National Pollutant Inventory

Emission Estimation Technique Manual

for

Coffee Roasting

First published in June 1999

EMISSION ESTIMATION TECHNIQUES
FOR
COFFEE ROASTING

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COFFEE ROASTING

LIST OF FIGURES AND TABLES

1.0 Introduction

The purpose of all Emission Estimation Technique (EET) Manuals in this series is to assist Australian manufacturing, industrial and service facilities to report emissions of listed substances to the National Pollutant Inventory (NPI). This Manual describes the procedures and recommended approaches for estimating emissions from facilities engaged in coffee roasting.

The coffee roasting industry includes those facilities processing green coffee beans into roasted coffee products including whole and ground beans, and soluble coffee products.

EET MANUAL: Coffee Roasting

HANDBOOK: Snack Foods and Prepared Meals

ANZSIC CODES :   2179

This Manual was drafted by the NPI Unit of the Queensland Department of Environment and Heritage on behalf of the Commonwealth Government. It has been developed through a process of national consultation involving State and Territory environmental authorities and key industry stakeholders.

2.0   Processes and Emissions

The following section presents a brief description of the coffee roasting industry and identifies likely sources of emissions.

2.1 Process Description

The coffee roasting process consists of cleaning, roasting, cooling, grinding, and packaging operations. Figure 1 illustrates a typical coffee roasting operation.
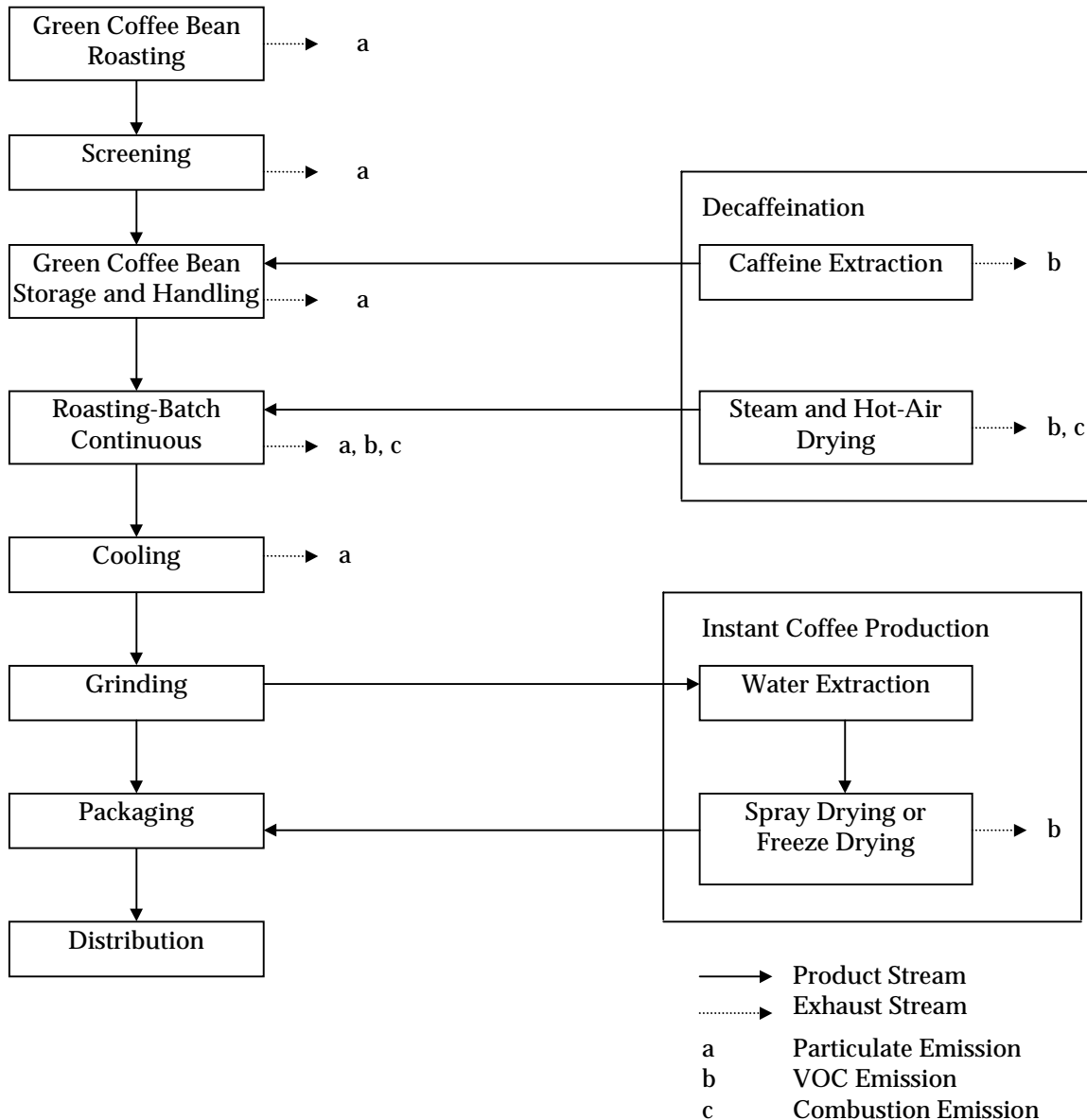
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┌──────────────────────┐
│ Green Coffee Bean     │·········►  a
│     Roasting          │
└──────────────────────┘
          │
          ▼
┌──────────────────────┐
│     Screening         │·········►  a
└──────────────────────┘
          │                                    ┌───────────────────────────────────────────┐
          ▼                                    │ Decaffeination                            │
┌──────────────────────┐                       │   ┌─────────────────────┐                 │
│ Green Coffee Bean     │◄──────────────────────│   │ Caffeine Extraction │·······►  b      │
│ Storage and Handling  │·········► a           │   └─────────────────────┘                 │
└──────────────────────┘                       │                                           │
          │                                     │   ┌─────────────────────┐                 │
          ▼                                     │   │ Steam and Hot-Air   │·······► b, c    │
┌──────────────────────┐◄──────────────────────│   │     Drying          │                 │
│ Roasting-Batch        │                       │   └─────────────────────┘                 │
│   Continuous          │·········► a, b, c     └───────────────────────────────────────────┘
└──────────────────────┘
          │
          ▼
┌──────────────────────┐
│     Cooling           │·········►  a
└──────────────────────┘
          │                                    ┌───────────────────────────────────────────┐
          ▼                                    │ Instant Coffee Production                 │
┌──────────────────────┐                       │   ┌─────────────────────┐                 │
│     Grinding          │──────────────────────►│   │  Water Extraction   │                 │
└──────────────────────┘                       │   └─────────────────────┘                 │
          │                                     │             │                             │
          ▼                                     │             ▼                             │
┌──────────────────────┐                       │   ┌─────────────────────┐                 │
│     Packaging         │◄──────────────────────│   │ Spray Drying or     │·······►  b      │
└──────────────────────┘                       │   │  Freeze Drying      │                 │
          │                                     │   └─────────────────────┘                 │
          ▼                                     └───────────────────────────────────────────┘
┌──────────────────────┐
│    Distribution       │
└──────────────────────┘
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──────► Product Stream
········► Exhaust Stream

a   Particulate Emission
b   VOC Emission
c   Combustion Emission

Figure 1 - **Typical Coffee Roasting Operation**
Source: Adapted from USEPA AP-42 Section 9.13.2, 1995

2.2 Emission Sources and Control Technologies

2.2.1 Emissions to Air

Air emissions may be categorised as:

Fugitive Emissions

These are emissions that are not released through a vent or stack. Examples of fugitive emissions include dust from stockpiles, volatilisation of vapour from vats, open vessels, or spills and materials handling. Emissions emanating from ridgeline roof-vents, louvres, and open doors of a building as well as equipment leaks, and leaks from valves and flanges are also examples of fugitive emissions. Emission factor EETs are the usual method for determining losses through fugitive emissions.

Point Source Emissions

These emissions are exhausted into a vent or stack and emitted through a single point source into the atmosphere.

The likely air emissions from coffee roasting include:

Table 1 - Common Air Emission of NPI-Listed Substances from Coffee Roasting

Substance
Volatile Organic Compounds (VOC)
Sulfur Dioxide (SO_2)
Particulate Matter (PM_{10})
Carbon Monoxide (CO)
Oxides of Nitrogen (No_x)
Ammonia (NH_3)*
Chlorine (Cl_2) *

Source: Queensland Department of Environment and Heritage, 1998

* Ammonia and Chlorine are common substances used for refrigeration and disinfecting/cleaning purposes, hence a possible emission source.

Air emission control technologies, such as electrostatic precipitators, fabric filters or baghouses, and cyclones, are commonly installed to reduce the concentration of particulates in process off-gases before stack emission. Where such emission abatement equipment has been installed, and where emission factors from uncontrolled sources have been used in emission estimation, the collection efficiency of the abatement equipment needs to be considered. Guidance on applying collection efficiencies to emission factor equations is provided in later sections.

With regards to emission controls for PM_{10} emissions (particulate matter with an equivalent aerodynamic diameter of 10 micrometres or less ie. $\leq 10 \mu m$), in the absence of measured data, or knowledge of the collection efficiency for a particular piece of equipment, an efficiency of 90% should be used in the emission factor equation to calculate actual mass emissions. This default should only be used if there is no other available control efficiency.

2.2.2 Emissions to Water

Emissions of substances to water can be categorised as discharges to:

- Surface waters (eg. lakes, rivers, dams, and estuaries);
- Coastal or marine waters; and
- Stormwater.

Because of the significant environmental hazards posed by emitting toxic substances to water, most facilities emitting NPI-listed substances to waterways are required by their relevant State or Territory environment agency to closely monitor and measure these emissions. This existing sampling data can be used to calculate annual emissions.

If no wastewater monitoring data exists, emissions to process water can be calculated based on a mass balance or using emission factors.

The discharge of listed substances to a sewer does not require you to report to the NPI. However, leakage and other emissions (including dust) from a tailings storage facility are reportable. (See also Section Three of *The NPI Guide.*)

2.2.3 Emissions to Land

Emissions of substances to land on-site include solid wastes, slurries, sediments, spills and leaks, storage and distribution of liquids and may contain listed substances. These emission sources can be broadly categorised as:

- surface impoundments of liquids and slurries; and
- unintentional leaks and spills.

For the coffee roasting industry, emissions to land may occur as a result of irrigating with treated wastewater. It is only necessary to report emissions to land from irrigation if it contains an NPI-listed substance.

3.0   Emission Estimation Techniques

Estimates of emissions of NPI-listed substances to air, water and land should be reported for each substance that triggers a threshold. The reporting list and detailed information on thresholds are contained in *The NPI Guide* at the front of this Handbook.

In general, there are four types of emission estimation techniques (EETs) that may be used to estimate emissions from your facility.

The four types described in *The NPI Guide* are:

- sampling or direct measurement;
- mass balance;
- fuel analysis or other engineering calculations; and
- emission factors

Select the EET, (or mix of EETs), that is most appropriate for your purposes. For example, you might choose to use a mass balance to best estimate fugitive losses from pumps and vents, direct measurement for stack and pipe emissions, and emission factors when estimating losses from storage tanks and stockpiles.

If you estimate your emission by using any of these EETs, your data will be displayed on the NPI database as being of 'acceptable reliability'. Similarly, if your relevant environmental authority has approved the use of EETs that are not outlined in this handbook, your data will also be displayed as being of 'acceptable reliability'.

This Manual seeks to provide the most effective emission estimation techniques for the NPI substances relevant to this industry. However, the absence of an EET for a substance in this handbook does not necessarily imply that an emission should not be reported to the NPI. The obligation to report on all relevant emissions remains if reporting thresholds have been exceeded.

> **You are able to use emission estimation techniques that are not outlined in this document. You must, however, seek the consent of your relevant environmental authority. For example, if your company has developed site-specific emission factors, you may use these if approved by your relevant environmental authority.**

You should note that the EETs presented in this manual relate principally to average process emissions. Emissions resulting from non-routine events are rarely discussed in the literature, and there is a general lack of EETs for such events. However, it is important to recognise that emissions resulting from significant operating excursions and/or accidental situations (eg. spills) will also need to be estimated. Emissions to land, air and water from spills must be estimated and added to process emissions when calculating total emissions for reporting purposes. The emission resulting from a spill is the net emission, ie., the quantity of the NPI reportable substance spilled, less the quantity recovered or consumed during clean up operations.

The **usage** of each of the substances listed as Category 1 and 1a under the NPI must be estimated to determine whether the 10 tonnes (or 25 tonnes for VOCs) reporting threshold is exceeded. If the threshold is exceeded, **emissions** of these Category 1 and 1a substances must be reported for all operations/processes relating to the facility, even if the actual emissions of the substances are very low or zero.

3.1   Direct Measurement

You may wish to undertake direct measurement in order to report to the NPI, particularly if you already do so in order to meet other regulatory requirements. However, the NPI does not require you to undertake additional sampling and measurement. For the sampling data to be adequate and able to be used for NPI reporting purposes, it would need to be collected over a period of time, and to be representative of operations for the whole year.

3.1.1 Sampling Data

Stack sampling test reports often provide emissions data in terms of parts per million (ppm) or grams per cubic metre (g/m^3) (dry standard). Annual emissions for NPI reporting can be calculated from this data. Stack tests for NPI reporting should be performed under representative (ie. normal) operating conditions. You should be aware that some tests undertaken for a State or Territory license condition may require the test be taken under maximum emissions rating, where emissions are likely to be higher than when operating under normal operating conditions.

For the coffee roasting industry it is likely that some sampling may be required under environmental licensing in individual states or territories. This may include sampling of substances such as particulate matter and combustion products.

Emissions of ammonia may be determined by considering the losses from the refrigeration system in any given year. This information may be available through determining how much the refrigeration system required 'topping up' in a given year.

3.1.2 Continuous Emission Monitoring System (CEMS) Data

A continuous emission monitoring system provides a continuous record of emissions over time, usually by reporting pollutant concentration.

Once the pollutant concentration is known, emission rates are obtained by multiplying the pollutant concentration by the volumetric gas or liquid flow rate.

It is important to note that prior to using CEMS to estimate emissions, you should develop a protocol for collecting and averaging the data in order that the estimate satisfies your relevant environmental authority's requirement for NPI emissions estimations.

Most food processing industries however, will not be required to use this method of EET for the reporting of substances.

3.2   Mass Balance

A mass balance identifies the quantity of substance going in and out of an entire facility, process, or piece of equipment. Emissions can be calculated as the difference between input and output of each listed substance. Accumulation or depletion of the substance within the equipment should be accounted for in your calculation.

3.3   Engineering Calculations

An engineering calculation is an estimation method based on physical/chemical properties (eg. vapour pressure) of the substance and mathematical relationships (eg. ideal gas law).

3.3.1 Fuel Analysis

Fuel analysis is an example of an engineering calculation and can be used to predict SO_2 and metal emissions based on application of conservation laws, if fuel rate is measured. The presence of certain elements in fuels may be used to predict their presence in emission streams. This includes elements such as sulfur, which may be converted into other compounds during the combustion process.

The basic equation used in fuel analysis emission calculations is the following:

Equation 1

$$E_{kpy, i} = Q_f * \text{pollutant concentration in fuel} * (MW_p / EW_f) * OpHrs$$

where:

$E_{kpy, i}$ =   emissions of pollutant i, kg/yr
Q_f =   fuel use, kg/hr
MW_p =   molecular weight of pollutant emitted, kg/kg-mole
EW_f =   elemental weight of substance in fuel, kg/kg-mole
OpHrs=   operating hours, hr/yr

For instance, SO_2 emissions from coal combustion can be calculated based on the concentration of sulfur in the coal. This approach assumes complete conversion of sulfur to SO_2. Therefore, for every kilogram of sulfur (EW = 32) burned, two kilograms of SO_2 (MW = 64) are emitted. The application of this EET is shown in Example 1.

Example 1 - **Using Fuel Analysis**

This example illustrates how SO_2 emissions can be calculated from oil combustion based on fuel analysis results and the fuel flow information. The facility is assumed to operate 1500 hours per year.

$E_{kpy,SO2}$ = may be calculated using Equation 1.

Fuel flow   =   2 000 kg/hr
Weight percent sulfur in fuel   =   1.17

$$E_{kpy,SO2} = Q_f * \text{pollutant concentration in fuel} * (MW_p/EW_f) * OpHrs$$
$$= (2\ 000) * (1.17 / 100) * (64 / 32) * 1\ 500$$
$$= 46.8\ \text{kg/hr} * 1\ 500\ \text{hr/yr}$$
$$= 70\ 200\ \text{kg/yr}$$

3.4   Emission Factors

An emission factor is a tool that is used to estimate emissions to the environment. In this Manual, it relates the quantity of substances emitted from a source to some common activity associated with those emissions. Emission factors are obtained from US, European, and Australian sources and are usually expressed as the weight of a substance emitted divided by the unit weight, volume, distance, or duration of the activity emitting the substance (eg. kilograms of sulfur dioxide emitted per tonne of air-dried unbleached pulp produced).

Emission factors are used to estimate a facility's emissions by the general equation:

Equation 2
$$E_{kpy,i} = [A * OpHrs] * EF_i * [1 - (CE_i/100)]$$

where :

$E_{kpy,i}$	=	emission rate of pollutant i, kg/yr
A	=	activity rate, t/hr
OpHrs	=	operating hours, hr/yr
EF_i	=	uncontrolled emission factor of pollutant i, kg/t
CE_i	=	overall control efficiency of pollutant i, %.

Emission factors developed from measurements for a specific process may sometimes be used to estimate emissions at other sites. Should a company have several processes of similar operation and size, and emissions were measured from one process source, an emission factor could be developed and applied to similar sources. You are required to have the emission factor reviewed and approved by State or Territory environment agencies prior to its use for NPI estimations.

3.4.1 Industry-Wide Emission Factors

The following emission factors may be used to estimate emissions of particulate matter and carbon monoxide from coffee roasting operations.

Table 2 - Emissions Factors for Coffee Roasting Operations[a]

Source	Particulate Matter [b] (kg/tonne)	VOC [b] (kg/tonne)	Carbon Monoxide [b] (kg/tonne)
Batch Roaster with Thermal Oxidiser	0.06	0.024	0.28
Continuous Cooler with Cyclone	0.014	ND	ND
Continuous Roaster	0.33	0.7	0.75
Continuous Roaster with Thermal Oxidiser	0.046	0.08	0.049
Green Coffee Bean Screening, Handling, and Storage System with Fabric Filter	0.03	ND	ND

Source: USEPA AP-42 Section 9.13.2, 1995
[a] Emissions factors have a rating code of D.
[b] Emission Factors are based on tonnes of green bean feed. Factors represent uncontrolled
emissions unless noted.
ND = no data

Example 2 - Using Emission Factors

Table 2 shows that for a batch roaster with a thermal oxidiser, 0.28 kg of carbon monoxide is emitted for every tonne of green beans fed.

Assume the facility processes 10 000 tonnes of green coffee beans per year.

It is assumed that the control efficiency of the equipment has already been taken into consideration in the emission factor.

$$\text{Emission Factor (EF}_{\text{Carbon Monoxide}}) = 0.28 \text{ kg/tonne}$$
$$\text{Green Beans Processed (A)} = 10\,000 \text{ tonne/year}$$

$$
\begin{aligned}
E_{\text{Carbon Monoxide}} &= [A] * EF_i \\
&= 0.28 \text{ kg/tonne} * 10\,000 \text{ tonne/yr} \\
&= 2\,800 \text{ kg of carbon monoxide/yr.}
\end{aligned}
$$

Therefore, 2.8 tonne of carbon monoxide per year is emitted from the batch roaster.

3.4.2 Predictive Emission Monitoring (PEM)

Predictive emission monitoring is based on developing a correlation between pollutant emission rates and process parameters. A PEM allows facilities to develop site-specific emission factors, or emission factors more relevant to their particular process.

Based on test data, a mathematical correlation can be developed that predicts emissions using various parameters.

4.0 Emission Estimation Techniques: Acceptable Reliability and Uncertainty

This section is intended to give a general overview of some of the inaccuracies associated with each of the techniques. Although the National Pollutant Inventory does not favour one emission estimation technique over another, this section does attempt to evaluate the available emission estimation techniques with regards to accuracy.

Several techniques are available for calculating emissions from coffee roasting operations. The technique chosen is dependent on available data, available resources, and the degree of accuracy sought by the facility in undertaking the estimate. In general, site-specific data that is representative of normal operations is more accurate than industry-averaged data, such as the emission factors presented in Section 3.4.1 of this Manual.

4.1 Direct Measurement

Use of stack and/or workplace health and safety sampling data is likely to be a relatively accurate method of estimating air emissions from coffee roasting and processing facilities. However, collection and analysis of samples from facilities can be very expensive and especially complicated where a variety of NPI-listed substances are emitted and where most of these emissions are fugitive in nature. Sampling data from a specific process may not be representative of the entire manufacturing operation and may provide only one example of the facility's emissions.

To be representative, sampling data used for NPI reporting purposes needs to be collected over a period of time, and to cover all aspects of production.

In the case of CEMS, instrument calibration drift can be problematic and uncaptured data can create long-term incomplete data sets. However, it may be misleading to assert that a snapshot (stack sampling) can better predict long-term emission characteristics. It is the responsibility of the facility operator to properly calibrate and maintain monitoring equipment and the corresponding emissions data.

4.2 Mass Balance

Calculating emissions from a coffee roasting facility using mass balance appears to be a straightforward approach to emission estimations. However, it is likely that few Australian facilities consistently track material usage and waste generation with the overall accuracy needed for application of this method. Inaccuracies associated with individual material tracking or other activities inherent in each material handling stage can often result in large deviations of total facility emissions. Because emissions from specific materials are typically below 2 percent of gross consumption, an error of only $\pm$ 5 percent in any one step of the operation can significantly skew emission estimations.

4.3   Engineering Calculations

Theoretical and complex equations or *models* can be used for estimating emissions from coffee roasting.

Use of emission equations to estimate emissions from coffee roasting facilities is a more complex and time-consuming process than the use of emission factors. Emission equations require more detailed inputs than the use of emission factors but they do provide an emission estimate that is based on facility-specific conditions.

4.4   Emission Factors

Every emission factor has an associated emission factor rating (EFR) code. This rating system is common to EETs for all industries and sectors and therefore, to all Industry Handbooks. They are based on rating systems developed by the United States Environmental Protection Agency (USEPA), and by the European Environment Agency (EEA). Consequently, the ratings may not be directly relevant to Australian industry. Sources for all emission factors cited can be found in Section 5.0 of this Manual. The emission factor ratings will not form part of the public NPI database.

When using emission factors, you should be aware of the associated EFR code and what that rating implies. An A or B rating indicates a greater degree of certainty than a D or E rating. The less certainty, the more likely that a given emission factor for a specific source or category is not representative of the source type. These ratings notwithstanding, the main criterion affecting the uncertainty of an emission factor remains the degree of similarity between the equipment/process selected in applying the factor, and the target equipment/process from which the factor was derived.

The EFR system is as follows:

A	-	Excellent
B	-	Above Average
C	-	Average
D	-	Below Average
E	-	Poor
U	-	Unrated

5.0   References

National Pollutant Inventory Homepage
http://www.environment.gov.au/epg/npi/home.html

USEPA. September 1995. *Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources, fifth edition, AP-42. Section 9.13.2 Coffee Roasting.* United States Environmental Protection Agency, Office of Air Quality Planning and Standards. Research Triangle Park, NC, USA.
http://www.epa.gov/ttn/chief/ap42.html

The following Emission Estimation Technique Manuals referred to in this Manual are available at the NPI Homepage and from your local environmental protection agency (see the front of the NPI Guide for details):

- Emission Estimation Technique Manual for Combustion in Boilers;
- Emission Estimation Technique Manual for Combustion Engines;
- Emission Estimation Technique Manual for Snack Foods Roasting & Frying; and
- Emission Estimation Technique Manual for Fuel & Organic Liquid Storage.