SESHA Texas Hill Country Chapter
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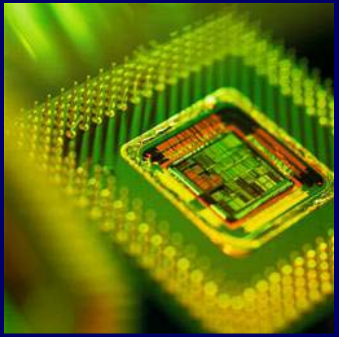
Accelerating Sustainable Manufacturing

EPA Mandatory Reporting Rule Update and ISMI Greenhouse Gas Activities

Assessing Industry Impacts and Alternative Strategies Developments



Laurie S. Beu, P.E.

Consultant to ISMI

laurie.beu@ismi.sematech.org

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Background

- U.S. semiconductor industry fluorinated greenhouse gas (F-gas) emissions are 0.08% of total U.S. industrial greenhouse gas (GHG) emissions [1].
- GHG Reporting Rule (40CFR Part 98) Subpart I (Electronics Manufacturing) final rule published December 1, 2010.

[1] U.S. GHG Inventory 2010, pp. ES-3 and 4-69.

ISMI ESH Technology Center

- **I**nternational **S**EMATECH **M**anufacturing **I**nitiative (ISMI) **E**SH **T**echnology **C**enter is a world-wide collaborative research consortium of semiconductor device manufacturers, equipment and material suppliers
- The ESH Technology Center provides data-driven solutions and industry best practice benchmarking to address challenges of sustainable semiconductor manufacturing including climate change.
  - Conducted and published multiple Fluorinated GHG (F-gas) abatement, recycle, alternative chemistry and process optimization evaluations.
  - Developed F-gas test plan templates and environmental characterization guidelines (1995, 2001, 2006, 2009).
  - Prepared Perfluorocompound (PFC) State-of-Technology reports (white paper-1994, baseline-1995, state-of technology-1998, 2005).
  - Conducted industry GHG surveys and technical data gathering, (2009 to present).

ISMI Assessment of Final MRR Subpart I Impact

- At end of 2010, ISMI conducted industry survey to determine final rule impact on U.S. device manufacturers.
- “ISMI Analysis of the Impact of Final Mandatory Reporting Rule Subpart I on U.S. Semiconductor Facilities” tech transfer report published on ISMI Public website January 31, 2011: http://www.sematech.org/docubase/abstracts/11015139A-TR.htm

Presented 11-Jan-2011 to EPA by Laurie Beu

Summarized Cost Comparison:
Based on EPA Cost Elements

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	First Year Cost (Millions $)	Subsequent Year Cost (Millions $)
ISMI Estimate for EPA Cost Elements:		
Developing facility-wide gas-specific, container-specific heel factors per fab using measuring devices with 1% full scale accuracy and precision.[2]	4.2	4.2
Apportioning process GHG usage by process category or individual process using EPA proposed method based on wafer passes.[2]	> 14	> 14
Development and recordkeeping for etch recipe-specific emission factors [1]	> 56	> 17
Estimating emissions and by-products by specific process type - Updated IPCC Method defaults (5 categories).	5.6	5.6
Collecting all data required to be reported/retained for POU abatement devices.[2]	0.3	0.3
Collecting all data required to be reported/retained for heat transfer fluids [2]	0.70	0.70
ISMI Estimated Cost: Total Semiconductor Industry Costs for EPA Cost Elements	**> 81**	**> 42**
EPA Estimated Subpart I - Total Electronics Industry [3]	**2.9**	**5.4**

[1] ISMI November 2010 Survey

[2] ISMI Estimate applying EPA costs to 29 large facilities and 62 non-large facilities

[3] 40 C.F.R. §98, Table 12

- Costs for additional cost elements (not encompassed in EPA estimate) are shown in Slide 11 (Slide 7 in this presentation).

Compliance Costs:

Additional Costs Not Considered by EPA

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Additional Semiconductor Industry Cost Elements:	First Year Cost (Millions $)	Subsequent Year Cost (Millions $)
Infrastructure to Verify Apportioning Model with Actual Data* [1]	9	29
Testing POU Abatement Units [2]	7	7
Cost of Equipment Downtime for Etch emissions testing	22	3.9
ISMI Estimated Cost Total: Additional Semiconductor Industry Costs	**38**	**40**

* Infrastructure cost estimate based on 2009 Proposed Rule requirements for MFCs and weigh scales - cost may be lower depending on EPA's interpretation of the final rule's requirements. Capital costs are annualized over 10 years at 7.5% interest. Capital equipment require annual calibrations (O&M) and other upkeep.

[1] ISMI Technology Transfer #09065012A-TR, June 2009

[2] ISMI Technology Transfer #10065097A-TR, June 2010

- Assumes same infrastructure is required to **validate apportioning model** as required by 2009 proposed rule required, capital costs ~**$65 Million**.
- **Testing abatement** in accordance with RSASTP results in **$7 Million** in annual costs.
- Etch recipes testing requires taking etch process tools out of production.

ISMI Cost Analysis Summary

- EPA has under-estimated semiconductor industry Subpart I compliance costs.

	First Year Cost (Millions $)	Subsequent Year Cost (Millions $)
ISMI Estimated Cost: Total Semiconductor Industry Costs for EPA Cost Elements	> 81	> 42
ISMI Estimated Cost Total: Additional Semiconductor Industry Costs	38	40
ISMI Estimated Total Semiconductor Industry Costs*	**>119**	**>82**
EPA Estimated Subpart I: Electronic Industry Cost	**2.9**	**5.4**

Semiconductor first year compliance costs are more than 40 times greater than EPA's estimate for entire electronics industry while subsequent year costs are more than 15 times greater.

January 2011 ISMI Report Conclusions

- ISMI finds the U.S. semiconductor industry's cost to comply with the final rule is more than 40X greater than the EPA's estimate for the entire electronics industry while subsequent year costs are more than 15X greater.
- Data reporting and recordkeeping requirements raise significant intellectual property concerns.
- The final rule does not appropriately balance accuracy with burden.

Subpart I Status

- SIA has challenged Subpart I and is in settlement discussions with EPA.
- Interim final rule published September 27, 2011.
  - Extends the time period for which companies are granted automatic use of BAMM until Dec-31-2011.
  - Allows large facilities to use Tier 2c default emission factors to calculate etch emissions for 2011 thru 2013.
  - Pushed deadline for submitting BAMM petitions for post-2011 compliance out to October 17, 2011.
- EPA has extended the 2011 reporting deadline by 6 months from March to September 2012.
- Industry is working on alternatives to current rule requirements.
- Both industry and EPA are working to revise Subpart I.

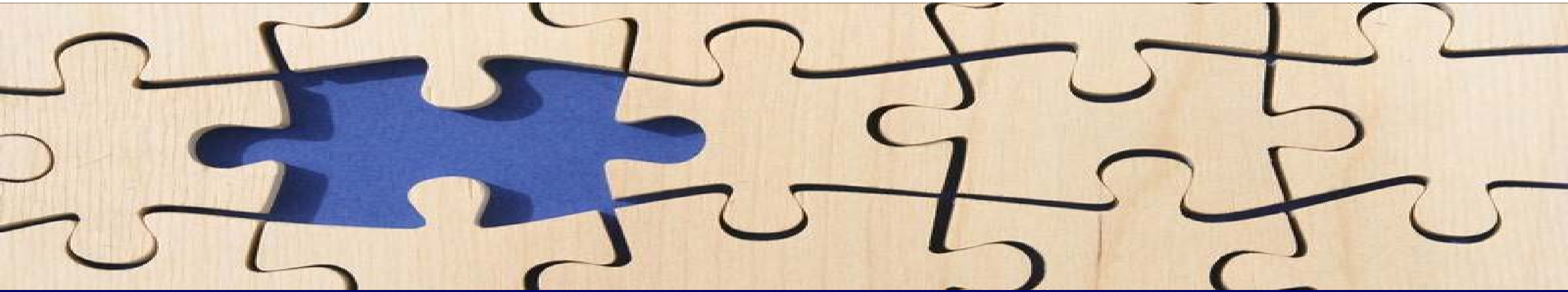
SIA is Partnering with ISMI to Develop Alternatives

- Surveys conducted to gather benchmark data
- No single alternative to recipe testing is cost effective for all large fabs. Alternatives are needed and are appropriate.
- Three technical teams working to develop alternatives
  - Stack Testing Team
  - Etch Alternative Team
  - POU Abatement Team

Technical Teams Focus

- Stack Testing: Evaluate feasibility of stack testing and correlation between measured stack GHG emissions and fab activity data.
- Etch Alternative: Partner with equipment suppliers and device manufacturers to develop additional etch emissions data so that new, more robust default etch emission factors can be established.
- Abatement: Estimate emissions by applying measured DRE directly to allocated use. Develop alternative POU abatement testing requirements.
- Teams have also focused on addressing compliance issues such as BAMM petitions and rule implementation.

Stack Testing



Why Stack Testing?

- Stack testing is widely accepted as a direct measure of emissions, and has long been used to demonstrate compliance at a variety of facilities nationwide including semiconductor facilities.
- In most Fabs, a large number of F-gas using tools are exhausted from the building via a relatively small number of stacks.
- Stack testing substantially reduces the intellectual property exposures associated with process specific apportioning and testing.
- Depending upon the number of stacks that require testing at a particular facility and the required frequency of testing, stack testing can be a cost-effective means to determine and report F-gas emissions, while also protecting intellectual property.

Historical Context for Stack Testing

- ISMI survey of 25 large fabs found:
  - Most fabs have tested stacks for regulated air pollutants and most stacks are equipped for sampling.
  - The number of stacks receiving F-gas emissions ranges between 1-35 per fab.
  - Frequency of current compliance stack testing ranges from annually to once every 10 years.
  - Cost for stack testing (incl. analysis) for air permit compliance:
    - Ranges from $15-30K per stack.
    - Requires 40-80 in-house technical man-hours.
    - Cost for GHG emissions testing is estimated to be $10K per stack but could be higher depending on the required duration of testing.

Stack Testing Pilot Studies

- Pilot studies conducted at 8 large semiconductor fabs to demonstrate feasibility of measuring F-gases at low concentrations and correlating emissions to fab activity.
  - 5 semiconductor companies have conducted stack tests
  - Both 200 and 300 mm fabs
  - Variety of products manufactured in these fabs
  - Varying levels of F-gas abatement

Analytical Methods for Pilot Studies

- FTIR spectroscopy at the stack or mains using scientifically accepted practice.
  - Samples were taken at ~6-8 minute intervals for a minimum 24-hour period.
  - Stacks sampled sequentially.
  - EPA Method 320 spiking performed at two fabs.
- Summa canister sample collection with GC/MS analysis in the lab.
  - 3-2 hour composite samples collected per stack.
  - Stacks sampled simultaneously.

Stack Testing Analytical Methods Summary

- Feasibility of stack testing demonstrated using FTIR at the stack:
  - Ability to measure F-gas emissions from a stack demonstrated
  - Appropriately low detection limits demonstrated
- Additional work required to develop and qualify a canister/GC-MS method.
- EPA has agreed that stacks can be sampled sequentially using FTIR and that simultaneous sampling is not required.
- Potential challenges associated with stack testing:
  - Determining what concentrations are likely to be in the exhaust streams and ensuring that Method 320 spiking occurs at appropriate concentrations
  - Accurately measuring F-gas usage during stack tests

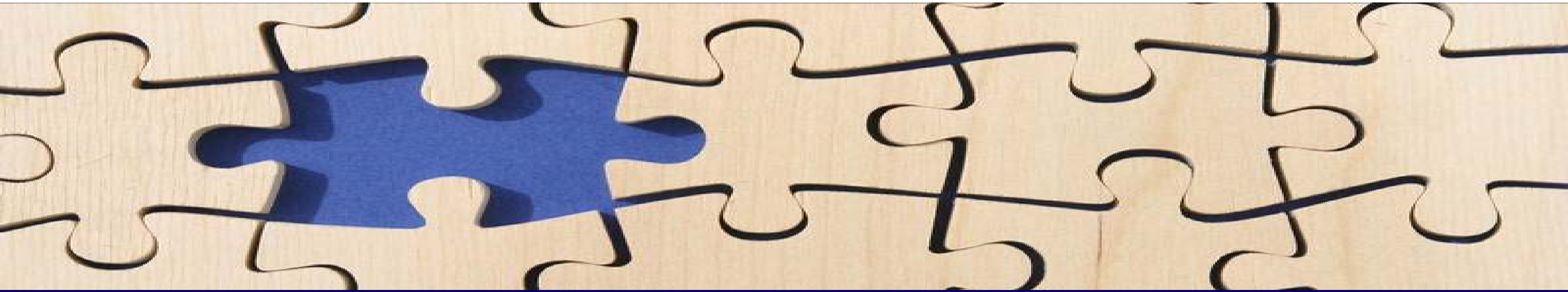
Stack Test Findings

- Testing conducted by five semiconductor companies at eight 200 mm and 300 mm fabs which manufacture a variety of semiconductor products demonstrates:
  - Established test methods can accurately measure process GHG emissions at semiconductor fabs
  - Fab GHG emissions are a direct function of gas use
    - Emissions from one period (when correlated to gas use) can be used to determine emissions at the fab over an extended period of time
  - Results of testing over a defined duration can be scaled to annual emissions quantities
- Numerous benefits of stack test method – both to EPA and the industry
  - Improved accuracy
  - Minimizes cost and CBI concerns

Stack Test Next Steps

- Establish testing frequency criteria.
- Establish proposal for a minimum emissions threshold for testing a stack.
- Address issues of minor sources of emissions, minor uses, stack test frequency, POU abatement changes and identification of major process changes to trigger stack re-testing.

Etch Emission Factors Alternative



Etch Alternative Goal

- Increase the accuracy of etch emissions estimates using Refined Emission Factors.
- Collect existing etch emissions characterization data and statistically analyze to:
  - Identify appropriate etch categories, and
  - Develop default input F-gas emission factors and byproduct emission factors.

Default Factor Development

- Under current rule, data collection and testing is required of hundreds of recipes in multiple etch tools at each large fab.
  - Recipe approach (EPA Tier 2d) introduces additional sources of error in apportioning gas usage.
- Under the proposed etch alternative, etch emissions characterization data has been collected across the industry and supply base.
- Collected data can be managed in a central database (AP-42, IPCC, or other) and factors updated periodically when new process technologies are developed or industry moves to larger diameter wafers.

Data Overview

- Device manufacturers and etch equipment suppliers were asked to provide etch emissions characterization data for inclusion in an ISMI database.
- ISMI Total Data Sets
  - 976 data sets from etch tools/recipe steps.
  - Database is 10 times greater than the one EPA used to establish Final Rule Tier 2c emission factors.
- Input Gas Emission Factor has been analyzed vs. 13 possible input parameters in this data set to develop refine models.
- **This data set has been transmitted to EPA.**

Analyzed Parameter Set

1. Wafer Diameter
2. Power
3. Pressure
4. Flowrate
5. Multiple Gases (Y/N)
6. Stabilization (Y/N)
7. Ratio of Stabilization to Etch Time
8. Principal Film Type
9. Feature Type
10. Film Stack (Y/N)
11. Measurement Protocol
12. Process Type (Etch, Non-Etch)
13. Input Gas Name

Little to no data received for these parameters.

Data Analysis

- Based on data correlations, ISMI developed refined two- and three-factor etch emission factor models
  - 2-factor based on wafer size and input F-gas
  - 3-factor based on wafer size, input F-gas and principal film etched
- ISMI completed Statistical Analysis:
  - Compared results obtained using IPCC Tier 2b, EPA 2c, ISMI 2- and 3-factor models, and modified Tier 3 method as a proxy for EPA Tier 2d; applied each method to 2009 and 2010 gas usage data from 12 large fabs.
  - Conducted precision and accuracy analysis of the different methods accounting for uncertainty is data sets and apportioning error.

Etch Alternative Findings

- The ISMI database is sufficiently robust to provide representative emissions factors for Gas/Wafer Size.
  - 976 data sets.
  - Emission factors provided for 99.7% of etch gas usage.
- Based on ISMI analysis, a 2-factor model is the most appropriate method to estimate semiconductor etch emissions.
  - Improved precision and accuracy vs. other methods
  - Minimizes apportioning error
  - Avoids technical feasibility and intellectual property issues associated with current Subpart I
  - Provides additional datasets which improve current rule Tier 2c defaults and that can feed into the IPCC process to ensure increased accuracy of semiconductor emissions estimates world-wide
- Additional data sets will be added to the ISMI database in 2012.

POU Abatement

POU Abatement Goals

- Estimate Emissions Based on F-gas use allocation and application of abatement unit Destruction Removal Efficiency (DRE).
  - Compare fab emissions calculated using direct application of DREs to F-gas usage to emissions estimate using process based default factors.
- Develop alternate POU abatement testing requirements.
- Applicability:
  - Fabs with Significant Number of Abatement Units.

Abatement Alternative Status

- Survey completed to collect data on installed base of abatement units by type, process on which they are installed, F-gases being abated. DRE test results are also being collected and analyzed.

Conclusions

- ISMI is working with SIA and suppliers to develop alternatives which improve the accuracy of F-gas emissions estimates while not infringing on intellectual property.
- A single emissions estimating method may not fit all fabs – multiple alternatives are being developed to ensure implementation feasibility at all fabs.
  - For some fabs, the stack alternative is the optimal approach; for other fabs, the etch alternative is best
  - EPA provided options in other MRR subparts
- Results have been shared with EPA and discussions are on-going.

Acknowledgments

- ISMI-SIA Stack Test Team Members.
- ISMI-SIA Etch Alternative Factors Team Members.
- ISMI POU Abatement Team Members.
- Etch equipment suppliers that have provided emissions characterization data.