O&M Strategy

CO_2 Capture – BOD & Tender Specifications

AEB Amsterdam

Date: 12 January 2024

Report 416041-47990-B-06-006Document No., Rev. D Final Updated

AEB Document No.

advisian.com

Disclaimer

This report has been prepared on behalf of and for the exclusive use of Afval Energie Bedrijf Amsterdam and is subject to and issued in accordance with the agreement between Afval Energie Bedrijf Amsterdam and Advisian. Advisian accepts no liability or responsibility whatsoever for it in respect of any use of or reliance upon this report by any third party. Copying this report without the permission of Afval Energie Bedrijf Amsterdam and Advisian is not permitted.

COVID-19

Advisian is committed to providing the Services to you in a timely and professional manner. Advisian is also committed to ensuring the health and safety of all of its people and its Customers. The COVID-19 pandemic has caused us to modify our business behaviour. This means that Advisian may only provide you with Services in a manner in which it deems safe. Advisian employees may provide some or all of the Services from their home and travel to business meetings or site may be affected. Advisian will take steps to mitigate any delays associated with the provision of Services to you but accepts no liability or responsibility for the delayed or non-performance of any Services caused by the modification of its behaviour to ensure the containment COVID-19 or the health and safety of its people.

Company details

Worley Nederland B.V., trading as Advisian
Company Registration No.: 24301248

Wilhelmina van Pruisenweg 2
2595 AN Den Haag, The Netherlands
T: +31 88 625 7510

AEB Document No.
Document Title: O&M Philosophy
Document Subtitle: CO2 Capture – BOD & Tender Specifications

Rev	Description	Authors	Review	Advisian approval	Revision date
A	For Client Review	L de Best	G Picheo	K de Jong	16-06-2023
B	Final	L de Best	G Picheo	K de Jong	14-07-2023
C	Final (Updated)	L de Best	G Picheo	K de Jong	03-08-2023
D	Final (Updated)	A. Thattai	K de Jong	K de Jong	12-01-2024

Table of Contents

Appendices

Advisian
Worley Group

Acronyms and Abbreviations

Acronym/abbreviation	Definition
AEB	Afval Energie Bedrijf
AEC	Afval Energie Centrale / Waste to Energy Plant
ALARP	As Low As Reasonably Practicable
App	Appendix
BoD	Basis of Design
CBM	Condition Based Maintenance
CCR	Central Control Room
CMMS	Computerised Maintenance Management System
CO_2	Carbon Dioxide
ConOps	Concurrent Operations
EPC	Engineering Procurement Construction
ESD	Emergency Shut Down
F&G	Fire and Gas
FEED	Front End Engineering Design
HAZOP	Hazard and Operability Study
HRC	Hoog Rendement Centrale
HSSE	Health Safety Security and Environment
ICS	Industrial Control Systems
LCC	Life Cycle Costing
LOTOTO	Lock Out Tag Out Try Out
MJOP	Meerjarenonderhoudsplan
O&M	Operations and Maintenance
OCAP	Organic CO2 for Assimilation by Plants
OR	Operational Readiness
P&ID	Piping and Instrumentation Diagram
PCC	Post Combustion Capture
PEFS	Process Engineering Flow Scheme
PFD	Process Flow Diagram
PM	Preventive Maintenance
RAM	Reliability, Availability and Maintainability
RBM	Risk Based Maintenance
RCM	Reliability Centred Maintenance
RTF	Run To Failure
TA	Turn Around
TBD	To be determined
TCO	Total Cost of Ownership

1 Objectives of This Document

This Operations and Maintenance (O&M) strategy is ~~a~~ key input for further basic and detailed design of AEB's PCC plant, to ensure economical operability and maintainability of the plant over its lifecycle.

An effective O&M strategy ensures the reliable operation and maintenance of assets, while minimizing downtime, reducing costs, and ensuring the safety of personnel and the environment. In case of brownfield developments (e.g., upgrade or extension of the assets), seamless integration with the current waste incinerator plant's O&M strategy is an additional requirement that also governs the design.

Whereas the O&M strategy focuses on lifecycle operations, the transition time from Mechanical Completion to Initial Startup requires close co-operation in case of brownfield developments, due to the interfaces and process connections. Specifically non-interrupted operation of the existing plant and HSE are critical, both in the design and in construction site management.

In this stage of the project (pre-FEED), the requirements from Operations need to be laid down to ascertain a design that fulfills the objectives of management for the PCC during the operational phase of the project. These will be the foundation for safe and optimum operations, during initial start-up, performance testing and assurance, first year running and the remaining full life cycle of the plant.

Ensuring the operability and maintainability in the PCC design is key to successful performance of the plant for AEB and its shareholders.

2 O&M Philosophy

This Operation & Maintenance (O&M) Philosophy provides an overview of Operations Concepts and documents the philosophy for operating the new facilities according to the present understanding. The operational requirements need to be confirmed, applied, and further elaborated in the next project phase(s). Operations key priorities in this respect are: HSSE, license to operate & production.

The Operations Philosophy is/will be a key document in the Company's Operational Readiness (OR) process and shall at least include a detailed description of:

1. Operational profile and aspects associated with operability and maintainability to achieve a minimum of 96.5% of availability of the PCC system. Availability of PCC being defined as overall probability of the system to remove 60t/h CO_2.
2. Manned / normally unmanned operations, necessary maintenance interventions only in dedicated time slots (e.g., interval for preventive maintenance every two weeks only). PCC maintenance activity execution will be aligned with the AEB schedules for maintenance execution.
3. Field Inspections (e.g., on-site, remote, et cetera)
4. Working shifts at site
5. Automation levels
6. Innovative technology application in the PCC
7. Maintenance regimes: Preventive maintenance and its intervals, expectation is that plant PM/CM is as per industry standard ~90%
8. Critical failures modes and required corrective maintenance, including considerations for critical spare components.
9. Sparing philosophy of equipment e.g., N+1 and its basis (redundancy philosophy)
10. Regular maintenance and specialized overhauls.
11. CO_2 awareness both in design and operations is required and appropriate training material and courses need to be developed.
12. Concurrent Operations (ConOps) philosophy/procedure and approach.
13. Use of the existing operational management systems in use at AEB which will, as much as practicable, be extended for PCC Operations.
14. HAZOP results and mitigations for operational Risks: the CO_2 plant, amine toxicity, ammonia and other hazardous substances, and relative complexity of the plant will present operational risks which shall be managed by competent design, equipment isolation, safe work instructions and appropriate competent personnel and personnel protective equipment. Latest industry experience must be included.

15. Operability: Contractor to provide a comprehensive description of the operability aspects of the plant, covering at least the following elements:

- Process – P&IDs, PFDs.
- Plant operation: monitoring 24/7 by one panel operator in CCR (integration, layout).
- Physical access – 3D modelling, access to equipment and sensors and hoisting operations
- HSSE – evacuation, leak detections, ESD systems.
- Historical data capturing and analysis methodology, in line with AEB's requirements.

16. Control and automation – plant fully automated with minimum operator intervention, integrated central control room with AEB existing plants, remote startup/shutdown, and ramp up/ramp down.

17. Alarm management philosophy.

18. Historical data capturing for failure analysis.

19. Interaction input/output (flue gas – OCAP export).

20. The operations of the PCC plant shall have minimum interference with AEB's normal/existing plant operations. In case of a PCC shutdown, the flue gas flow (hence AEC/HRC operations) remain undisturbed, including the additional interfaces with the plant (water, steam, electricity, instrument air, et cetera).

21. The AEB production priorities related to PCC are:

    1) deliver heat to district heating
    2) deliver steam and electricity to PCC
    3) deliver electrical power to the grid.

    Required turndown ratio's to be confirmed by the design Contractor such that the set targets on production are met.

22. Availability and reliability requirements for the packages including clear definitions, minimum and expected target levels. (Processing, export, economical)

23. Description of the criticality of availability on integrated and/or connected systems (flue gas, cooling water, instrument air, export systems, F&G, et cetera). Since this will affect the overall availability of the PCC, options for start-up and shutdown durations should be described, allowing for multiple starts and stops of the PCC per day.

24. How to operate the plant with the least amount of energy needed to maximize energy-efficiency.

3 Maintenance Strategy

3.1 Design for Lifecycle

The design of the facilities must consider the life cycle of the plant. Current design life of the PCC plant after start-up is 16 years. Contractor to provide a PCC maintenance strategy, which includes as a minimum:

1. Maintenance Objectives, Maintenance Policies (refer to existing policies or, when needed, establish the guidelines in line with Company Formats (refer also to Appendix A).

2. Maintenance Planning: Plant turnaround approach for the main equipment items (CO_2 capture & conditioning units, compressors, pumps, integrity maintenance), based on the vendor's recommendation.

   AEB uses explosive cleaning year around to clean i.e., remove accumulated ashes from the coils of the present waste incinerator boilers (HRC boilers daily, AEC boilers weekly). This should be considered by the Contractor during the design phase. Independent louvre damper(s) shall be used to control flow of flue gas from the 6 lines to the FG trunk line, however AEB's objective is to avoid flue gas bypass operation around the PCC during these boiler cleaning operations to minimize louvre damper movements thus minimizing related fatigue and louvre maintenance. Contractor is to advise on the potential impact of the temporary upset of flue gas ash loads on amine degradation & entrainment.

3. Preventive Maintenance: Outline procedures for regular inspections, servicing, and maintenance tasks

4. Corrective Maintenance: Define procedures for addressing unplanned maintenance events or breakdowns.

5. Recommendations on equipment/unit maintenance strategy:
   a. Reliability-Centred Maintenance (RCM)
   b. Preventive Maintenance (PM)
   c. Condition-Based Maintenance (CBM)
   d. Run-to-Failure (RTF)
   e. Proactive Maintenance
   f. Risk-Based Maintenance (RBM):
   g. Predictive Maintenance

6. Equipment, process measurement and sensor techniques embedded into the design to allow for above strategies to be executed

7. Description and design of the required level of automation to allow for the minimum/normally unmanned operation of PCC

8. Spare Parts Management: Strategies for managing spare parts inventory and required storage arrangements (include in the design and layout)

9. Training and Skills Development: Identify training needs for maintenance and operations personnel, and use of simulators to enable training, with reference to competency verification (development of a competency matrix for each role) following training.
10. To ensure these are in line with AEB specifications, reviews need to be conducted by Contractor that assets (including integrated plant) are safe, reliable, and maintainable:
    a. Hazops, safety reviews
    b. Operability, maintainability, reliability, and availability reviews (specifically due to the possible modular design specification). Included shall be the layout spacing review for accessibility, lifting and major servicing.
    c. 3D modelling of facility (digital twin) for accessibility
    d. The CMMS of AEB will be used as Plant Maintenance package (currently JD Edwards). Documents and formats to be able to be loaded into the CMMS (e.g., ICS coding for functional locations). Design Contractor to confirm CMMS used by AEB at time of design. It is also important to note that not all documents are fed into the CMMS, AEB also uses document control software (SmartPlant®) for general technical documentation.
11. Integration and alignment with the existing AEB maintenance strategy where applicable, the relevant AEB maintenance strategy shall be provided in the next design phase.
12. Life Cycle Costing model for maintenance (LCC): LCC involves considering the total maintenance cost of ownership over the entire life cycle of an asset: staffing levels, spares, capital spares, TA’s. A multi-year maintenance plan (MJOP) to be also set-up by contractor.

3.2 Maintenance Strategy - Pre-Start up

In the next project phase, the required maintenance between construction/commissioning and initial start-up shall be confirmed. This must include any preservation measures (including e.g., mothballing) to cover the time between mechanical completion and start commissioning, or for unexpected events leading to an extended period of idleness of the equipment.

3.3 Reliability and Redundancy

In the next project phase, the following requirements shall be confirmed:

1. Uninterrupted operations of the PCC in case of main equipment failure.
2. An N+1 sparing philosophy to be applied where required to meet the plant availability targets and stable export.

These requirements shall be specified by the outcome from a RAM study on the PCC design.

Further:

- Loss of any system may not lead to loss of more than one unit. All mechanical, electrical and instrumentation and control systems of each of the key units are to be configured independently.
- Deadlock prevention: Shutdown of PCC may not lead to shut down in HRC/AEC or interfacing supply's – cross interference which prevent start-up must be designed out (integrated ESD design)
- Independent failure of any component besides the main critical units (treatment processing, compression, transformers, amine regeneration and steam) shall not lead to a reduced availability of the plant and the AEC/HRC. This applies for mechanical, electrical and instrumentation (pumps, valves, measurements).
- When the plant is not operated, it is still required to be available for immediate deployment. Therefore, maintenance can only be executed to the extent this execution would be possible and safe with a plant in full operation. The requirement to the design cannot assume opportunistic maintenance to be part of the 'normal' way of working. Most maintenance should only be done when the plant is in full stop to minimise exposure to maintenance staff (e.g. double block and bleed, isolation and other safety measures). Full stop is not assumed when the plant is on turndown or recycle (e.g. due to power or steam limitations). The design needs to be robust to cater for a prolonged breakdown of a critical piece of equipment, since only very limited opportunistic maintenance is possible in the 'live' plant if it needs to be started up relatively quick (once power or steam are sufficiently available again).
- All maintenance that requires the plant to be out of operation reduces availability. These activities need to be grouped in dedicated shutdown slots, which coincide with the AEC/HRC shutdowns/Turn arounds (refer Appendix B).
- Contractor to describe the Lock Out Tag Out Try Out (lototo) strategy specifically for the flue gas shut-off devices (maintenance under Lototo without stopping the boilers). Other equipment to be identified during the HAZOPs.
- Non-shutdown related maintenance activities (First line and preventive maintenance) will be executed every two weeks in dedicated maintenance time slots (grouped in two-weekly windows) for HSE exposure reasons.

4 Operations Strategy

The PCC is integrated into the systems of AEB and therefore depends on the availability of some of the AEB assets (refer to battery limit interfaces).

4.1 Operations Modes

In the next project phase, the Operations modes of the plant shall be confirmed considering:

1. Maximizing uptime and availability of the PCC to at least 96.5% (refer to section 2 – O&M Philosophy)

2. The minimum and maximum inputs from the flue gas assets (AEC and HRC) turn down/up rates. The Plant is to be designed such, that in normal operating conditions it can accommodate the expected variations in flue gas at intake (volume and quality).

3. PCC recycling or hot standby modes, where applicable, should be designed to reduce start up duration of the PCC and allow fast ramp up to maximized CO2 capturing. The PCC full recycle option should be considered as an option for a pre-determined number of hours in the following cases (number of hours to be detailed in the next design phase):

   a. Flue gas temporarily not available.
   b. OCAP/Porthos/Artemis temporary shutdown.
   c. Shortage of steam and/or electricity (reduced steam/electricity in PCC recycle mode needs to be calculated).
   d. Auxiliary systems supply interruptions (e.g., steam, air, et cetera).

4. Hot start and stop to be enabled from the CCR

5. Cascading shutdown or incompatible start up sequencing needs to be addressed in the design through process simulation.

6. All the above scenarios should be validated through a dynamic modelling to confirm assumptions on flexibility and start up/shutdown of the PCC.

7. Remote operation from the CCR and automated processing will be part of the design. Since AEB is a 24/7 operation, the PCC needs to operate 24/7 as well.

8. Flexibility and controllability: the PCC processing must be able to accommodate significant variations in the flue gas composition, as specified by AEB during normal incineration operations. Refer to AEB measurements. To achieve this, the following needs to be provided:

   a. Development of steady-state and dynamic models, including sizing and/or performance of all major pieces of equipment and automatic disturbance rejection ability
   b. Process operating constraints need to be identified (e.g., approach to entrainment flooding in stripper)

c. With respect to changing ambient conditions and variable fuel inputs, demonstrate feasible operation over the expected domain of uncertain parameters (i.e., flexibility test problem). For other variables (i.e., plant load, CO_2 recovery, et cetera), quantify the amount of flexibility/variability
d. Start-up/shutdown: Modelling transient operating conditions e.g., start-up / shutdown and the dynamic performance

9. Include important performance metrics such as time to start-up/shutdown, cost of start-up/shutdown, minimum up- and downtimes.

4.2 Staffing

In the next project phase, the following staffing requirements shall be adhered in the design:

1. Normal operations will be normally unmanned for economic (e.g., minimize OpEx) and safety reasons (exposure to risks for the operators).
2. The PCC plant operation shall be managed using three shifts/day (8 hrs/shift) organization working 7 days a week
3. Maintenance staffing will be aimed at minimum intervention and a 2-weekly interval for preventive maintenance or, in case of breakdowns, on a call off basis
4. Sharing resources with current operations will require further discussion with AEB operations after FEED
5. Training for operators and maintenance staff to be included in the FEED in Initial Operating/Maintenance manuals where applicable, including a simulator for training purposes.

4.3 TCO Parameters

In the next project phase, TCO for specific options (options to be confirmed) including the following elements shall be specified:

- Subsidy per ton CO_2,
- Life cycle costs of selected capture technology (specifically solvent replacement),
- Total maintenance costs
- Energy-efficiency
- Impact of scheduled/unscheduled deferment
- Cost associated with staffing levels operations and maintenance
- Impact of critical equipment availability assumptions & performance

4.4 Life Cycle Operations Support

To enable operations support, a comprehensive Operations & Maintenance manual shall be specified, which contains at least:

1. Process overviews
2. Mode of operations
3. Start up and shutdown
4. Relevant failure modes (process and equipment)
5. Intake and export characteristics/specifications PCC
6. Training
7. Maintenance execution methodologies

In the next, project phase(s), a process simulation tool for PCC in line with the current AEB IT tools: Ebsilon, shall be provided. The model must be integrated with the current models AEB has in use for the HRC/AEC plants.

Training: include training materials and training delivery for operations and maintenance personnel with a full-scale simulator to train desk top operators. Also, in coordination with Technicom proper learning material for future operators, technicians, and work preparators (incl. formats and approaches) is to be developed.

Describe minimum training and troubleshooting competencies required for major equipment, including innovative technologies in the PCC plant and its interfaces.

4.5 Interfaces/Battery Limits

All interfaces at battery limits must be robust and without interference with the existing operations. Since PCC will use existing plant to supply instrument air, steam, power, dynamic behavior, and start-up shutdown of systems need to be reflected into the design update (ESD matrix). Additional interfaces may apply.

- Construction of the plant will occur during normal plant operations in AEB. Construction methodology to reduce the impact on current operations to a minimum and be coordinated with operations.
- Construction during tie ins will need close interaction with AEB.
- Tie ins (including in the CCR) will require zero interference with ongoing operations, Contractor to propose methodology statement for operations to review.

5 HSSE

Safety and risk management: Contractor to identify risks associated with operations for all operating modes (start-up/shutdown, normal operation, emergency shutdown, et cetera), maintenance activities, ensuring compliance with safety regulations, and implementing measures to eliminate and/or mitigate risks to ALARP.

The design should eliminate as far as reasonably possible the risks of the PCC, and management of these risks need to be identified in the HSE risk register (refer HSE part of the design).

Environmental emissions and wastewater are part of separate permits, but need to be included into the operations manual for non-routine operations

As a side note:

Some of the products in PCC (amine, CO_2) are new to AEB. Specific care must be given into the design and operations manual to prevent accidents whilst working in/around the PCC. This applies onsite, but also offsite (dispersion of CO_2 cloud calculations, wind vanes and safe zones). HSE training must address these HSE risks and mitigation measures explicitly.

6 Concurrent Operations

6.1 During PCC Construction

Contractor to provide a Concurrent Operations (ConOps) procedure for AEB PCC during the construction and commissioning/startup/first year operations phases whilst the HRC/AEC and auxiliary systems are running.

During construction, operation of all six (6) incineration lines (AEC, HRC) must be minimally impacted due to PCC plant installation, commissioning and startup operations.

Contractor to propose the concurrent operations procedure during construction which stipulates the communication hierarchies, Permit to Work, civil works, et cetera between Operations department and PCC Construction Management.

Contractor to describe specifically battery limit connections and CCR integration whilst operations is ongoing (ESD, F&G, testing, hook-up, commissioning testing, uninterrupted instrument air supply, et cetera).

Contractor to provide the operating and maintenance routines for the period between installation and start-up, and equipment preservation method statements.

6.2 During PCC Commissioning

Commissioning procedures to include:

- Approved testing and performance testing schedules by operations
- operations staff training

6.3 PCC Initial Operations & Transitioning

The PCC shall be operated with support from the technology provider/Contractor for:

- At least during initial operations after installation & commissioning.
- AEB plant personnel shall be trained, and a training schedule/plan shall be developed together between AEB and the technology provider/Contractor
- Handover/commissioning to be described in commissioning and handover philosophy document
- Contractor to prepare Initial Operations Philosophy for the Initial operations (including maintenance and integrity), including interfaces with AEB operations (ConOps procedure).

7 Technical Terms and Definitions

Technical term	Definition
Operability	Operability is the ability to keep a piece of equipment, a system, or a whole industrial installation in a safe and reliable functioning condition, according to pre-defined operational requirements.
Availability	Is defined as the overall probability that the system is capable of achieving a specified level of performance, considering planned and unplanned outages.
Reliability	Reliability is defined as the probability that a product, system, or service will perform its intended function adequately for a specified period of time or will operate in a defined environment without failure.
ConOps	Multiple independent operations that occur on a location at the same time. Events of any one operation may impact the safety of personnel or equipment of another operation (i.e. routine operations, construction, heavy traffic, welding or working at heights).
Normally Unmanned	A Normally Unmanned Installation (NUI) is a type of automated plant designed to be primarily operated remotely, without the constant presence of personnel.
Hot Start / Cold Start	Hot start A start of the PCC from the CCR, PCC is still at operating temperature or in full recirculation mode. Cold start A start of the PCC after a shutdown that required the PCC to cool down to ambient temperatures. Operator involvement in the field is needed.

Appendix A
Operations Procedure Formats

Refer to the AEB standards manual during the design phase

Appendix B
Planned Stops AEB HRC/AEC Plants – Example

Number of weeks scheduled outage time for boilers AEC and HRC

		2020			2021			2022			2023			2024			2025		
	# weeks	spring	summer	autumn	spring	summer	autumn	spring	summer	autumn	spring	summer	autumn	spring	summer	autumn	spring	summer	autumn
AEC	K11				4				1		4				1		4		
AEC	K12				4				1		4				1		4		
AEC	K23	4				1		4				1		4				1	
AEC	K24	4				1		4				1		4				1	
HRC	K35			1			4			1			4			1			4
HRC	K36			1			4			1			4			1			4

		2026			2027			2028			2029			2030			2031		
	# weeks	spring	summer	autumn	spring	summer	autumn	spring	summer	autumn	spring	summer	autumn	spring	summer	autumn	spring	summer	autumn
AEC	K11		1		4				1		4				1		4		
AEC	K12		1		4				1		4				1		4		
AEC	K23	4				1		4				1		4				1	
AEC	K24	4				1		4				1		4				1	
HRC	K35			1			4			1			4			1			4
HRC	K36			1			4			1			4			1			4