### REVISION SCHEDULE

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<th>Date</th>
<th>Details</th>
<th>Prepared by</th>
<th>Reviewed by</th>
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<td>24/03/2016</td>
<td>Draft for Client Review</td>
<td>Caroline Donnelly</td>
<td>Danny Ward</td>
<td>Peter Hassett</td>
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<td>Principal Environmental Engineer</td>
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<td>2</td>
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<td>Final Issue</td>
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1. INTRODUCTION

AECOM Infrastructure & Environment Ireland (hereafter referred to as “AECOM”) is pleased to present this completed Solvent Management Plan (SMP) report for calendar year 2015 to Analog Devices International (Analog).

The requirement to undertake an SMP for Analog is provided for in Condition 5.10 (refer Box 1) contained in Technical Amendment C to IPC licence register number P0224-02. The Technical Amendment is dated 21st February 2013.

5.10 Solvent Management Plan (SMP)

This report is the third SMP prepared in response to Condition 5.10. The first report was prepared for the calendar year 2013.

2. OBJECTIVE & AIMS

The objectives of this SMP are:

1. Demonstrate, for calendar year 2015, compliance with fugitive emissions of volatile organic compounds limits presented in Condition 5.11(i) of Technical Amendment to IPC licence register number P0224-02 (refer Box 2), noting that Solvent Input at Analog is greater than 10 tonnes per year;

2. Provide a documented description of the methodology used for data collection (as required under Condition 5.10).

Box 2:

5.11 Fugitive Emissions of Volatile Organic Compounds

(ii) For calendar years where solvent input, in other surface cleaning as defined in Council Directive 1999/13/EC, is greater than 10 tonnes per year, the fugitive emissions limit value from the activity is 15% of the solvent input.

Assessment of compliance with these fugitive emission limit values shall be reported annually as part of the AER.
### 3. DEFINITIONS

Appropriate definitions for this SMP are provided (refer Box 3, Box 4, Box 5, Box 6, Box 7):

**Box 3:**

**Surface Cleaning:**

Any activity except dry cleaning using organic solvents to remove contamination from the surface of material including degreasing. A cleaning activity consisting of more than one step before or after any other activity shall be considered as one surface cleaning activity. This activity does not refer to the cleaning of the equipment but to the cleaning of the surface of products.

**Box 4:**

**Solvent Consumption:**

The total input of organic solvents into an installation per calendar year, or any other 12-month period, less any VOCs that are recovered for reuse.

**Box 5:**

**Organic Compound:**

Any compound containing at least the element carbon and one or more of hydrogen, halogens, oxygen, sulphur, phosphorus, silicon or nitrogen, with the exception of carbon oxides and inorganic carbonates and bicarbonates.

**Box 6:**

**Organic Solvent:**

Any VOC which is used alone or in combination with other agents, and without undergoing a chemical change, to dissolve raw materials, products or waste materials, or is used as a cleaning agent to dissolve contaminants, or as a dissolver, or as a dispersion medium, or as a viscosity adjuster, or as a surface tension adjuster, or a plasticiser, or as a preservative.

**Box 7:**

**Volatile Organic Compound (VOC):**

Any organic compound having at 293,15 K a vapour pressure of 0.01 kPa or more, or having a corresponding volatility under the particular conditions of use.

---

4. SOLVENT MANAGEMENT AT ANALOG

4.1 Organic Solvents and Surface Cleaning at Analog

Analog manufactures integrated circuits via Wafer Fabrication at its facility in Raheen, Limerick. Key activities in this process include:

- Manufacture of integrated circuits on silicon wafers;
- Testing of the silicon wafers via Water Probe;
- Laser Wafer Branding; and
- Final electrical testing.

In the context of the activity ‘Solvent Cleaning’ (refer Box 3), organic solvents are used primarily during the photoresist strip and chemical polishing steps of wafer manufacture. Since these steps are surface cleaning of the final product, then materials used in these steps, and which contain organic solvents, are included for assessment in this SMP.

Organic solvents (primarily Isopropyl Alcohol) are used to clean manufacturing tools and room surfaces but since such usage is not related to the cleaning of products, then associated organic solvent usage is not considered in the SMP.

4.2 Preventing Fugitive Emissions at Analog

Manufacturing at the Analog site must occur in a highly controlled atmosphere in order to eliminate contaminants on the final integrated circuit products. This in turn facilitates the minimisation of fugitive emissions of chemical substances, including organic solvents, from the facility. Notable techniques used to prevent organic solvent fugitive emissions include:

- The design of the clean rooms (or Fab areas) where manufacturing takes place is such that conditioned air flows are captured and channelled to the site main emission to air points. It is in these rooms where organic solvents are used in the main;
- Organic solvent is delivered using a Bulk Chemical Distribution System (BCD). The solvent is automatically pumped from the source drums in the Fab via valve manifold boxes (VMB’s) located in the basement (known as Subfab) back to the tools in the Fab.
- The small VMB’s located in the Subfab comprise a number of actuated valves delivering pulses of organic solvent (and other chemical substances) to the manufacturing tools. The VMBs are entirely automated. In turn, the valves within the VMBs are enclosed and the VMBs are extracted to the site main emission points to atmosphere;
- As previously mentioned, the Subfab area contains the VMBs. It also contains all waste solvent piping and most of waste solvent handling infrastructure. This area is fed by a fresh, conditioned air flow. The air flow is removed via the various extracts connected to equipment in the area which are linked to the main emission points.
- Pipework with the potential to contain organic solvents are generally of two types:
  - Small diameter tooling solvent feed (25 mm to 50 mm) stainless steel; and
  - Larger (approximately 100 mm) carbon steel liquid waste lines from the manufacturing area

The pipework is comprised largely of welded sections and there are flange connections at locations only where it is necessary (for example, as a rodding point access or for equipment access purposes). The site manufacturing building design inherently captures organic solvent emissions and directs them to the main emission points under IPC licence P0224-02. Such emissions are not fugitive emissions.
5. SMP APPROACH & BASIS

5.1 Approach

Analog, in accordance with Condition 5.10 of their ipc licence (refer Box 1) completed the SMP using appropriate guidance set out in Schedule 6 of the European Union (Installations and Activities using Organic Solvents) Regulations, 2012 (S.I. No. 565 of 2012), hereafter referred to as 'the Solvents Regulations'.

AECOM notes that the guidance set out in Schedule 6 of the Solvents Regulations is that also contained in Schedule 6 of the 2002 regulations of the same title, referred to in Condition 5.10. The approach is also mandated in 2005 EPA Guidance on Surface Cleaning. Furthermore AECOM notes that the Solvent Regulations have been transcribed to Chapter V of Council Directive 2010/75/EC on Industrial Emissions.

Analog used mass balance terms appropriate to compliance assessment against fugitive emission limit values and as specified in Para. 3(b) of Schedule 6 to the Solvents Regulations.

Specifically, the following mass balance equation was used:

\[
F = O_2 + O_3 + O_4 + O_9 \quad [\text{Equation 1}]
\]

Where

- \( F \) = Fugitive emissions of organic solvents;
- \( O_2 \) = Organic solvents lost in water, taking into account waste water treatment;
- \( O_3 \) = The quantity of organic solvents which remain as contamination or residue in products output from the process;
- \( O_4 \) = Uncaptured emissions of organic solvents into air. This includes the general ventilation or rooms, where air is released to the outside environment via windows, doors, vents and similar openings; and
- \( O_9 \) = Organic solvents released on other ways.

All data for use in Equation 1 are expressed in kilograms per annum (kg/a).

Table 1 provides an assessment of the outputs from Equation 1.
Table 1: Assessment of Equation 1 Outputs (O)

<table>
<thead>
<tr>
<th>OUTPUT</th>
<th>ASSESSMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>O2</td>
<td>Analog trade effluent is analysed regularly for volatile organic compounds. Volatile Organic Compound results for 2015 have indicated less than laboratory limits of detection. Therefore, it is concluded there the value for O2 is insignificant.</td>
</tr>
<tr>
<td>O3</td>
<td>By virtue of production necessity, the final wafer product must not contain any contaminants which may interfere with using the integrated circuits. Therefore, it may be concluded that the final product will not contain organic solvents.</td>
</tr>
<tr>
<td>O4</td>
<td>Analog identified the potential for uncaptured emissions to air of organic solvents from the following operations:</td>
</tr>
<tr>
<td></td>
<td>• Vent emissions from the basement located solvent waste transfer tanks;</td>
</tr>
<tr>
<td></td>
<td>• Fugitive emissions from the valves and diaphragm pumps associated with the basement located solvent waste transfer tanks;</td>
</tr>
<tr>
<td></td>
<td>• Vent emissions from the bulk solvent waste storage tank located in the facility yard; and</td>
</tr>
<tr>
<td></td>
<td>• Vent emissions from the IBC’s receiving photoresist waste from the basement transfer tanks.</td>
</tr>
<tr>
<td>O9</td>
<td>Analog has not identified other means by which there may be fugitive emissions of organic solvents associated with the surface cleaning activities on site. Nonetheless, operations on site can change and Analog should maintain vigilance on testing this conclusion.</td>
</tr>
<tr>
<td></td>
<td>During 2015 there were no spillages or other similar releases that may have resulted in the emission of fugitive organic solvents.</td>
</tr>
</tbody>
</table>

Based on the assessment of Table 1, then for calendar year 2015, Equation 1 can be simplified to:

\[ F = O4 \]  \[\text{[Equation 2]}\]

In order to assess compliance with the percentage limit value for fugitive emissions of 15% of total input (refer Box 2), it is necessary to estimate solvent input (I).

Schedule 6 of the Solvents Regulations defines the total solvent input (I) as:

\[ I = I_1 + I_2 \]  \[\text{[Equation 3]}\]

Where:

- \( I_1 \) = The quantity of organic solvents or their quantity in mixtures purchased which are used as input into the process for product surface cleaning in the time frame over which the mass balance is being calculated; and

- \( I_2 \) = The quantity of organic solvents or their quantity in mixtures recovered and reused as product surface cleaning solvent into the process.

At Analog, \( I_2 = 0 \text{ kg/a} \) as solvent is not recovered and reused for site operations. Hence:

\[ I = I_1 \]
In order to assess compliance with Licence Condition 5.11, Equation 4 is used:

<table>
<thead>
<tr>
<th>Percentage Fugitives = (F/I) *100</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Equation 4]</td>
</tr>
</tbody>
</table>

5.2 Basis

The 2015 SMP was based on:

1. Calendar Year 2015 data; and

2. Substances containing organic solvents where the total 2015 usage of that substance exceeds 1.0 tonnes in 2015. This represents > 98% of the mass of all substances on site used for product surface cleaning. There are many other substances used as product cleaning reagents, some of which contain organic solvents. However, they are used in very small quantities and it is impractical to consider an extended list for this SMP assessment.

6. 2014 SMP CALCULATIONS/ESTIMATIONS

The calculations and estimations for the 2015 SMP are as follows:

6.1 Estimation of Solvent Input (I)

A spread sheet was prepared listing all chemical reagents used in production. The spread sheet was then filtered as follows:

- Filtered for chemical reagents used as defined in the Surface Cleaning activity (refer Box 3);
- Filtered for chemicals reagents for product surface cleaning where 2015 usage > 1 tonnes (excludes iso-propyl alcohol which is used for room and equipment surface cleaning, not product cleaning);
- The list was then filtered for chemical reagents containing organic solvents. Here there are two sub-criteria:
  - Requirement to contain at least the element carbon and one or more of hydrogen, halogens, oxygen, sulphur, phosphorus, silicon or nitrogen, with the exception of carbon oxides and inorganic carbonates and bicarbonates (refer Box 5); and
  - Since the definition of ‘organic solvent’ refers to VOC’s (refer Box 6), then apply the VOC definition of “any organic compound having at 293.15 K a vapour pressure of 0.01 kPa or more, or having a corresponding volatility under the particular conditions of use” (refer Box 7).

Each chemical reagent remaining on the list comprises a mixture of organic solvents and other substances. Where there were percentage ranges of organic solvent concentrations of in each reagent, a mid-point value was chosen. For example, if chemical reagent EKC 265 contains 2-(20aminoethoxy) ethanol 50 to 100%, then the organic solvent concentration chosen was 75%.

Knowing the mass used in 2015 for each screened chemical reagent, the associated solvent input for each reagent was calculated by multiplying the total reagent mass by the mid-point percentages.

The total solvent input (I) was then calculated as the sum of the individual chemical reagent organic solvent inputs.

The value achieved for 2015 is calculated as:

Total Solvent Input, \( I = 86,061 \text{ kg for 2015} \)

The source spread sheet is available on site for inspection, in addition to relevant associated information such as substance safety data sheets and purchasing records.

6.2 Estimation of Fugitive Emissions, F

As per Equation 2, it has been determined that \( F = O4 \).
Table 1 lists the components of O4 as:

- Vent emissions from the small, basement located, solvent waste transfer tanks (both ‘solvent waste’ and ‘photo resist’ waste transfer tanks);
- Fugitive emissions from the valves and diaphragm pumps associated with the basement located solvent waste transfer tanks (on the pressure side of the pumps);
- Vent emissions from the bulk solvent waste storage tank located in the facility yard; and
- Vent emissions from the IBC’s receiving photoresist waste from the basement transfer tanks.

Vent emissions for the fixes transfer and storage tanks were estimated, for the calendar year 2013, using U.S. EPA TANKS4 software which uses empirical equations combined with local meteorological data and user storage or transfer tank engineering data. It is noted that the liquid solvent and photo-resist wastes contain on average > 60% water. This means that the vapour space concentrations of organic solvents being displaced from tanks to atmosphere via the vents will be very low.

Emission estimates for the IBC receiving vessels were assumed to be equal to the vent emissions from the basement located photo resist transfer tanks. This is reasonable given that the total approximate vapour displacement is the same for both systems and that the photo-resist waste being transferred is common to both the transfer tanks and the receiving IBC’s.

Table 2 summarises the TANKS4 based fugitive emission estimates of organic solvents, using waste throughput data for the calendar year 2015. Given that waste composition did not change for the calendar year 2015 the TANKS4 software was not run but rather Table 2 was updated on a pro rata basis based on the changes in Resist and Solvent waste volumes for 2015 in comparison to 2013.

<table>
<thead>
<tr>
<th>Tank Description</th>
<th>Waste Stream</th>
<th>Waste Throughput (kg/a)</th>
<th>Organic Solvent Fugitive Emissions (kg/a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500 litre capacity Photo resist Waste transfer tanks x 2</td>
<td>Resist waste</td>
<td>53,987</td>
<td>0.83</td>
</tr>
<tr>
<td>1000 litre IBC’s</td>
<td>Resist waste</td>
<td>53,987</td>
<td>0.83</td>
</tr>
<tr>
<td>500 litre capacity Solvent Waste transfer tank</td>
<td>Solvent Waste</td>
<td>163,000</td>
<td>&lt;0.1 (*)</td>
</tr>
<tr>
<td>Bulk Solvent Waste storage tank</td>
<td>Solvent Waste</td>
<td>163,000</td>
<td>&lt;0.1 (*)</td>
</tr>
</tbody>
</table>

(*) The main organic solvent detected in analysis of Solvent Waste is 2-(2-aminoethoxy)ethanol, a component of EKC 265 but which is not a VOC by definition under the Solvents Regulations by virtue of the substances’ very low vapour pressure. Solvent Waste consists of between 70% and 90% water. Other organic solvents detected in the Solvent Waste also have vapour pressures on the lower end of the spectrum and thus are not expected to result in substantial fugitive releases.

Emission estimates for assumed minor fugitive releases from the basement transfer tank pumps and valves are unreliable without specific measurement for these emissions but are expected to be very small and substantially smaller than estimates presented in Table 2.

Based on the assessment above, the total value for F is estimated as:
0.83 kg/a + 0.83 kg/a + 0.1 kg/a + 0.1 kg/a = 1.86 kg/a.

i.e.,

\[ F = 1.86 \text{ kg for 2015} \]

Applying Equation 4, the percentage fugitives are therefore calculated as:

\[ \text{Percentage Fugitives} = \left( \frac{1.86}{86061} \right) \times 100 = 0.0022\% \]

7. DISCUSSION & CONCLUSION

The total fugitives of organic solvents is estimated at 0.0022 %. This is << 15% the maximum allowable under Condition 5.11 of IPC licence P0224-02. Therefore, it can be concluded that Analog Devices is well in compliance with Condition 5.11. This figure is in line with that for 2013 which was 0.0023 % and 2014 which was 0.0025 %.

The reason for the low percentage value is the limited sources of fugitive emissions on the Analog site related to surface cleaning activities. This in turn is due to the manufacturing building design which inherently captures organic solvent emissions and directs them to the main emission points under IPC licence P0224-02. Such emissions are not fugitive emissions.
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