking requirements of the proposed rule is $0.72 million per fab; the estimated annual operating cost is $0.22 million per fab.

4.2 Point-of-Use Abatement

4.2.1 Proposed Rule Requirements and Implications

The proposed rule defines abatement as "…a point-of-use (POU) abatement system whereby a single abatement system is attached to a single process tool or single process chamber of a multi-chamber tool." This definition does not include multi-chamber POU abatement devices (which are commonly used in the industry) and larger non-POU abatement systems. If a facility uses POU abatement and wishes to claim reductions, the proposed rule requires that destruction or removal efficiency (DRE) be verified experimentally following a procedure outlined in the rule to measure dilution through the abatement system (April 10, 2009 FR, p.16649–50). Alternatively, the facility can, "Install abatement devices that have been tested by a third party (e.g., UL)" following EPA's *Protocol for Measuring Destruction or Removal Efficiency of Fluorinated Greenhouse Gas Abatement Equipment in Electronics Manufacturing* (draft protocol). The majority of abatement devices currently installed in U.S. fabs have not been tested according to this draft protocol.

The frequency of abatement testing is not explicitly defined in the proposed rule; however, the Regulatory Impact Analysis (RIA) cost estimate addresses testing frequency by stating "[e]ach abatement device would be tested once every three years."

The 2006 IPCC *Guidelines for National Greenhouse Gas Inventories* provides default DRE factors for POU abatement devices. The guidelines state that factors can be used only if the abatement devices

- "Are specifically designed to abate FCs [fluorocompounds]
- Are used within the manufacturer's specified process window and in accordance with specified maintenance schedules
- Have been measured and has [sic] been confirmed under actual process conditions using a technically sound protocol which accounts for know measurement errors including, for example, CF4 byproduct formation during C2F6 as well as the effect of dilution, the use of oxygen or both in combustion abatement technologies." (IPCC2006, Vol.3, 6.20)

The technical experts who developed the IPCC guideline for the electronics industry believed that a properly maintained abatement device would maintain DREs over time and did not require periodic retesting. Although the proposed rule uses the 2006 IPCC guideline as the basis for estimating emissions, it does not allow the guidelines' default abatement DRE factors to be used.

4.2.2 Survey Questions

Figure 3 shows the survey questions asked to ascertain the impact of the proposed rule's abatement testing requirements.

1. **Approximately how many PFC-specific abatement devices (capable of abating PFCs in CVD and etch) will you need to test if you want to claim DRE?**
2. **What percentage of the PFC POU abatement devices at your facility have been characterized by your company with a standard industry methodology that accounts for dilution of PFCs in the POU abatement device or by a third party using the draft EPA protocol?**
3. **What percentage of the PFC POU abatement devices at your facility have been characterized by your abatement supplier with a standard industry methodology that accounts for dilution of PFCs in the POU abatement device?**
4. **What methodology was used to characterize performance of POU abatement devices?**
   - ☐ **Emissions not characterized; using default emission factors**
   - ☐ **2001 ISMI Guideline**
   - ☐ **2006 ISMI Guideline**
   - ☐ **Draft EPA Protocol**
   - ☐ **Epson Method**
   - ☐ **Facility has no POU abatement installed**
   - ☐ **Other (e.g. internal testing, info from suppliers - please specify)**

Figure 3 Survey Questions on Characterization of Abatement Devices

4.2.3 Survey Results and Analysis

POU abatement for process GHG emissions is currently used by 10 of 21 survey respondents representing 21 of the 29 respondent fabs. Survey respondents have 1111 GHG POU abatement devices currently installed in fabs. Eleven of the 21 (28% of respondent fabs) do not use POU abatement to reduce emissions. For fabs that will be operating when the proposed rule takes effect, the survey indicates that the average number of abatement devices per fab with abatement is 61; the high is 158. Here again, the survey revealed several EPA misperceptions about industry practice.

EPA Statement	Industry Practice
"…we propose an emission estimation method that would account for destruction by abatement equipment only if facilities verified the performance of their abatement equipment…" (April 10, 2009 FR, p.16498)	50% of all respondents with abatement have not characterized abatement DREs; of those 25% use defaults 25% use DRE measurements provided by suppliers Only one respondent has characterized the majority of its installed POU abatement units.
"…install abatement devices that have been tested according to EPA's Protocol by a third party (e.g., UL)…" (April 10, 2009 FR, p.16650)	<<1% of currently installed POU devices have been tested using the EPA's draft protocol.

Less than 1% of installed abatement devices have been tested using EPA's draft protocol, which has not yet been published. The preamble and proposed rule imply that, if a facility conducts POU abatement testing instead of using a third party, the facility must test all abatement devices (not just a representative process-specific sample). The survey did not address the cost of this testing. Testing will likely require extensive use of third parties because most companies do not have equipment or personnel to conduct in-house testing. Very few third parties in the U.S. have experience characterizing semiconductor process emissions or testing semiconductor POU abatement devices (UL, the example cited by the EPA, is not one of them); still fewer have experience testing in an operating manufacturing fab.[4] Only a single third party is known to have experience using the EPA draft protocol.

4.2.4 Basis for Cost Estimate: Compliance with POU Abatement Testing Requirements

Survey data were used to calculate the average number of abatement devices per fab for those fabs so equipped. This number was multiplied by the testing cost to calculate an average total POU abatement testing cost per fab. If respondents provided a range for the number of abatement devices, the minimum of the range was used in calculations to ensure that the reported costs were a minimum.

The following assumptions were made:

- Emissions testing would be conducted by a third party
- Estimates would be based on testing one-third of the installed POU abatement devices because the proposed rule allows testing of a "random sample" (April 10, 2009 FR, p.16499) when testing is conducted by a third party

[4] Feedback of ISMI Greenhouse Gas Working Group Members.

- Third-party testing would cost $35,000/week based on testing three POU abatement devices per week (including set-up, testing and data analysis according to the EPA draft protocol, and report generation).

4.2.5 Estimated Cost for an Average Fab to Comply with POU Abatement Testing Requirements

The average cost per fab to test POU abatement devices is $0.24 million over 7 weeks. A fab with 158 POU devices will spend $0.62 million over 18 weeks to test 53 devices. These costs for testing one-third of all devices would also equal the average cost per year if each abatement device must be tested once every three years as stated in the RIA cost estimate. Given the lack of experienced third parties, it is unlikely that most semiconductor facilities would be able to meet the POU abatement testing requirements of the proposed rule unless they develop in-house analytical capabilities (i.e., hire personnel and acquire analytical instrumentation). The proposed rule requires those facilities that use in-house capabilities to test 100% of their POU abatement devices (April 10, 2009 FR, p.16499), an approach the preamble acknowledges is likely to be more costly than third-party testing (April 10, 2009 FR, p.16499). For these reasons, industry POU abatement testing costs are likely to be significantly greater than the minimum estimates above.

4.3 Estimating Emissions

4.3.1 Proposed Rule Requirements and Implications

The proposed rule establishes production capacity-based reporting thresholds rather than emissions-based thresholds (April 10, 2009 FR, p.16497). Semiconductor production facilities with production capacity >1,080 m^2 silicon must report. Large semiconductor facilities (production capacity >10,500m2 silicon) are required to estimate emissions using an approach based on the IPCC Tier 3 (company-specific emission factors) while all other semiconductor facilities must use an approach based on the IPCC Tier 2b method (process-specific default emission factors) (April 10, 2009 FR, p.16498). Both approaches require gas consumption data by process that the EPA believes "is often gathered as business as usual" (April 10, 2009 FR, p.16498). EPA further contends that "…DRE for each process is readily available from tool manufacturers…" (April 10, 2009 FR, p.16498). The proposed rule requires that gas utilization and byproduct formation measurements as required by the Tier 3 method be conducted using the *Guideline for Environmental Characterization of Semiconductor Process Equipment* (2006 ISMI Guideline).

4.3.2 Survey Questions

Figure 4 shows the survey questions asked to ascertain the impact of the proposed rule's process emissions estimating requirements.

4.3.3 Survey Results and Analysis

Respondents were asked what methodology they currently use to estimate process GHG emissions. Results are shown in Figure 5.

1. **What emissions estimating methodology do you currently use to estimate your process GHG emissions?**
   - ☐ **IPCC 2006 Tier 1 (aggregate default based on silicon area processed)**
   - ☐ **IPCC 2006 Tier 2a (default emission factors by process gas)**
   - ☐ **IPCC 2006 Tier 2b (default emission factors by process gas and process type)**
   - ☐ **IPCC 2006 Tier 3 (process specific emission factors)**
   - ☐ **Don't currently estimate**
   - ☐ **Combination of Tiers or Other (please specify)**

For large facilities:

2. **Approximately how many "unique process platforms running varying PFC gases" in representative processes does your facility have?**
3. **What is the approximate maximum number of unique PFC-using recipes with varying process conditions run in your facility?**
4. **What methodology was used to characterize process emissions and byproducts?**
   - ☐ **Emissions not characterized; using default emission factors**
   - ☐ **2001 ISMI Guideline**
   - ☐ **2006 ISMI Guideline**
   - ☐ **Epson Method**
   - ☐ **Other (please specify)**

Figure 4 Survey Questions on Emissions Characterization Methodology

1. What emissions estimating methodology do you currently use to estimate your process GHG emissions?

	Response Percent	Response Count
IPCC 2006 Tier 1 (aggregate default based on silicon area processed)	0.0%	0
IPCC 2006 Tier 2a (default emission factors by process gas)	28.6%	6
IPCC 2006 Tier 2b (default emission factors by process gas and process type)	19.0%	4
IPCC 2006 Tier 3 (process specific emission factors)	4.8%	1
Don't currently estimate	9.5%	2
view **Combination of Tiers or Other (please specify)**	**38.1%**	**8**

Figure 5 Percentage of Respondents Using Various Estimating Methods

One responding company uses the IPCC Tier 3 method. Two respondents do not currently track process GHG emissions. The operation for one of those respondents is "large" as defined by the proposed rule (>10,500 m^2 silicon); however, the facility has only one PFC-using process tool and, thus its process GHG emissions are low. The second respondent is not an SIA member and is therefore not a party to the voluntary PFC Reduction/Climate Partnership for the Semiconductor Industry. Thirty-eight percent of respondents are using a combination of tiers to estimate emissions; the majority uses a combination of Tiers 2a and 2b.

Most of the respondents do not track gas consumption by process. Those that do report emissions by process (i.e., are using Tiers 2b or 3) apply engineering estimates to determine the split of gas consumption between chemical vapor deposition (CVD) and etch.

The survey highlighted several EPA misperceptions about the impact of requiring large facilities to estimate emissions using a Tier 3-like approach.

EPA Assertion	Industry Practice
Large semiconductor facilities are already using Tier 3 methods. (April 10, 2009 FR, p.16498)	Only one U.S. company is estimating emissions using IPCC Tier 3. Others use Tier 2a, 2b, or a combination.
Large facilities have the data required to use Tier 3. (proposed rule requires use of 2006 ISMI guideline) (April 10, 2009 FR, p.16498)	50% of large companies do not have any data required to use Tier 3. For 75% of the responding companies with some emissions data, the data were not generated with ISMI's 2006 guidelines (instead earlier versions of industry guidelines were used). Only 10% of all emissions characterizations used ISMI's 2006 guidelines.

While the proposed rule requires ISMI's 2006 guidelines to be used to develop utilization and byproduct emission factors, the survey shows that only 10% of all process emissions characterizations were based on those guidelines; much of the data were generated using earlier versions of ISMI and industry guidelines. The Tier 3 requirement is based on process emissions data being "…readily available from tool manufacturers…" (April 10, 2009 FR, p.16498). When required by purchase specifications, process equipment manufacturers may provide baseline process emissions characterizations to semiconductor companies purchasing new equipment. Growth in U.S. semiconductor manufacturing capacity has slowed in recent years, and since the 2006 guideline was published, only three large volume manufacturing fabs have been built in the U.S. (*SEMI World Fab Watch*, May 2009). Process equipment manufacturers have little motivation to characterize baseline emissions from tool sets that are already in manufacturing fabs.

For large facilities, the proposed rule calls for the use of "process-specific utilization and byproduction formation factors" (April 10, 2009 FR, p.16648); however, it does not define "process-specific." Large facility respondents representing 15 fabs provided data on the approximate number of unique process platforms and unique perfluorocompound (PFC)-using recipes run in their fabs. "Unique process platform" was defined in the survey as specific tool models using a specific PFC for either CVD chamber cleans or etch, with examples provided. "Unique PFC-using recipes with varying process conditions" was defined as the estimated total number of different process platforms running different PFC gases, gas flow rates, gas ratios, process times, and/or stabilization times in the fab. "Unique process platforms" and "unique PFC-using recipes" can serve as a lower and upper bound, respectively, for the range of process

emission characterizations required of large facilities. An average number of unique process platforms and PFC-using recipes was calculated by adding the number of process platforms or recipes reported by each respondent and dividing by the total number of fabs represented by the responses. When respondents provided a range, the lower end of the range was used to calculate the average so that a minimum estimate was generated. For large fabs, the average number of unique process platforms was 37, while the average number of unique process recipes was 455.

4.3.4 Basis for Cost Estimate: Large Facility Process-specific Emission Factors

Because the EPA does not define "process-specific," the scope of emissions characterization efforts required by large facilities is uncertain. A minimum cost estimate was developed for the average large facility to comply with rule requirements to develop process-specific utilization and byproduct formation factors. The following assumptions were made:

- Emissions testing would be conducted by a third party because most semiconductor facilities do not have the qualified personnel or equipment to conduct in-house testing;
- Third-party testing would cost $35,000/week
  - For estimating the cost of process emissions testing on a per platform basis, assume a third party can test three unique process platforms per week (including set-up, testing, data analysis, report generation).
  - For estimating the cost of process emissions testing on a per unique recipe basis, assume the third party can test six process recipes per week (including set-up, testing, data analysis, report generation).

4.3.5 Estimated Cost for an Average Large Facility to Develop Process Emission Factors

The cost to develop Tier 3 emission factors for an average large fab ranges from $0.43 million over 12 weeks if testing is required on a per platform basis. If each individual process recipe must be characterized, the cost for the average large fab rises to $2.7 million over 76 weeks. Few third parties have experience testing semiconductor process equipment emissions in a manufacturing fab. Given the amount of emissions characterization required by the proposed rule and the lack of experienced third parties, it is unclear how EPA's estimated 29 large manufacturing fabs will develop process-specific emission factors in the timeline outlined in the proposed rule.

4.4 Comparison of IPCC Methodologies (Supplementary Data from One Survey Respondent)

The preamble states, "The use of the IPCC Tier 3 method and standard site-specific DRE measurement would provide the most certain and practical emission estimates for large facilities" (April 10, 2009 FR, p.16498). One survey respondent provided additional data from an analysis to compare the results of the 2006 IPCC Tier 2a, 2b and 3 methods for three 200 mm fabs over 3 years and three 300 mm fabs (one for 1 year and two for 3 years each). Figure 6 presents the results of 16 sets of comparison data.

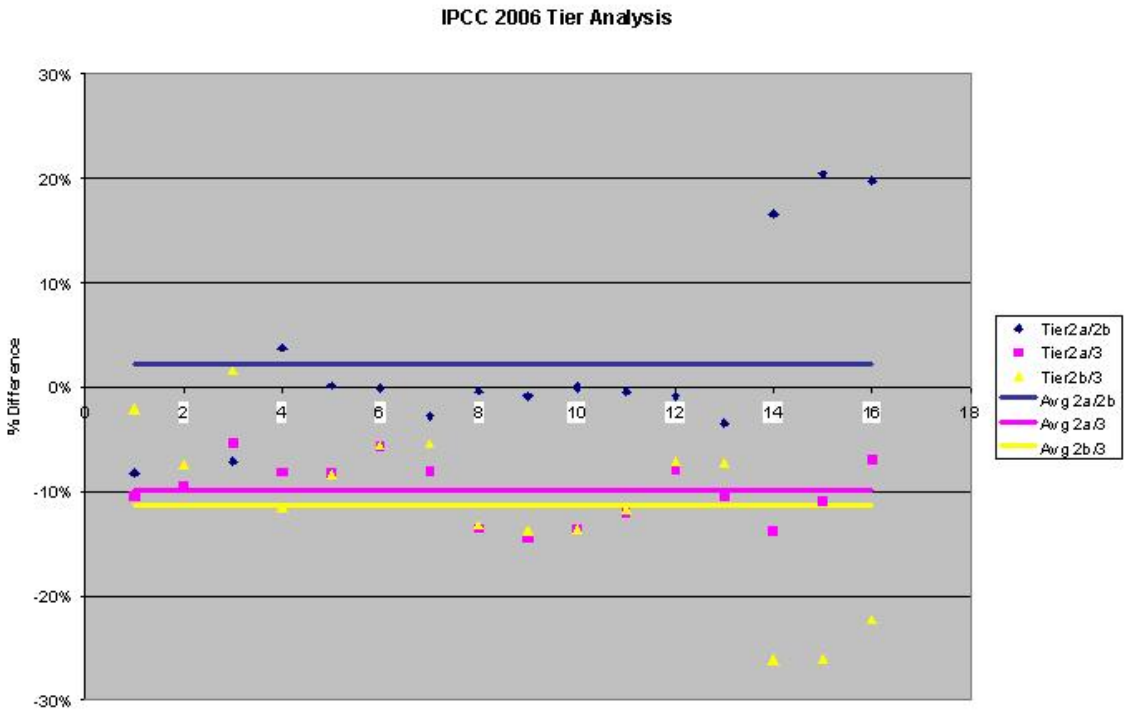

Figure 6 2006 IPCC Tier Analysis for Six Fabs

The data sets show that Tier 2a and Tier 2b produce similar results with Tier 2a averaging +2% higher (standard deviation 9%). Compared to Tier 2a and 2b, Tier 3 yielded an estimated 10% and 11% lower, respectively (standard deviation 3% and 8%). The IPCC methods for the electronics industry require 100-year time horizon global warming potentials (GWP100) to calculate CO_2 equivalent emissions. As noted in the IPCC Fourth Assessment Report, uncertainties for GWP100 are ±35% (IPCC 4th ARWG1, Ch.2, p.214). The greatest difference among methods is less than one-third of the uncertainties for GWP100.

The Tier 3 method offers only incremental improvement in accuracy over the Tier 2 methods; this improvement is small compared to the overall uncertainty in these calculations due to the uncertainties in the GWP100.

4.5 Recordkeeping and Reporting

The proposed rule lists several data reporting requirements for semiconductor facilities that could be made available to the public. Survey respondents were asked to indicate whether the data elements listed are currently available for each facility and which elements they consider Confidential Business Information (CBI). Table 1 lists those data elements that >50% of the respondents do not currently have available or consider CBI.

Table 1 Required Data that Majority of Respondents Do Not Have Available or Consider CBI

Rule required data that >50% of respondents do not currently have available or that >50% consider to be Confidential Business Information (CBI).			
Required Data	**Data Available (% of All Respondents)**	**Data Not Available (% of All Respondents)**	**CBI**
GHG emissions for all plasma etching	45%	55%	55%
GHG emissions for all chamber cleaning	45%	55%	55%
GHG emissions for all CVD processes	20%	80%	55%
GHG emissions for all HTF use	5%	95%	10%
Mass of each gas fed into each process type	25%	75%	95%
Production capacity (m2 Si)	95%	5%	90%
Emission control technology DREs and their uncertainties	10%	90%	30%
Fraction of gas fed into each process type w/ emissions control technologies	30%	70%	70%
Description of abatement controls	45%	55%	5%
Inputs to mass balance calculations (for heat transfer fluids)	25%	75%	10%

5 IMPACT ASSESSMENT

The impact of the proposed rule on the semiconductor industry has been underestimated by EPA.

EPA Proposed Rule	**Estimated Industry Costs**
The rule contains stringent requirements for tracking gas consumption that require ALL reporting facilities to undertake costly infrastructure modifications.	EPA estimates the rule applies to 91 semiconductor fabs. Based on survey results, the minimum estimated total industry cost to comply with gas consumption data requirements is $65 million for infrastructure installation and $20 million for annual operating costs.
To claim DRE for POU abatement, abatement units must be tested by the user or a third party using the EPA protocol.	The survey indicates 72% of fabs use GHG-specific POU abatement. Assuming 66 fabs (72% of 91 fabs) use abatement, the minimum estimated total industry cost to comply with POU abatement testing is $17 million over 450 weeks of testing.
Large semiconductor facilities are already using Tier 3 methods or have data available to perform Tier 3.	The minimum estimated cost for the EPA-estimated 29 large facilities to develop Tier 3 data is $13 million to $77 million over 360 to 2,200 weeks of testing.

EPA erroneously assumes that that manufacturing facilities "monitor gas consumption using equipment (e.g., flowmeters) that is already in place…" (RIA Cost Appendix, p.21). Based on this assumption, The EPA does not include capital or operating and maintenance (O&M) costs in the estimate. The total minimum industry cost for installing infrastructure to track gas consumption as required by the proposed rule is $65 million. O&M costs to calibrate and maintain gas consumption monitoring systems is $20 million per year. The EPA's estimated cost for the industry to comply with POU abatement device testing is $1.359 million per year, while the estimated minimum cost based on survey data is $17 million per year. The EPA assumes that large facilities have the data to comply with the proposed rule and, therefore, incur no cost for compliance; for the large facilities, the cost to comply with the requirements for Tier 3 is $13 million to $77 million. Initial compliance with the proposed rule requires an estimated 16 to 51 years of third-party testing; ongoing POU abatement evaluations will require a minimum of 8.7 years of third-party testing each year (assuming the third party can test three process platforms, six process recipes, or three POU abatement devices per week).

In 1999, the members of the World Semiconductor Council (WSC) approved a goal to reduce aggregate absolute emissions of PFCs from semiconductor manufacturing facilities by 10% or more from baseline levels by 2010. They also agreed to use IPCC Tier 2 methods to estimate emissions so that a common methodology would be used across all regions and data would be comparable. Based on the survey responses from the four non-U.S. located respondents, semiconductor facilities in other countries are not subject to requirements comparable to those in the proposed rule.

6 CONCLUSIONS

ISMI's survey to gather facility-specific data on the impact of the proposed rule on fab operations resulted in 21 responses from companies representing 58% of total U.S. silicon area production capacity. Survey respondents included 25 of the EPA's estimated 29 large fabs.

Much of the EPA's basis for the proposed rule is contradicted by survey data:

- Contrary to the EPA's assertion, the industry is *not* currently collecting or equipped to collect significant portions of the data required by the proposed rule.
- The EPA assumes the industry will incurs no capital or O&M costs under the proposed rule. This assumption is incorrect. The minimum estimated industry capital cost to comply with gas consumption tracking requirements is $65 million and O&M costs are $20 million per year
- Analysis of the survey data indicates the industry's first year compliance costs will be $95–159 million, 26X to 44X greater than the EPA's estimated $3.6 million (RIA, p. 4-124). Ongoing compliance costs are estimated to be a minimum of $37 million per year. Note that the survey-based cost estimate is a minimum that does not include the costs associated with production downtime. It also does not include the costs to comply with requirements for fluorinated heat transfer fluids, combustion related emissions reporting, or reporting and recordkeeping requirements.

In its requirements for gas consumption tracking, process emissions characterization, and POU abatement testing, the proposed rule goes beyond the requirements of the IPCC Tier 2b and 3 methods. Based on responses received by the four respondents not located in the U.S.,

semiconductor facilities in other countries are not subject to requirements that are comparable to those in the proposed rule.

The proposed mandatory GHG reporting rule requires that the industry spend large amounts of money that the EPA does not accounted for in its regulatory impact assessment. The first year compliance costs will be 26X to 44X greater than estimated by the EPA, and subsequent compliance costs are >10X the EPA's estimate.

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