Neo P5 Process Description and Emissions

Process Description and Emissions

Content

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1 Introduction

1.1 Scope of the document

This document provides a detailed technical description of the Enespa Neo P5 pyrolysis plant, the first commercially available decentralized and scalable pyrolysis technology for the conversion of pre-treated plastic waste into high-quality pyrolysis oil. The system has been specifically developed to process polyolefin-rich plastic fractions (such as HDPE, LLDPE, PP, and PE) in compliance with defined feedstock specifications and under oxygen-free conditions.

The Enespa Neo P5 stands out for its modularity, compact footprint, and operational flexibility, making it particularly suitable for local waste valorization and integration into circular economy strategies. By enabling decentralized deployment at industrial or municipal sites, the Neo P5 allows for the direct conversion of plastic waste streams into reusable hydrocarbons—thus reducing transportation costs, minimizing environmental impact, and supporting the transition from fossil-based to circular raw materials.

With a nominal feed capacity of approximately 200 kg/h, the system produces up to 160 kg/h of pyrolysis oil, divided into high-temperature (HTC) and low-temperature (LTC) fractions. These oil products can serve as valuable feedstock for the chemical industry or as raw material for further upgrading and refining processes.

The following sections describe the core process components of the Neo P5 system, including pre-treatment, plastification, pyrolysis, residue discharge, condensation, and storage. Critical process parameters, quality control mechanisms, and system boundaries are defined to ensure reliable, safe, and efficient operation. This documentation is intended to support technical planning, regulatory approval, and integration into sustainable material recovery concepts.

The second part of this document provides a detailed overview of the energy concept based on the utilization of non-condensable pyrolysis gases in a gas generator. The chemical energy contained in the gas is converted into electrical energy to supply power to the plant. To illustrate this approach, a sample calculation is presented, including an evaluation of the self-efficiency rate of the system, with specific reference to a single Neo-P5 unit.

Following the energy concept, the document provides an in-depth analysis of emissions for the reference project in Dade City, Florida. This section includes detailed emission calculations and is intended to serve as a baseline for future environmental assessments related to similar configurations.

The final part of the document outlines the equipment layout within Building C at Dade City Business Park and identifies all relevant emission points to be considered in the context of environmental impact assessments.

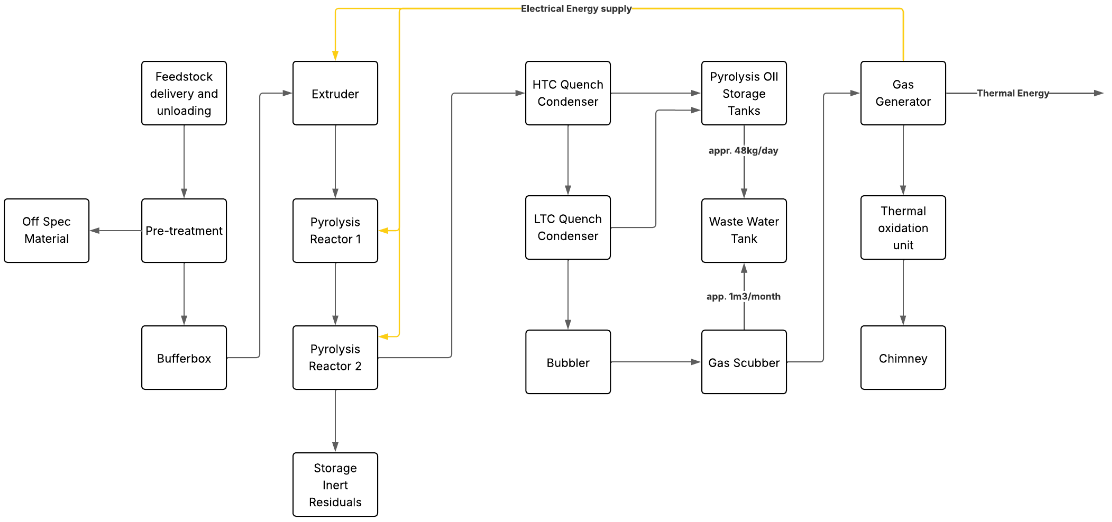
Together, these sections provide a comprehensive guideline for evaluating the energy concept and its associated emissions, forming a solid foundation for permitting and regulatory review processes.

2 Process Description of on Neo P5 Unit

The pyrolysis process consists of a number of process steps.

The plastic feedstock is sorted, shredded, dried, agglomerated and buffered before entering the pyrolysis process. During pyrolysis, the plastic material decomposes and exits the reactor as pyrolysis vapors or pyrolysis gas along with a small portion of solid residue or coke.

Pyrolysis oil is then recovered through a two stage condensation as the main product.



BFD see Attachment 2

2.1 Pre-treatment

The delivered, pre-sorted plastic waste is first processed in a dedicated shredding unit. The shredded material is then conveyed via belt systems to fully automated sorting units. These systems are designed to efficiently separate polyolefins (such as PE and PP) from non-target materials and contaminants. The separation process ensures that interfering substances—such as PVC, PET, and non-plastic residues—are reliably removed from the feedstock.

After sorting, the purified polyolefins are transferred to a dry cleaning unit, where remaining surface contaminants are removed without the use of water. This dry-washing step is essential to reduce chlorine, sulfur, and other limiting elements that may negatively affect pyrolysis performance or the quality and marketability of the resulting pyrolysis oil.

The cleaned polyolefins are then fed into an agglomerator. Agglomeration not only improves the bulk density and flow properties of the material for storage and handling but also helps prevent moisture accumulation. The agglomerates are subsequently transported via conveyor belt into a buffer box, which serves as the feeding point for the downstream pyrolysis system.

The entire pre-treatment system is designed, sourced, constructed, and commissioned in close cooperation with Source One GmbH. A reference plant has been in operation in Germany since 2023, demonstrating that this process chain is capable of producing polyolefin agglomerates with purity levels of up to 98%. This high-quality input material is ideally suited for pyrolysis, ensuring optimal process efficiency and yielding high-grade pyrolysis oil fractions suitable for use in chemical recycling and industrial applications.

2.2 Plastification

The plastification unit comprises the main components: side feeder, extruder, and a three-way start-up valve.

The agglomerated material is continuously discharged from the buffer box into a weighing hopper positioned above and connected to the side feeder. This hopper is mounted on load cells to precisely measure the mass flow of agglomerates being discharged. The collected data enables real-time monitoring of the material input and supports the establishment of a continuous mass balance for the process.

The side feeder, located directly beneath the weighing hopper, compensates for fluctuations in bulk density of the agglomerates. It ensures that the extruder, to which it is directly connected, is consistently and evenly fed with material of stable density—critical for achieving uniform extrusion and reliable melt quality.

Inside the extruder, the material is continuously melted at temperatures of up to 270 °C. The extruder is equipped with electric heating elements and cooling fins connected to a water-cooling circuit, enabling precise thermal control in each zone of the extruder. This combination of heating and cooling allows for an optimal plastification profile and prevents thermal degradation of the material.

At the end of the extruder, the molten material is directed through a three-way valve. During start-up or shut-down, the melt is diverted into a sampling container, where its visual appearance and consistency can be checked and samples can be collected. Once a stable and homogeneous melt flow is verified, the valve switches to process mode and transfers the melt directly into Reactor 1 of the pyrolysis system.

This plastification stage ensures a stable and precisely conditioned feed of molten polyolefins into the reactor, forming a critical interface between mechanical pre-treatment and thermochemical decomposition.

2.3 Pyrolysis Reactors

The pyrolysis stage consists of Reactor 1 and Reactor 2 and serves as the core of the thermal decomposition process.

The molten plastic from the extruder is introduced into Reactor 1 via a lateral inlet nozzle. Inside the reactor, the melt is conveyed along the axial length of the reactor tube by a rotating screw conveyor, which also provides a mixing effect. The conveyance speed is precisely defined to ensure optimal residence time and controlled thermal treatment of the material.

An inert nitrogen atmosphere is maintained within the reactor to exclude oxygen and prevent unwanted oxidation reactions. The required thermal energy for depolymerization, as well as the exclusion of atmospheric oxygen, is supplied by electrically heated jackets installed along the external wall of the reactor tube. Multiple heating zones are distributed along the reactor axis, allowing for controlled, gradual heating and avoiding uncontrolled cracking / coaking of the polymers

As the melt travels through Reactor 1, it transitions from a molten to a fluidized state, initiating the breakdown of long-chain polyolefins into short-chain hydrocarbon vapors. The gas generated during this process flows continuously from Reactor 1 into Reactor 2, and subsequently exits through a riser pipe into the condensation unit.

At the end of Reactor 1, any non-pyrolyzed fraction is transferred via a transfer nozzle into Reactor 2. Here, the remaining material is again conveyed by a specially designed screw conveyor, now operating at different rotation speeds, toward the residue discharge and gas outlet.

Non-pyrolyzable residues are discharged through an outlet port into a residue collection vessel, which is also heated. This ensures post-pyrolysis of any residual hydrocarbons, resulting in a dry, ash-like solid that is free of further volatile content.

The pyrolysis gas flows through the riser or connecting pipe directly into the first-stage quench condenser for downstream cooling and separation.

Temperature control within the pyrolysis reactors is ensured through a combination of internal product temperature sensors and external surface temperature sensors mounted on the heating zones. The entire heating system is governed by a patented control loop, allowing precise regulation with a temperature deviation of no more than ±1 °C. This ensures a stable, reproducible pyrolysis process and prevents the formation of undesired by-products due to thermal overrun or uneven heating.

2.4 Condensation

The pyrolysis gas exiting Reactor 2 is directed into the first condensation stage, the high-temperature quench column (HTC). The gas is introduced at the bottom of the column, where it flows upward against a quench cone. This physical design forces the condensation of the heavier hydrocarbon components.

The condensed pyrolysis oil collects at the bottom of the quench column and is transferred into a collection vessel. From there, the liquid oil is pumped through a heat exchanger, where it is cooled to approximately 80 °C. This cooled oil is then recirculated to the top of the quench column and injected back into the gas stream via a full-cone quench nozzle. The recirculation and injection process ensures efficient and forced condensation of pyrolysis vapors by direct contact with the cooled liquid.

The non-condensable gas rises to the top of the HTC column and is transferred via an interconnecting pipe to the second-stage condensation unit, the low-temperature quench column (LTC). In the LTC, the gas is again introduced at the bottom of the column, where it encounters a second quench cone. Using the same principle as in the HTC, the remaining condensable components are liquefied.

In the LTC stage, the condensed oil is cooled even further—to below ambient temperature—by passing it through a dedicated heat exchanger. This ensures maximum condensation efficiency under environmental conditions and maximizes the recovery of valuable pyrolysis oil.

The residual non-condensable pyrolysis gas exits from the top of the LTC column and is routed into a bubbler system. In the bubbler, the gas is passed through a dip tube submerged in water or another suitable scrubbing liquid. This serves to remove any remaining contaminants or aerosols from the gas stream.

From the bubbler, the cleaned gas flows through a pipeline to a gas distribution unit, which consists of two switching valves. Depending on the operational mode, the gas is either directed to an emergency flare system or to further thermal utilization. This may include combustion in a gas generator or routing to a thermal oxidation unit.

When used in a gas generator, the chemical energy of the non-condensable gases is converted into electrical power, which can then be used to operate the plant itself. In our U.S.-based projects, the integration of a gas generator is planned specifically to enable energy self-sufficiency by utilizing the syngas produced during pyrolysis.

2.5 Pyrolysis Gas Generator - Energy Recovery and Power Supply Integration

The non-condensable pyrolysis gas, which cannot be liquefied during the condensation phase, has a calorific value comparable to natural gas (approx. 10 kWh/Nm³). This energy-rich gas is utilized in a gas engine-generator system to produce electricity for internal plant use.

Gas Treatment and Combustion Process

Before combustion, the gas is cleaned in a scrubber unit using a sodium hydroxide (NaOH) solution to remove chlorine and sulfur compounds. The purified gas is then fed into the injection system of a high-efficiency gas engine, which drives a coupled generator. Inside the combustion chamber, the chemical energy of the pyrolysis gas is converted into mechanical energy and then into electrical energy.

The exhaust gases from the combustion process are routed to a thermal post-combustion chamber, where any unburned hydrocarbon residues are oxidized. This ensures that all emissions remain within the applicable emission limits for stationary gas-fired CHP units in Florida, including:

- $NO_x \leq 0.50$ lb/MMBtu
- $CO \leq 3.5$ g/kWh
- VOC ≤ 5.0 lb/MMBtu
- Total hydrocarbons (THC), HCl, SO_2, and PM: controlled via gas treatment and clean combustion

On October 31, 2023, a pyrolysis trial was carried out at the laboratory of Enespa-GRT Innovation GmbH using a raw material known as MPO-95, which precisely matches the defined feedstock specifications of our pyrolysis system.

Following the pyrolysis process, condensation, and gas treatment via the Bubbler system, the non-condensable pyrolysis gas was collected in a gas sampling bag and analyzed in the laboratory. A key outcome of this analysis was the determination of the net calorific value (NCV) of the gas.

The result showed a calorific value of **72 MJ/Nm³, equivalent to 20 kWh/Nm³.** This value has been used as the reference for all subsequent energy recovery and self-sufficiency calculations involving the gas engine generator. The corresponding test report is attached as an appendix to this document.

For the energy conversion process, a gas engine of the MAN MA250BG series, modified and adapted by Völkl Motorentechnik GmbH, was used. This specific engine configuration served as the reference system for calculating electrical output and system efficiency. The MA250BG engine series (see attachment 2) is also planned for use in our upcoming projects in Florida, where it will serve as the core component for decentralized energy generation from pyrolysis gas.

2.5.1 Example Calculation – Power Generation from 200 kg/h of Feedstock

In this example, we refer to our general massbalnce of a pyrolysis system processing 200 kg of plastic feedstock per hour, with 15 wt% converted into non-condensable gas. The calorific value is 72 MJ/Nm^3 (equal to 20 kWh/Nm^3), and the gas engine-generator system has an electrical efficiency of 38,6%.

Mass of pyrolysis gas per hour:	200kg/h x 0,15 = **30kg/h**
Conversion to standard cubic meters (gas density = 1,2kg/Nm^3	30kg/h / 1,2kg/Nm^3 = **25Nm^3/h**
Chemical energy content:	25Nm^3/h x 20kWh/Nm^3 = **500kWh/h**
Electrical output at 38,6% electrcial efficiency	500kWh/h x 0,386 = **193,25 kWh/h**

Power Demand of Pyrolysis Maschine during continious operation:
The pyrolysis system has a specific power demand of **0.4 kWh per kg** of feedstock:

200kg/h x 0,4kWh/kg = **80 kWh/h**

Summary:

- Electricity generated by gas engine: **~193–194 kWh/h**
- Electricity demand of the plant: **80 kWh/h**
- Self-sufficiency level: 193 / 80 x 100% = **241,25%**

The pyrolysis machine is therefore fully energy self-sufficient, with an electricity surplus of approx. 113 kWh/h. This surplus can be used for auxiliary equipment, pre-treatment or feed into the grid.

2.6 Pyrolysis oil storage and Logistics

The pyrolysis oil produced by the P5 machines is continuously transferred into dedicated storage tanks connected to the system. Based on the real-time fill level monitoring, the process control system automatically determines which tank receives the currently produced oil. This ensures seamless and safe storage operation without overfilling or process interruption.

Each pyrolysis oil storage tank is equipped with:

- Nitrogen blanketing to prevent oxygen ingress and reduce vapor-phase flammability,
- A gas balancing (vapor recovery) system, and
- Detonation arrestors installed on all incoming and outgoing pipelines to prevent flame propagation and enhance safety.

Once a tank reaches its defined maximum fill level, the sampling and release process is initiated. The operations manager is responsible for sample verification and approval. Only after formal release can the tank be discharged.

The released pyrolysis oil is then pumped from the storage tank into an intermodal ISO tank container provided by the downstream offtake partner. These ISO containers are used for the safe and certified transport of pyrolysis oil to the customer's refining or upgrading facility.

Further logistics processes—such as container labeling, documentation, nitrogen blanketing for transport, and traceability within ISCC PLUS or comparable certification systems—are integrated into the plant's digital tracking infrastructure and quality assurance protocol.

2.7 Inert Residual Storage

The non-pyrolyzable residues from Pyrolysis Reactor 2 are discharged via a screw conveyor into a dedicated residue collection container. These residues primarily consist of inert solids such as carbon-rich ash, inorganic fillers, and minor metallic contaminants that cannot be further decomposed by pyrolysis.

Once the maximum fill level is reached, the container must either be:

- Manually exchanged for an empty one, or
- Emptied continuously using a secondary screw conveyor system connected to a twin-shaft transfer unit (Doppelmaschine) for controlled discharge.

The residues are cooled and dried before entering the downstream handling process. Afterward, they are transferred into a buffer container, from where a gripper-equipped forklift moves the material to the designated final storage unit.

In the Florida project, the final storage solution consists of a 10 m³ roll-off container, equipped with a stationary unloading interface. Once filled, the container can be:

- Delivered to a qualified residue offtake partner, or
- Exchanged for an empty unit as part of a closed logistics cycle.

In addition to safe storage and transport, efforts are underway to valorize the inert carbon-rich residues. Industrial applications where the carbon content can serve as a carrier material are being explored. For example:

- Ongoing tests are being conducted with WACKER Chemie AG, evaluating the use of the pyrolysis residue as a carbon-based process additive.
- The residue may also be suitable for use as a solid fuel substitute in coal-based power generation, or as a reductant in steel production.

These applications could enable material recovery, reduce waste disposal, and support the plant's overall circularity and carbon utilization strategy.

3 Multi-Line Operation of Neo-P5 Systems

While the previous Chapter 2 described the operation of a **single Neo-P5 pyrolysis unit**, the technology has been designed to also support **multi-line installations** with several identical modules operating in parallel at one site. This modular and scalable configuration allows for highly flexible **capacity adjustments** tailored to local feedstock volumes, offtake commitments, and expansion timelines.

Each P5 module has a **construction lead time of approximately four months** and can be **installed and commissioned within five days**. This short realization timeframe enables rapid deployment and expansion of production capacities at existing or new locations.

All Neo-P5 units can be operated **individually or in combination**, depending on site layout and operational requirements. For autonomous operation, each P5 unit can be equipped with a dedicated **buffer box** that ensures continuous feeding of the machine. Alternatively, the buffer boxes may be filled centrally from a **larger, shared pre-treatment facility** supplying multiple units.

The **pyrolysis oil** produced from each machine is transferred directly to the plant's storage tanks. The selection of the appropriate **target tank** is managed centrally by the site's **SCADA system**, which communicates with each individual machine control system to coordinate oil flows and optimize tank usage.

In a multi-unit setup, **larger gas generator systems** are deployed. As a general design principle, **two P5 modules are paired with one gas engine-generator unit**. This configuration ensures that maintenance can be performed on part of the system without having to shut down the entire site. It also allows for rotational service intervals while maintaining continuous production.

- **Reference Site: Dade City Business Center, Florida**
    - **Building 14938 – 14960**

As an example of a multi-line implementation, a plant configuration for Dade City, Florida has been developed. The site is designed to operate:

- 12 x Neo-P5 units
- 2 x centralized pre-treatment lines
- 6 x gas engine-generator systems (each connected to two P5 units)
- 6 x storage tanks, each with a volume of 100 m³, for pyrolysis oil

This setup illustrates the scalable and modular design philosophy of the Neo-P5 system and highlights the flexibility to rapidly adapt to market demand while maintaining operational independence and energy self-sufficiency at site level.

3.1 Infrastructure requirement

The following infrastructure is required at the Dade City site to operate the twelve Neo P5 units as well as the two pre-treatment systems.

Required utility infrastucture on site	
Tap Water supply pipe line [m³/h]	16,0
Rated Amps supply [Ampere]	1000,0
Rated natural Gas supply [kg/h]	449,6
Natural gas supply pipe diameter [inch]	3"
Natural gas supply pressure [psig]	50-60

Material storage	
Storage time Feedstock/PPO [d]	4,0
Storage feedstock [t]:	240,0
Bulk density flakes [t/m³]:	0,4
Bulk density granulate [t/m³]:	0,7
Storage height feedstock [m]	1,5
Estimated storage area feedstock [m²]:	228,6
Density PPO [kg/m³]:	0,8
Storage product [m³]:	300,0

Estimated inside process area [m²]:	1102,9
Estimated outside process area [m²]:	663,4
Estimated administration area [m²]:	738,0

Buildings	
Min. amount of employees (shift):	4
Oerator / control room [m²]:	40
Officeroom [m²]:	80
Electrical room [m²]:	480,0
Storage area (spare parts) [m²]:	138,0

3.2 Emissions

To determine the combustion characteristics, exhaust flow and pollutant emissions of pyrolysis gas (from PP / PE 80 / 20 feedstock) when fired in a reciprocating gas engine, in order to demonstrate compliance with U.S. industrial emission standards.

The exhaust treatment chain comprises three sequential stages:

1. **Gas Engine Combustion** – Pyrolysis gas is burned in a lean-burn reciprocating engine (38.6 % electrical efficiency), generating raw exhaust.

2. **Thermal Oxidizer (TO)** – Hot oxidation (850 °C, ≥ 2 s) destroys CO, CH_4, NMHC, formaldehyde (> 99 %) but forms ~ +10 % thermal NO_x.

3. **Selective Catalytic Reduction (SCR)** – Urea-driven NH_3 injection over catalyst removes 92 % of NO_x, ensuring < 500 mg/Nm³.

Assumptions:

- Engine efficiency and lean-burn behavior apply to H_2/olefin-rich pyrolysis gas.
- TO kinetics from vendor data.
- SCR removal at 92 % for high-temperature NH_3 catalyst.

Example (for 12xP5):

- Pyrolysis gas flow: 312.5 Nm³/h → 2 412.5 kWh electric (312.5×20 kWh/Nm³×0.386).

Objective: Demonstrate, step-by-step, that the combined engine + TO + SCR system reduces all regulated pollutants to within **Texas & Florida** heavy-industry emission limits.

The following calcualtuion is based on the assumption of 12 x P5 machines in operation.

The resulting Total Pyrolysis gas flow (F_{gas}) has been calcaulated based on a yielt of 15% gas to 312,5Nm^3/h.

The resulting electrical energy generated by the chosen Völkel Gas Engine with an electrical efficiency of 38,6% has been calculated:

$$P_{el} = 2412{,}5\ kWh/h$$

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3.2.1 Pyrolysis gas feedstock and properties

The pyrolysis gas was produced and sampled at the Enesoa pyrolysis P1 plant in Tankstedt, using a feedstock blend of 80 % polypropylene and 20 % polyethylene. The gas composition was then analyzed by GC-RGA and SCD. The results are shown in the table below, along with each component's approximate contribution to the lower heating value (LHV).

Component	Formula	Vol.-%	LHV Contribution[1] (MJ/Nm^3)
Hydrogen	H_2	6.6	0.066 × 10.8 = 7.13
Methane	CH_4	21.8	0.218 × 35.8 = 7.81
Ethylene	C_2H_4	12.6	0.126 × 59.0 = 7.43
Ethane	C_2H_6	11.8	0.118 × 65.0 = 7.67
Propylene	C_3H_6	26.6	0.266 × 85.8 = 22.82
Propane	C_3H_8	2.8	0.028 × 93.0 = 2.60
C_4-Hydrocarbons[2]	C_4H_n	10.4	0.104 × 110.0 ≈ 11.44
1,3-Butadiene	C_4H_6	1.2	0.012 × 97.5 ≈ 1.17
n-Pentane	C_5H_{12}	1.7	0.017 × 125.0 ≈ 2.13
C_6+ Hydrocarbons	$>C_6$	0.6	0.006 × 136.0 ≈ 0.82
Total combustibles	**96.0**	**≈ 72 MJ/Nm^3**	
Inerts & others[3]	N_2, CO_2, CO, O_2, H_2S…	**4.0**	—

[1] Typical LHV values for pure gases from fuel-property tables.

[2] Includes isobutane, n-butane, 1-butene, isobutene, trans- and cis-2-butene.

[3] Inerts and minor species (total ~4 vol %) are excluded from LHV calculation but accounted for in exhaust stoichiometry.

3.1 Exhaust Flow & Conversation

Calculating the **dry exhaust volumetric flow** is a critical step because all subsequent pollutant concentrations (mg /Nm³) are referenced to that flow. Without an accurate exhaust volume, you cannot translate mass emission rates (g/h) into stack concentrations, which are the metrics regulated by air quality standards. In addition, the exhaust volume determines the residence time and sizing requirements for the Thermal Oxidizer and SCR system—too small a volume, and the pollutants won't be fully treated; too large, and the equipment will be oversized and uneconomical.

Formula:
$V_{dry} = F_{gas} \times f_{ex}$

With f_{ex} = 13,75 dry exhaust / Nm gas

How f_{ex} is derived:

It represents the sum of stoichiometric CO_2 produced by combusting all carbon in the fuel, plus the nitrogen from the combustion air, on a dry-gas basis (i.e., excluding water vapor).

Example calculation:
V_{dry} = 312,5Nm^3/h $_{gas}$ x 13,75 Nm^3 dry exhaust/Nm^3 gas = <u>4298 Nm^3/h (dry exhaust)</u>

Impact on Further Calculations:

- Concentration conversion: All pollutant mass flows (g/h) are divided by V_{\rm dry} to yield mg /Nm³.
- Equipment sizing: TO and SCR residence times and catalyst volumes depend directly on the volumetric flow.
- Regulatory compliance: Permit limits are stated in mg /Nm³; only with the correct exhaust flow can you demonstrate that your mg /Nm³ concentrations meet those limits.

3.2 Raw Emissions

In this chapter, we quantify the uncontrolled pollutant output directly from the engine—often called “raw emissions”—before any after-treatment. Determining these mass flows is essential both for sizing the downstream control equipment (TO and SCR) and for demonstrating, via conservative estimates, that the system can meet regulatory limits. We calculate raw emissions by multiplying established emission factors (EF, in g pollutant per kWh produced) by the engine’s hourly electrical output.

Purpose:

- Establish a baseline pollutant load.
- Provide input data for concentration conversion and subsequent treatment steps.
- Ensure the chosen EF values are transparent, defensible, and conservative.

Methodology:

1. **Select EF for each pollutant** based on AP-42, vendor data, and literature—adjusted for the high H_2/olefin content of pyrolysis gas.

2. **Calculate mass flow**:

$$m_{raw}[g/h] = EF[g/\dot{k}Wh] \times P_{el}[kWh/h]$$

3. **Document assumptions** and sources for each EF to satisfy permitting requirements and expert review.

3.2.1 Role and Source of Emission Factors (EF)

Emission Factors quantify the mass of pollutant (g) emitted per unit of useful energy produced (kWh). They are **standard practice** in air-permitting and engineering calculations when detailed stack testing isn't available. For a new fuel like pyrolysis gas, we select or adapt factors as follows:

1. **Regulatory and Industry Guidance**
    - **EPA AP-42** ("Compilation of Air Pollutant Emission Factors") provides default EF for stationary gas turbines and reciprocating engines burning pipeline natural gas, lean-burn engines, etc.
    - **Vendor Data Sheets** (e.g., GE Jenbacher, Waukesha) give measured EFs on similar engine models using a variety of hydrocarbons.
    - **Technical Literature** on syngas and producer gas combustion supplies slip and VOC factors for olefin-rich mixtures.
2. **Adjustment for Pyrolysis Gas**
    - **NO_x (1.2 g/kWh):** EPA lean-burn data (0.8–1.5 g/kWh) adjusted upward for higher flame temperatures from H_2/olefins.
    - **CO (0.8 g/kWh):** Within the EPA range (0.2–2.0 g/kWh), but olefins tend to increase raw CO, so we pick a conservative mid-range.
    - **CH_4 slip (0.2 g/kWh):** Methane slip often 0.05–0.4 g/kWh; high H_2 and unsaturates justify the upper half of that range.
    - **NMHC (0.20 g/kWh):** AP-42 groups all non-methane hydrocarbons at 0.10–0.15 g/kWh for natural gas; olefins increase VOC, so we use 0.20 g/kWh as a conservative estimate.
    - **Formaldehyde (0.01 g/kWh):** Typical raw exhaust for rich gas engines shows 5–20 mg/Nm³; back-calculated to ≈0.01 g/kWh.
    - **SO_2 (from H_2S):** Calculated stoichiometrically from measured H_2S fraction; not a vendor EF but derived directly from gas analysis.
3. **Permissibility and Conservatism**
    - All chosen EFs are within or slightly above the published AP-42 "typical" ranges, ensuring a **conservative margin**.
    - Regulatory agencies accept AP-42 and vendor-derived EFs when actual stack tests are unavailable, provided they are well-documented and justified.

3.2.2 Calculation Formula for Raw Emissions

$$m_{raw}[g/h] = EF[g/\dot{k}Wh] \times P_{el}[kWh/h]$$

Pollutant	**EF (g/kWh)**	**Raw Emission (g/h)**	**Basis / Justification**
NO_x	1.2	1.2 × 2412.5 = **2895**	EPA lean-burn, adjusted for H_2/olefins
CO	0.8	0.8 × 2412.5 = **1930**	AP-42 mid-range, conservative for olefins
CH_4 (slip)	0.2	0.2 × 2412.5 = **483**	Upper half of typical methane slip range
NMHC (VOC)	0.20	0.20 × 2412.5 = **483**	Conservative upper bound for VOC from olefins
Formaldehyde	0.01	0.01 × 2412.5 = **24.1**	Back-calculated from measured mg/Nm³ levels
SO_2 (H_2S)	—	76.2 (stoich.)	Derived from 0.0085 vol % H_2S in feed gas

Table 3.2.2

Example calcualtion for CH_4:

$$\dot{m}_{CH,raw} = 0{,}2\ \frac{g}{kWh} \times 2412{,}5\ kWh/h = 483\ g/h$$

Each of these EFs is documented and conservative, ensuring that the calculated raw emissions represent an upper bound of real engine performance on this novel pyrolysis gas.

At the PFD “Enespa NeoP5” these emissions are shown under the TAG No. 4.2.1

3.3 Raw Concentrations

In this chapter, we convert each pollutant’s raw mass emission (g/h) into a stack concentration (mg/Nm³), using the dry exhaust flow. This step is essential because regulatory limits are specified in mg of pollutant per standard cubic meter of exhaust gas.

Calculation Formula:

$$C_{ras}\,[mg/Nm] = \frac{\dot{m}_{raw}[g/h] \times 1000}{V_{dry}[\dot{N}m/h]}$$

Inputs:

- Raw emissions $\dot{m}_{raw}$ from table 3.2.2
- Dry exhaust flow $V_{dry} = 42\dot{9}8\ Nm^3/h$

Pollutant	**Raw Emission (g/h)**	**Raw Concentrations (mg/Nm³)**
NO_x	2 895	(2 895 × 1 000) / 4 298 ≈ **674**
CO	1 930	(1 930 × 1 000) / 4 298 ≈ **449**
CH_4	483	(483 × 1 000) / 4 298 ≈ **112**
NMHC[1]	483	(483 × 1 000) / 4 298 ≈ **112**
Formaldehyde	24.1	(24.1 × 1 000) / 4 298 ≈ **5.6**
SO_2	76.2	(76.2 × 1 000) / 4 298 ≈ **17.7**

3.3.1 Comparison with Florida & Texas Heavy industrial Limits

Before deciding whether additional exhaust treatment (such as a Thermal Oxidizer) is required, we must determine if the **raw engine emissions** alone already meet the applicable state limits for heavy-industrial zones. The table below compares the calculated **raw concentrations** against the **Florida** and **Texas** regulatory caps. If any pollutant exceeds its limit, subsequent treatment is mandatory.

Pollutant	**Raw Conc'n(mg/Nm³)**	**FL Limit(mg/Nm³)**	**TX Limit(mg/Nm³)**	**Compliant?**
NO_x	674	500	500	No
CO	449	1 000	1 000	Yes
CH_4	112	(as VOC)	(as VOC)	Yes
NMHC	112	150	150	Yes
Formaldehyde	5.6	40	40	Yes
SO_2	17.7	500 (typical)	500 (typical)	Yes

Note on Treatment Decision:

Although, apart from NO_x, all raw exhaust concentrations from the gas engine already fall within the Florida and Texas heavy-industry limits, we have voluntarily chosen to install a Thermal Oxidizer downstream of the engine. This ensures that even if the engine produces elevated NMHC (non-methane hydrocarbons) under varying load or fuel-quality conditions, all volatile residues and hydrocarbons are thermally degraded, thereby guaranteeing compliance with emission limits at all times.

To ensure compliance with the 500 mg/Nm³ NO_x limit, we have specified a Selective Catalytic Reduction (SCR) system immediately downstream of the Thermal Oxidizer. The SCR employs AdBlue® (urea solution) dosing to convert NO_x into N_2 and H_2O with approximately 92 % efficiency, guaranteeing that the final stack NO_x concentration of ~59 mg/Nm³ remains well below regulatory caps.

The detailed calculations of emissions **after the Thermal Oxidizer** and **after the SCR catalyst** are presented in the following chapters.

3.4 After thermal Oxidizer (TO)

When the hot exhaust leaves the gas engine, it is ducted directly into the Thermal Oxidizer (TO) unit. The process operates as follows:

1. **Exhaust Inlet and Preheat**
    - Engine exhaust (≈ 700 °C) enters the TO through a refractory-lined inlet duct.
    - A gas- or oil-fired burner upstream of the chamber brings the combined stream up to the **operating temperature of 850 °C**.
2. **Thermal Oxidation Zone**
    - The oxidizer contains a long, insulated combustion chamber sized to provide at least **2 minutes of residence time** (at the design volumetric flow).
    - Within this zone, oxygen in the exhaust reacts with CO, CH_4, NMHC (all volatile hydrocarbons) and formaldehyde in a series of **exothermic oxidation reactions**:

    $$CO + \frac{1}{2}O_2 \rightarrow CO_2, CH_4 \rightarrow 2O_2 \ \rightarrow CO_2 + 2H_2O, \ldots.$$

    - The high temperature and long residence ensure **> 99 % destruction** of theseorganics.
3. **Temperature Control & Energy Balance**
    - The exothermic heat release largely sustains the 850 °C setpoint.
    - A small amount of supplemental fuel (typically natural gas or propane) is added whenever the engine exhaust alone cannot maintain temperature under low-load or cold-start conditions.
4. **Exit to SCR**
    - After spending at least two minutes in the TO, the now-cleaned exhaust—still containing NO_x and SO_2—is drawn out through a transition duct to the **SCRcatalyst section** for final NO_x removal.

This thermal treatment guarantees that **all volatile residues and hydrocarbons** are fully oxidized prior to catalytic NO_x reduction, providing a robust margin of compliance even under variable engine operating conditions.

3.4.1 After thermal Oxidizer (TO) calculation

This chapter applies the Thermal Oxidizer's destruction or formation rates to the raw emissions. We calculate the treated mass flow for each pollutant and then convert it to mg/Nm³ as before.

Treatment formulars:

$$m_{TO} = \begin{Bmatrix} m_{raw} \times (1 + 0{,}10), & for\ NO(+10\,formation) \\ m_{raw} \times (1 - DRE), & for\ CO, CH, NMHC, HCHO \end{Bmatrix}$$

Formula concentration after TO

$$C_{TO} = \frac{m_{TO}[g/h] \times 1000}{V_{dry}}$$

Pollutant	**After TO Emission (g/h)**	**After TO Concentration (mg/Nm³)**
NO_x	2 895 × 1.10 = **3 184.5**	(3 184.5 × 1 000) / 4 298 ≈ **741**
CO	1 930 × 0.01 = **19.3**	(19.3 × 1 000) / 4 298 ≈ **4.5**
CH_4	483 × 0.005 = **2.4**	(2.4 × 1 000) / 4 298 ≈ **0.56**
NMHC	483 × 0.01 = **4.83**	(4.83 × 1 000) / 4 298 ≈ **1.12**
Formaldehyde	24.1 × 0.001 = **0.024**	(0.024 × 1 000) / 4 298 ≈ **0.006**
SO_2	**76.2** (unchanged)	(76.2 × 1 000) / 4 298 ≈ **17.7**

3.5 Selective Catalytic Reduction (SCR) of NOx

Following the Thermal Oxidizer, which effectively destroys volatile organics but elevates NO_x to ~741 mg/Nm³, a **Selective Catalytic Reduction (SCR)** stage is installed to bring NO_x below the 500 mg/Nm³ regulatory cap. The SCR injects a urea-water solution (AdBlue®) into the hot exhaust over a catalyst, converting NO and NO_2 into N_2 and H_2O with high efficiency. This chapter details the mass-balance calculation for NO_x reduction and the corresponding AdBlue® consumption needed to achieve compliance.

3.5.1 NOx Massflow into SCR

Calacualtion of the NOx massflow after TO unit:

$$m_{NOx,TO} = C_{NOx,TO}\,[mg/Nm] \times V_{dry}\,[Nm^3/h] \times 1000 = 741 \times 429810003184{,}5\ g/h$$

3.5.2 SCR Reduction Calculation

- Target removal efficiency: 92%
- Remaining fraction: 8%

Formula remaining fraction:

$$m_{NOx,SCR} = m_{NO,TO} \times 0{,}08 = 3184{,}5\,g/h \times 0{,}08 = 254{,}8\,g/h$$

Resulting concentration:

$$C_{NOx,SCR} = \frac{254{,}8\ g/h \times 1000}{4298\,Nm^3/h} = 59{,}3\ mg/Nm^3$$

3.5.3 AdBlue (Urea) Consumption

Calculation of removed NOx:

$$m_{NOx,removed} = m_{NOx,TO} - m_{NOx,SCR} = 3184{,}5 - 254{,}8 = 2929{,}7\, g/h = 2{,}93\ kg/h$$

- Pratical dosing ratio: $\sim 0{,}63\ kg\ Adblue\ per\ kg\ NO_x$ removed (includes stoichiometry, slip margin, control overhead)

Calcualtion of AdBlue consumption:

$$\dot{m}_{AdBlue} = 0{,}63 \times 2{,}93\ kg/h = 1{,}85\, kg/h$$

Calculation of volumetric AdBlue consumption

Density AdBlue: 1,13 kg/L

$$\dot{Q}_{AdBlue} = \frac{1{,}85\ kg/h}{1{,}13\ kg/L} = 1{,}64\ L/h$$

3.5.1 Summary of SCR Stage

- Inlet NO_x: 3 184.5 g/h (741 mg/Nm³)
- Outlet NO_x: 254.8 g/h (59.3 mg/Nm³)
- NO_x removal: 92 %
- AdBlue® requirement: ~1.85 kg/h (≈1.64 L/h)

This ensures that NO_x emissions remain well below the 500 mg/Nm³ limit under all operating conditions.

3.6 Overall Emission Compliance

This section summarizes the **final stack concentrations** after the complete treatment sequence (engine combustion, Thermal Oxidizer, and SCR) and compares them with the **regulatory emission limits** for heavy-industrial zones in Texas and Florida. The limits are drawn from the **Texas Commission on Environmental Quality (TCEQ) BACT guidelines** and the **Florida Department of Environmental Protection (FDEP) adoption of EPA NSPS Subpart JJJJ standards**.

Sources for Limits:
– **Texas:** TCEQ BACT Guidelines for Gas-Fired Engines
– **Florida:** EPA NSPS Subpart JJJJ (40 CFR Part 60, Subpart JJJJ)

Pollutant	**Final Conc'n(mg/Nm³)**	**FL & TX Limit(mg/Nm³)**	**% Below Limit**
NO_x	59.3	500	(500 − 59.3)/500×100 ≈ **88.1 %**
CO	4.5	1 000	(1 000 − 4.5)/1 000×100 ≈ **99.6 %**
CH_4	0.56	(as VOC)[1]	(150 − 0.56)/150×100 ≈ **99.6 %**
NMHC (VOC)	1.12	150	(150 − 1.12)/150×100 ≈ **99.3 %**
Formaldehyde	0.006	40	(40 − 0.006)/40×100 ≈ **99.98 %**
SO_2	17.7	500	(500 − 17.7)/500×100 ≈ **96.5 %**

All final emissions are comfortably below the applicable heavy-industry standards.

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4 Plan Layout

This chapter presents the planned layout for the installation and operation of the twelve e-Nespa Neo P5 pyrolysis units at the Dade City site, specifically within **Building C**. The overall system is divided into two operational units, each comprising six Neo P5 units arranged in a 2 × 6 block configuration.

Each operational block is centrally supplied with pretreated feedstock from a dedicated pre-treatment unit. The material is transferred via intermediate silos, with each silo feeding two Neo P5 units simultaneously.

The non-condensable gases generated during the pyrolysis process are collected in pairs. Two Neo P5 units feed their process gas into a shared gas generator, where the gas is converted into electrical power and usable thermal energy.

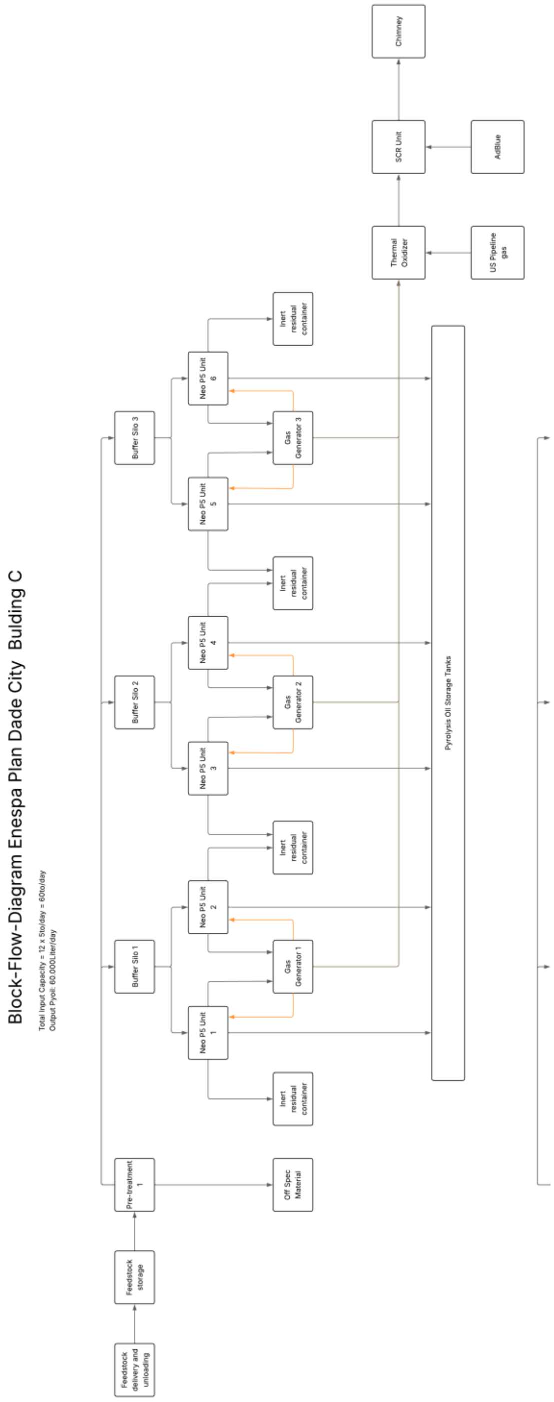
The exhaust gas from the gas generator is directed via a pipeline to a downstream thermal oxidizer. In this unit, the gas undergoes full thermal oxidation at 850 °C with a residence time of at least two minutes. This ensures complete combustion and compliance with emission limits as outlined in Chapter 3.

Following oxidation, the gas stream passes through an SCR (Selective Catalytic Reduction) system, where NOx emissions are reduced by injecting AdBlue. Only after this final purification step is the cleaned exhaust released to the atmosphere via a stack.

All process units and auxiliary systems—including the Neo P5 reactors, the pre-treatment system, gas generators, silos, pipelines, thermal oxidizer, and SCR system—are installed and operated **inside Building C at the Dade City site**. Building C is divided into two functional sections by a fire protection wall.

- **Section 1** of the building is designated for the installation and operation of the mechanical pre-treatment system.
- **Section 2** accommodates the twelve Neo P5 units arranged in two blocks, along with all associated auxiliary systems.

The produced pyrolysis oils are stored in a separate tank farm located outside the main process building. These double-walled storage tanks are equipped with overflow and leak detection systems. Loading of the pyrolysis oil into tank trucks takes place via a closed loading station with vapor return lines, ensuring zero emissions to the environment during the transfer process.



See Attachment 4 – BFD Enespa Plant Dade City

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4.1 Dade City Business Center

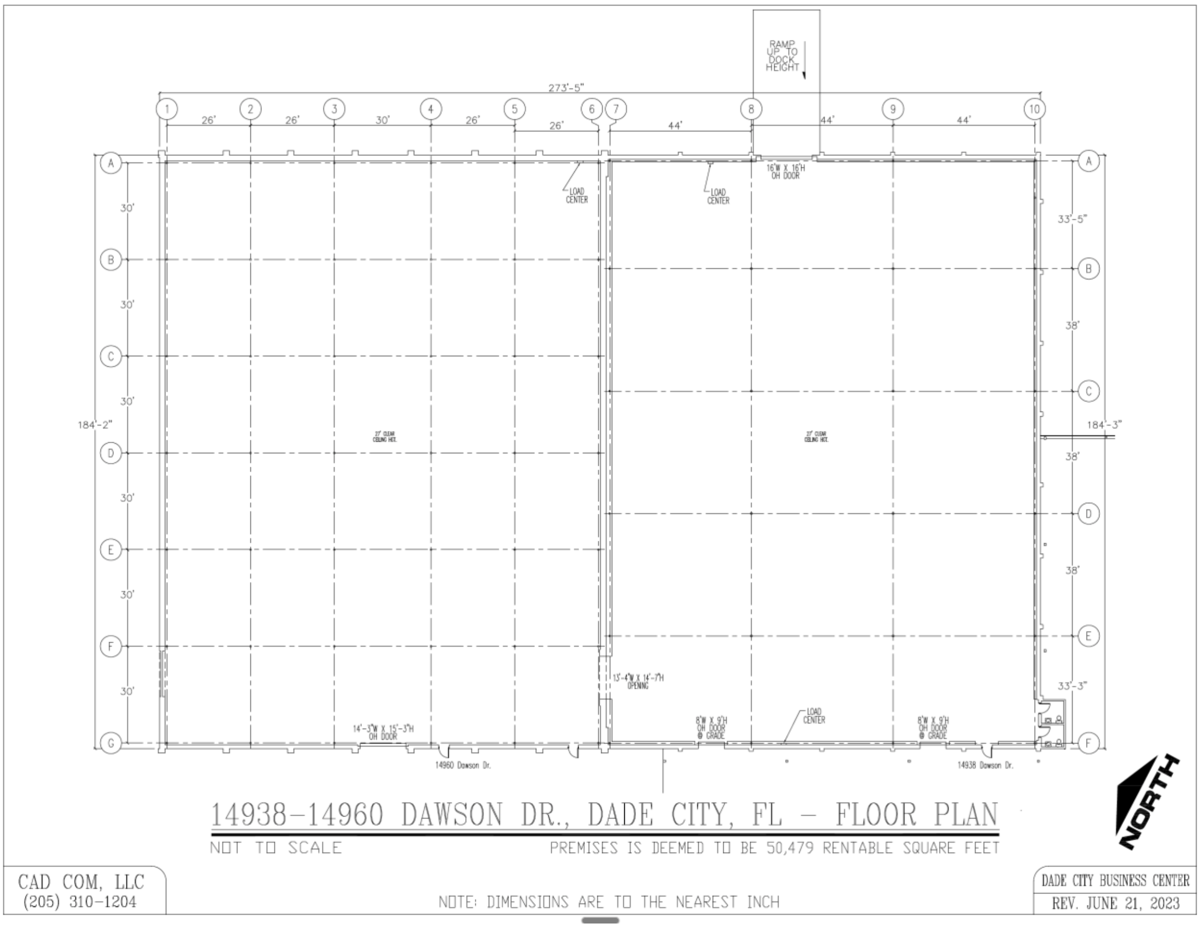
For the construction and commissioning of our first pyrolysis plant in Florida, we have selected the **Dade City Business Center**, located in 15486 US HWY 301, Dade City FL 33523, **Pasco County**. This location offers a strategic combination of infrastructure, utilities, and zoning advantages that align perfectly with the operational and regulatory requirements of our planned facility.

Key advantages of the Dade City Business Center include:

- **Existing Industrial Wastewater Treatment Facility** on-site, enabling reliable and regulation-compliant handling of process effluents.
- **On-site deep-water wells** providing high-quality water with excellent supply capacity.
- **Dedicated water utility infrastructure** supporting continuous industrial operations.
- **Industrial zoning**, ensuring full compatibility with our planned use case and streamlined permitting procedures.
- **Railway access**, facilitating cost-effective inbound and outbound logistics.
- **Direct access to U.S. Highway 301**, offering excellent connectivity for feedstock deliveries and distribution of produced pyrolysis oils.

The selected facility, **Building C**, features a total indoor area of **50,479 sft (appr. 4690 square meter)** and is divided into two functional sections. This layout provides sufficient space for the installation of twelve Neo P5 units, including all auxiliary systems, and allows for dedicated operational zones such as feedstock pre-treatment, oil storage, and product dispatch.

The combination of infrastructure readiness, water availability, logistics access, and industrial zoning makes Dade City Business Center a highly suitable location for scaling advanced recycling technologies in the Southeastern United States.



Floor Plan Building C

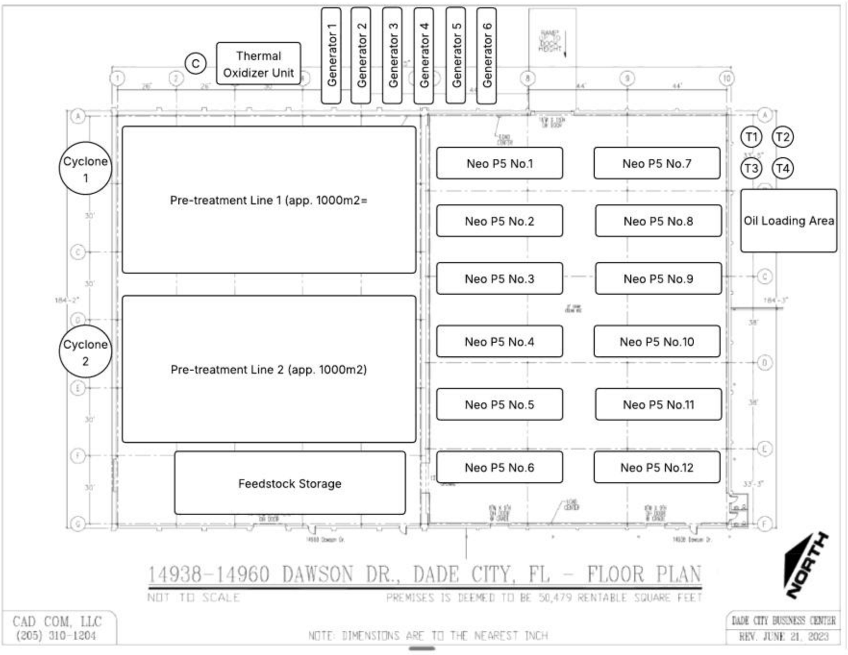
4.2 Indicative Layout of Main and Auxiliary Equipment – Building C

The indicative layout plan shown below illustrates the general arrangement of the main process units for operating the two pre-treatment lines and twelve Neo-P5 pyrolysis units. In addition to the primary equipment, the following **auxiliary systems** are also depicted:

- **Four pyrolysis oil storage tanks** with a **total capacity of 320 m³**, each tank holding **80 m³**.
- A **loading area** for transferring the produced pyrolysis oil into **tank trucks (TKWs)** or alternatively into **isotainers**.
- **Gas generators** for the utilization of non-condensable gases from the Neo-P5 units, located on the **north side** of the building. These are connected to the **thermal oxidizer unit** and the **exhaust stack** equipped with **AdBlue injection** for NOx reduction.
- On the **west side**, in the outdoor area, **two large cyclone separators** are installed. These are used for the removal of particulates from the **hall air extraction system** servicing Pre-Treatment Line 1 and Line 2.
- In the **southern section**, beneath Pre-Treatment Line 2, a **feedstock storage area of 400 m²** is designated, where incoming feedstock bales can be unloaded prior to being fed into the pre-treatment lines.

This layout is intended as an **indicative representation** to demonstrate the general feasibility of installing and operating the planned facility **within Building C**.

It serves as the basis for the permitting and regulatory approval process.



Notes on general layout:

Pre-treatment 1: 50m x 20m = 1000m2

1 x Neo P5: 20m x 5m = 100m2

Pyoil Tanks:
- Tank 1: 80m3
- Tank 2: 80m3
- Tank 3: 80m3
- Tank 4: 80m3

Required: 300m3
Scheduled: 4x80m3 = 320m3

Feedstock Storage:
storage of pre-sorted plastic flakes delivered in bales

Storage Area: app. 40m x 10m = 400m2

See Attachment 4.2

4.3 Emission Points – Building C

The following emissions are associated with the operation of the pre-treatment units and the Neo-P5 pyrolysis systems:

- **Pre-Treatment Area**

During operation of the shredding system, sorting equipment, and conveyor belts, dust emissions may occur. These are captured by localized extraction systems and directed to cyclone separators, where particulate matter is effectively removed.
The filtered air discharged from the cyclone separators complies with regulatory limits for dust emissions.
Inside the building, the point-source extraction systems ensure that ambient air quality within the hall remains within all applicable limits, thereby preventing the exceedance of occupational or environmental thresholds.

- **Neo-P5 Pyrolysis Area**

In the Neo-P5 section, no direct emissions occur due to the hermetically sealed design of the machines and piping systems. The non-condensable pyrolysis gases are transported via closed piping to the gas generators, where they are used to produce energy.

The exhaust gases from the generators are routed through sealed pipelines to the thermal oxidizer for complete thermal treatment. Following this step, the gas stream is passed through the SCR (Selective Catalytic Reduction) unit for NOx reduction, before being released into the environment through the chimney.

As such, the chimney labeled “C” in the indicative layout plan can be considered the primary emissions point of the entire facility.

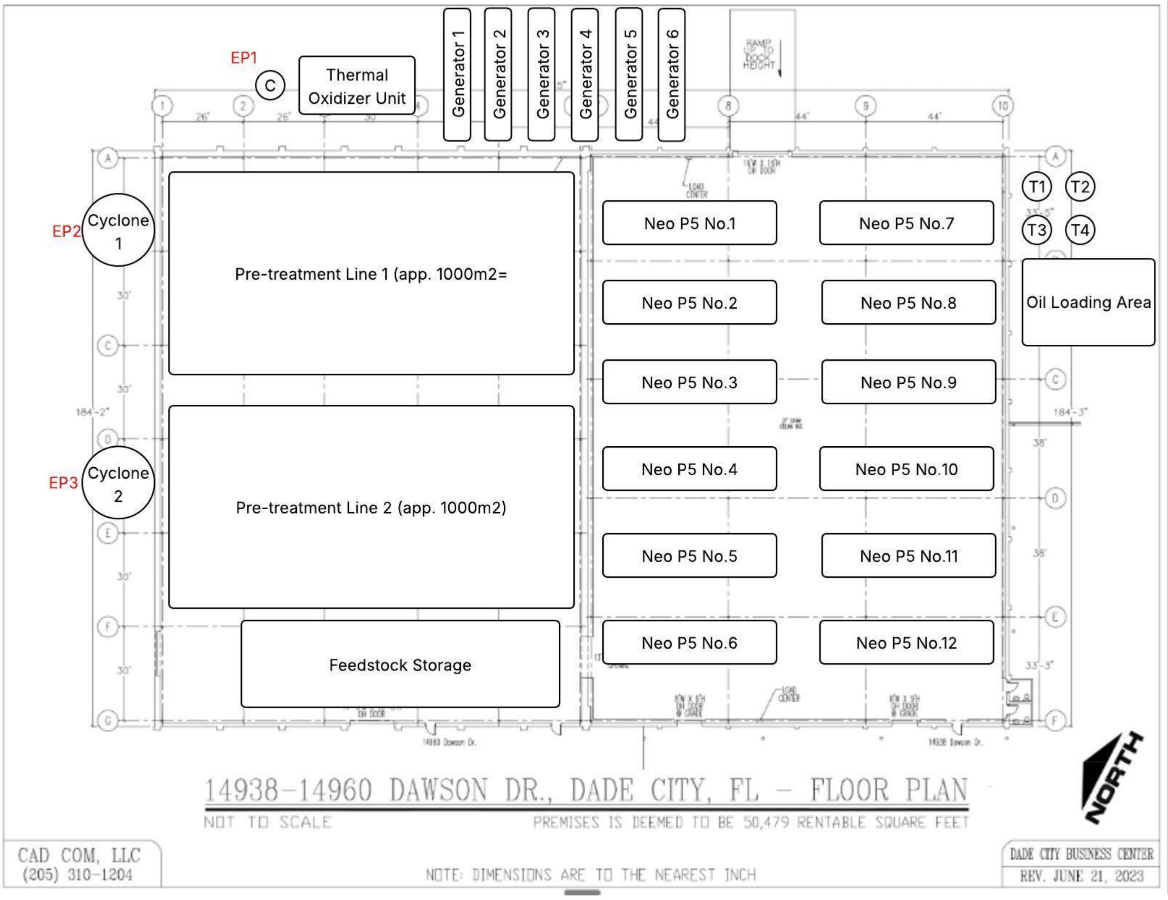
All emission concentrations at this point are listed in the corresponding table and are based on the emissions calculations provided in Chapter 3.

- **Tank Storage Operation and Emission Control**

The operation of Storage Tanks 1 through 4 is carried out under a nitrogen blanketing system combined with a vapor balancing (gas pendulum) system. Displaced vapors generated during filling or product transfer are collected and routed directly to the thermal oxidizer unit, where they are thermally destroyed in compliance with environmental standards.

For product transfer to tank trucks (TKWs) or isotainers, gas-tight dry disconnect couplings are used. This ensures that no fugitive emissions occur during loading or unloading operations.

The emission points are identified in the indicative layout drawing below and described in detail in the accompanying table.



See attachment 4.3 Emission Points Building C

TAG	Description	Emission calculation
EP1	Emissions from the thermal oxidation followed by SCR treatment of the non-condensable pyrolysis gases, discharged via Chimney C.	See chapter 4.3.1
EP2	Emissions from extracted air after dust and contaminant removal via Cyclone 1.	NN
EP3	Emissions from extracted air after dust and contaminant removal via Cyclone 2.	NN

4.3.1 Emission summary EP1

Dry exhaust flow $V_{dry} = 42\dot{9}8\ Nm^3/h$

Pollutant	**Final Conc'n(mg/Nm^3)**	**FL & TX Limit(mg/Nm^3)**	**% Below Limit**
NO$_x$	59.3	500	(500 − 59.3)/500×100 ≈ **88.1 %**
CO	4.5	1 000	(1 000 − 4.5)/1 000×100 ≈ **99.6 %**
CH$_4$	0.56	(as VOC)[1]	(150 − 0.56)/150×100 ≈ **99.6 %**
NMHC (VOC)	1.12	150	(150 − 1.12)/150×100 ≈ **99.3 %**
Formaldehyde	0.006	40	(40 − 0.006)/40×100 ≈ **99.98 %**
SO$_2$	17.7	500	(500 − 17.7)/500×100 ≈ **96.5 %**

(see also chapter 3.6)

4.3.2 Emission summary EP1

NN

4.3.1 Emission summary EP1

NN

5 Attachments

Following Attachments belonging to this document:

- Attachment 2 BFD Enespa Neo P5
- Attachnment 4 BFD Enespa Plant Dade City
- Attachment 4.2 Indicative Layout Building C
- Attachment 4.3 Emission Points Building C