

Product Carbon Footprint IT Platform

Concept Design

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Business Need for the PCF IT Platform. Global industry is experiencing a significant shift toward the measurement, management, and reduction of greenhouse gas (GHG) emissions. Governments, regulators, investors, customers, and society increasingly expect companies to demonstrate the environmental performance of their products and operations. Sustainability has evolved from a voluntary corporate initiative into a strategic business objective and, for many organizations, a prerequisite for maintaining market competitiveness.

The adoption of the Paris Agreement¹ and the introduction of national and regional decarbonization policies have accelerated this transition. At the same time, many leading global companies including Nestle, BASF, Unilever, IKEA, and numerous others have established ambitious targets to reduce GHG emissions throughout their value chains.

Effective emissions reduction begins with accurate measurement. As with any optimization initiative, organizations must first establish a reliable baseline, identify the major sources of emissions, and prioritize improvement opportunities before implementing corrective actions. Consequently, the ability to calculate and manage GHG emissions has become a fundamental business capability.

Every product generates GHG emissions throughout its life cycle. Raw materials, utilities, transportation, auxiliary materials, and manufacturing processes all contribute to the overall environmental impact of a product. Fuel combustion for electricity generation, process heating, transportation, and logistics results in emissions of carbon dioxide (CO₂) and other greenhouse gases.

By quantifying all GHG emissions generated throughout the product life cycle, from raw material extraction to delivery to the customer, and allocating these emissions to the quantity of product produced, organizations obtain one of the key sustainability metrics: the **Product Carbon Footprint (PCF)**.

Product Carbon Footprint (PCF) measures the total GHG emissions associated with a product throughout its life cycle.

At the corporate level, the aggregation of PCF values across all products provides a comprehensive understanding of the company's overall carbon footprint and enables informed decision-making regarding emissions reduction strategies, portfolio optimization, and sustainability reporting.

Although the underlying principles are applicable across virtually all industries, from food production to heavy manufacturing, this Concept Design focuses specifically on the refining, petrochemical, and chemical industries.

To ensure consistent reporting, GHG emissions are commonly classified according to the internationally recognized **Scope 1, Scope 2, and Scope 3** framework. This

classification distinguishes emissions generated directly by production facilities, indirect emissions associated with purchased energy and materials. PCF calculations require the integration of emissions across all relevant scopes applicable to the product life cycle.

Scope 1-3 emissions represent the internationally recognized framework for classifying GHG emissions across an organization's value chain.

For organizations producing only a limited number of products with relatively simple manufacturing processes, PCF calculations can be performed using spreadsheet-based tools such as Microsoft Excel. These solutions are often sufficient during the early stages of sustainability programs.

However, the refining, chemical, and petrochemical industries operate highly integrated manufacturing networks consisting of hundreds of process units, thousands of material streams, and extensive product portfolios. Calculating Product Carbon Footprints for hundreds or thousands of products requires continuous collection, validation, reconciliation, and processing of large volumes of operational data from multiple production facilities.

Under these conditions, spreadsheet-based solutions become increasingly difficult to maintain, scale, and govern. Managing enterprise-wide PCF calculations using spreadsheets would require substantial manual effort and would limit the organization's ability to perform timely and repeatable calculations.

A similar evolution has already occurred in financial management. As enterprise resource planning (ERP) systems such as SAP replaced manual accounting processes, PCF management now requires a dedicated enterprise platform capable of automating data collection, calculation, validation, reporting, and governance across the organization.

Despite rapidly growing market demand, comprehensive enterprise-scale PCF calculation platforms remain an emerging technology. While several software vendors and industrial companies have initiated development in this area, including collaborations such as BASF with Atos² and Dow with BCG³, the market is still at an early stage of maturity, with no universally adopted industry-standard solution.

Consequently, the development of a dedicated PCF IT Platform represents a timely opportunity to establish a scalable digital capability that supports enterprise-wide Product Carbon Footprint calculation, management, reporting, and continuous improvement while integrating seamlessly with a company existing MES and ERP platforms, and other operational information systems.

PCF IT Platform Capabilities and Business Value. The PCF IT Platform has to support a broad range of business processes by automating routine activities, improving calculation efficiency, and providing reliable PCF information for operational, tactical, and strategic decision-making.

To ensure a practical and phased implementation, the platform capabilities should be categorized into two groups:

- **Mandatory Capabilities**, representing the minimum functional scope required for a fully operational enterprise PCF Platform.
- **Preferred Capabilities**, representing advanced functionality that may require more sophisticated analytical methods, optimization algorithms, or artificial intelligence technologies and can be implemented in subsequent development phases.

This approach defines both the minimum functional requirements for the platform and its long-term development vision.

The **Mandatory Capabilities** establish the essential functionality required to calculate, manage, and report PCF across the enterprise. At a minimum, the platform shall provide the following capabilities:

- Automated calculation of PCF for products manufactured at existing operating facilities, as well as for products planned under future investment projects.
- Provide an intuitive, user-friendly interface that visually represents the production value chain and supports efficient navigation.
- Support both manual data entry and automated data collection for all information required to perform PCF calculations.
- Validation and processing of operational and business data required for PCF calculations.
- Support integration with modern enterprise systems, including MES, ERP, LIMS, process historians, and other relevant digital platforms.
- Support multiple PCF calculation methodologies and provide flexible configuration of calculation parameters, enabling efficient transition between methodologies without requiring changes to the platform architecture.
- Standardized reporting using predefined templates and customer- or regulation-specific reporting formats.
- Generate standardized and analytics-ready datasets for dashboards, BI tools, and management reporting.
- Full calculation traceability and auditability to support internal governance and external certification.
- Centralized management of emission factors, calculation parameters, and methodological configurations.

These capabilities establish the PCF Platform as the enterprise system of record for PCF calculations and reporting.

Beyond the mandatory functionality, the platform should progressively evolve into an intelligent decision-support solution capable of identifying optimization opportunities and supporting business decisions across the organization. Achieving this vision requires the incorporation of the **Preferred Capabilities**:

- Automated identification of optimal production routes that minimize PCF while satisfying operational, economic, and business constraints at both asset and enterprise levels.

- Automated detection of data anomalies, inconsistencies, and potential calculation errors by comparing current data with historical trends, integrated enterprise datasets, expected operating ranges, and statistical baselines, supplemented by machine learning techniques.
- Automated optimization of feedstock and auxiliary material selection to identify combinations that achieve a target or minimum PCF while satisfying operational, economic, supply chain, and business constraints.
- Support configurable scenario analysis for evaluating the impact of management decisions and potential operational, commercial, and structural changes across the production value chain on PCF. The platform should also enable automated generation of comparative reports, dashboards, and presentation materials for decision-making purposes.

The mandatory and preferred capabilities described above naturally result in the corresponding business benefits that can be achieved through the development and implementation of the PCF Platform.

Within the scope of the mandatory capabilities, the platform enables a significant reduction in engineering effort required to perform PCF calculations and prepare product certification packages. It also allows faster response to customer requests for PCF information, thereby supporting faster product qualification and reducing the time required to bring products to market.

Implementation of the platform and its recognition by certification bodies may also simplify the certification process. Instead of auditing individual PCF calculations for each product, certification bodies may certify the calculation methodology and the platform itself. In other words, confidence is established in the certified calculation process implemented within the platform, significantly reducing the need for multiplicity and repetition product certification.

Within the scope of the preferred capabilities, the platform enables the company to identify production solutions capable of delivering products with a target or reduced PCF while maintaining operational and economic feasibility. Such capabilities may allow the company to capture market premiums associated with lower-carbon products. The platform can also support optimization of feedstock and auxiliary material selection, strengthening negotiations with suppliers by incorporating PCF as an additional procurement criterion alongside traditional commercial consideration.

Overall, the platform can support a broad range of additional business applications and optimization opportunities that may emerge during its adoption and day-to-day use across the organization.

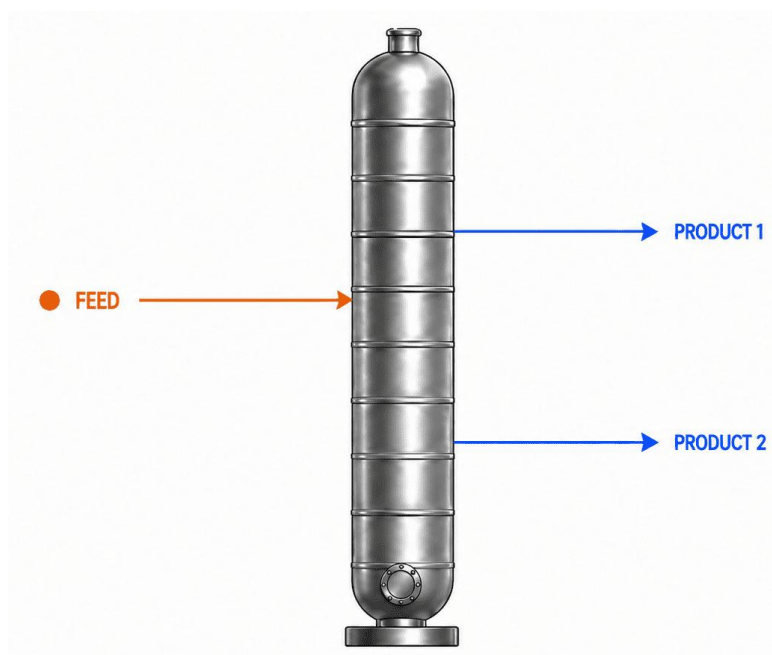
Finally, the preferred capabilities are not required for successful implementation of the platform and should be considered as part of its future evolution. The recommended approach is to initially deliver the mandatory functionality, enabling faster deployment, lower implementation cost, and earlier realization of business value. Advanced capabilities can then be introduced as business needs evolve.

Methodological Basis for PCF Calculation. At present, the most widely recognized methodological frameworks governing **Life Cycle Assessment (LCA)**, GHG accounting, allocation principles, and PCF calculation are **ISO⁴ 14040**, **ISO 14044**, **ISO 14067**, and the **GHG Protocol⁵**. These frameworks establish high-level principles and

general methodological requirements applicable across a broad range of industries and activities. By design, they provide a common foundation for PCF calculation while allowing flexibility in their implementation to accommodate different industrial sectors and production systems.

Life Cycle Assessment (LCA) or Life Cycle Analysis is a standardized scientific methodology used to evaluate the total environmental impact of a product, service, or process throughout its entire existence.

However, there is currently no universally accepted methodology specifically developed for the refining and petrochemical industries that addresses the unique characteristics of these highly integrated production systems. Several industry initiatives are working toward harmonizing calculation approaches. One of the examples is the Together for Sustainability (TfS)⁶ PCF Guideline, which builds upon the ISO standards and the GHG Protocol while providing more prescriptive guidance for the chemical industry. In parallel, leading companies such as BASF and Dow have developed their own internal PCF methodologies to support digital solutions and carbon accounting processes. Over time, these initiatives may contribute to the establishment of broadly accepted industry practices.

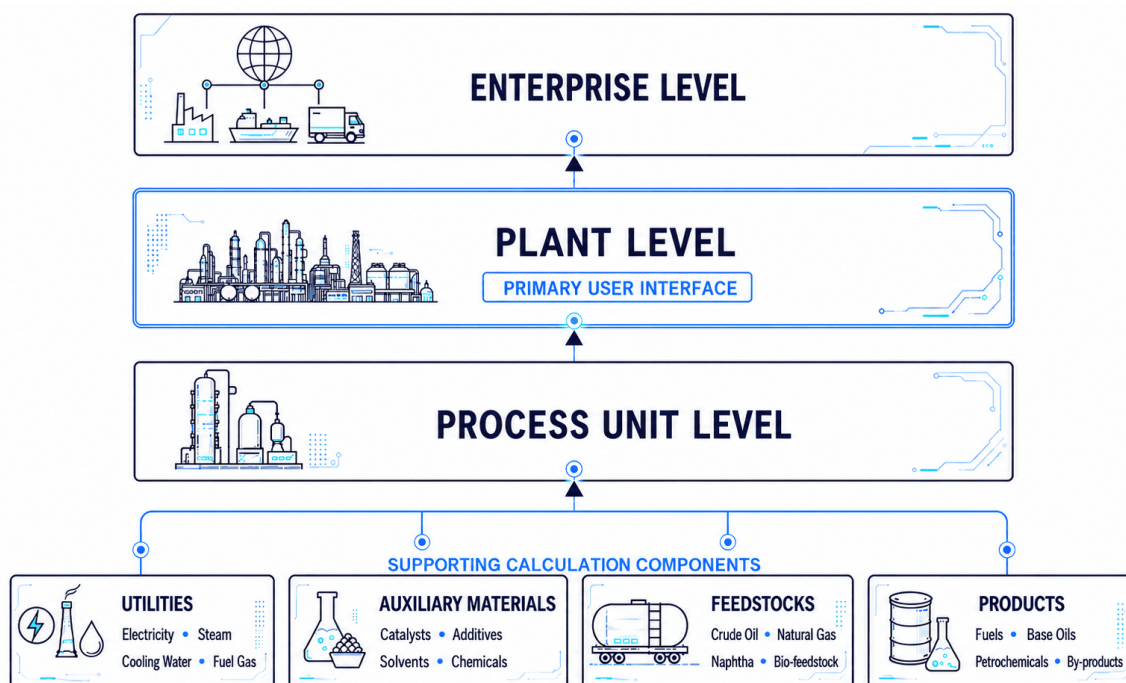


The need for industry-specific guidance can be illustrated using a simplified example. Consider a process unit with one feed stream, two output streams, and associated energy consumption. If both output streams are classified as products, the generated GHG emissions are allocated between them. However, if one of the output streams is instead classified as waste with no allocated environmental burden, the entire emissions of the process are assigned to the remaining product. Consequently, two technically identical production processes could produce significantly different PCF values solely because different allocation methodologies were applied.

In integrated refining and petrochemical facilities, the number and complexity of such methodological questions increase substantially. Examples include determining whether hydrogen produced within a steam cracking complex should be treated as a co-product or fuel, whether hydrogen from a catalytic reforming unit should be considered a co-product or an internal utility, how emissions should be allocated within highly integrated production systems containing multiple recycle streams, such as aromatic complexes. Numerous similar methodological decisions directly influence calculated PCF values.

The need for a dedicated industry methodology is therefore evident, and its development is expected in the coming years. Until such a methodology becomes broadly accepted, the PCF Platform should not be tightly coupled to a single calculation approach. Instead, it should support configurable calculation methodologies, allocation rules, and calculation parameters, allowing multiple methodologies to coexist and enabling future methodological changes to be incorporated without significant modifications to the platform. This flexibility will ensure that the platform remains aligned with evolving industry guidance, customer requirements, and regulatory expectations.

3-Level Platform Concept. The proposed PCF Platform is structured around three primary hierarchical levels aligned with the organizational management structure of



industrial companies. This approach enables users to analyze PCFs from the perspective of individual production units, entire manufacturing sites, or the enterprise as a whole while maintaining full traceability across the production value chain.

The three primary platform levels are:

- **Process Unit Level**
- **Plant Level**
- **Enterprise Level**

The **Process Unit Level** represents the fundamental calculation layer of the platform. At this level, operational and business data required for PCF calculations are collected either manually or through integration with enterprise systems. The platform performs PCF calculations for all products produced by the process unit while providing visualization of the production scheme, material and energy flows, key operating

parameters, calculated GHG emissions, and other process-specific analytical information.

The **Plant Level** integrates individual process units into a complete manufacturing facility. At this level, the platform provides an interactive process flow diagram representing the entire production chain for a selected product or for all products manufactured within the site. The platform calculates PCF across multiple interconnected production units and presents additional plant-level analytics, including GHG emissions, energy consumption, utilities, and other operational indicators.

The Plant Level is envisioned as the primary user interface of the platform. It serves as the main workspace where users construct, visualize, and analyze production chains ranging from individual products to the complete manufacturing site.

The **Enterprise Level** extends the calculation boundary beyond individual manufacturing sites to encompass the complete company supply chain. The platform provides a high-level representation of the production and logistics network from raw material extraction or procurement through manufacturing, transportation, distribution, and final product delivery. At this level, users can analyze PCFs across the entire value chain together with enterprise-wide GHG emissions and other sustainability performance indicators, enabling corporate-level reporting and strategic decision-making.

The Enterprise Level does not necessarily need to be implemented as an integral component of the PCF Platform. Depending on the organization's requirements and existing IT architecture, this functionality may instead be implemented as a separate enterprise-level application, integrated with the PCF Platform through standard interfaces.

In addition to the three primary hierarchical levels, the platform should include several supporting calculation components that provide standardized data used throughout the PCF calculations.

The proposed supporting components include:

- Utilities
- Auxiliary Materials and Components
- Feedstock
- Products

Utilities component defines the production schemes and calculation methodologies for utilities such as steam, electricity, cooling water, compressed air, industrial gases, and fuels consumed within the manufacturing process. For externally purchased utilities, the platform maintains the corresponding emission factors and supplier-specific characteristics required for PCF calculations.

Auxiliary Materials component maintains a centralized registry of auxiliary materials and production consumables, including catalysts, additives, chemicals, solvents, reagents, adsorbents, and other supporting materials. Where appropriate, production routes and PCFs may be defined for these materials, while externally supplied materials are characterized using supplier-specific or standardized emission factors.

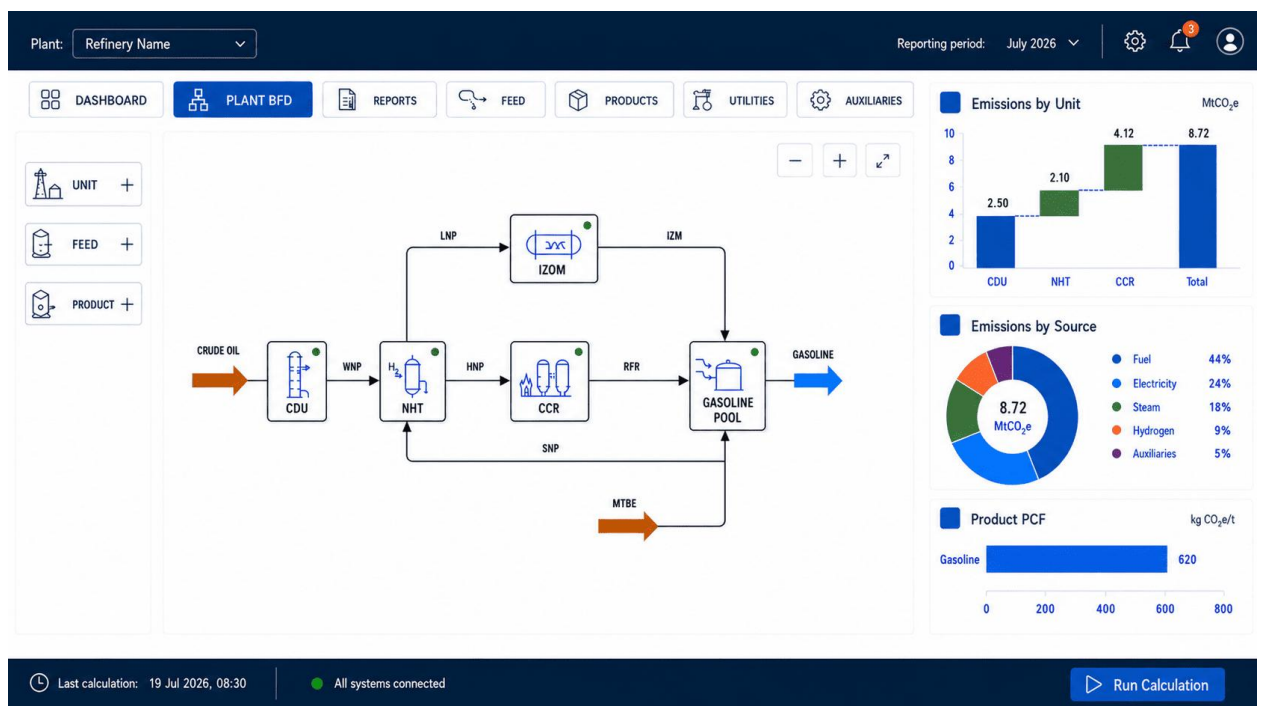
Feedstock component maintains the inventory of purchased raw materials processed within the manufacturing facilities. For each feedstock, the platform stores the relevant

physical properties, origin, supplier information, transportation characteristics, and Product Carbon Footprint values required for downstream calculations.

Products component maintains the centralized registry of finished products, intermediate products, and by-products manufactured by the enterprise. It stores product attributes, calculation settings, reporting parameters, and calculated Product Carbon Footprint values, serving as the primary repository for PCF reporting, certification, and business analytics.

This hierarchical architecture enables the platform to perform consistent and traceable PCF calculations across all organizational levels while maintaining a single, standardized source of calculation data for the entire enterprise.

Plant Level. The level serves as the primary user interface of the PCF Platform and is the first dialog window presented when the application is launched. It provides the main workspace for constructing and visualizing either the production chain of an individual product or the complete Block Flow Diagram (BFD) of a manufacturing facility. Within this interface, users define production units, process connections, feedstocks, intermediate products, and finished products, establishing the calculation model for PCF analysis.



The central area of the interface is occupied by the BFD representing either the production chain of a selected product or the entire manufacturing site. The gasoline production chain illustrated in the concept design is provided solely to demonstrate the functionality and operating principles of the Plant Level interface and does not represent a real production configuration.

To the left of the BFD is a panel containing the primary building blocks used to construct the production model. By selecting the UNIT, FEED, or PRODUCT icons, users can add the corresponding elements to the process diagram and progressively assemble the production scheme. This approach is primarily intended for environments where production models are created and maintained manually. In organizations implementing

seamless integration with real-time operational data, the production model would typically be configured during the initial platform implementation, with process equipment, material streams, quality parameters, and corresponding data tags automatically linked to enterprise historians, MES, and other operational systems.

Above the production diagram, the platform provides access to the principal functional subsystems:

- **Dashboard**
- **Plant PFD**
- **Reports**
- **Feed**
- **Products**
- **Utilities**
- **Auxiliaries**

The **Dashboard** subsystem provides configurable visualization of key performance indicators, operational parameters, PCF, and GHG emissions. The displayed information should be role-based, enabling customized dashboards for different user groups ranging from process engineers and operators to plant managers and corporate management. Dashboard subsystem window is the preferred landing page for monitoring and management users

The **Reports** subsystem enables users to configure, generate, and export standardized reports for operational monitoring, internal performance management, regulatory compliance, and customer communication. Report templates may also be developed to comply with the reporting formats and documentation requirements of bodies responsible for PCF certification.

The **Feed**, **Products**, **Utilities**, and **Auxiliaries** subsystems provide centralized management of the corresponding production elements used throughout the manufacturing process. Within these modules, users define, the list of items, its physical properties, calculation parameters, emission factors, supplier information, and other data required for PCF calculations. Where applicable, these subsystems also support the creation and calculation of production models for internally generated utilities (e.g., steam, electricity, hydrogen, and fuel gas) and auxiliary materials, allowing their PCF to be determined and consistently propagated throughout the production chain.

This Plant Level architecture provides an intuitive graphical environment for building, maintaining, and analyzing production models while serving as the central interface through which users interact with the PCF Platform.

Process Unit Level. Access to the Process Unit Level is provided by double-clicking the corresponding process unit icon on the Plant Level BFD. This level serves as the detailed calculation and data-management environment for an individual production unit.

The Process Unit Level comprises five principal subsystems:

- **Material Balance**
- **Utilities**
- **Auxiliaries**
- **Unit PFD**
- **Reports**

The Material Balance, Utilities, and Auxiliaries subsystems are primarily presented in tabular form. These subsystems are used to define the unit feedstocks, auxiliary materials, consumed utilities, and generated products required for PCF calculation.

The **Material Balance** subsystem consists of two principal tables. The upper table is used to define the feed streams entering the process unit, while the lower table is used to define the products and other output streams leaving the unit.

The screenshot displays the 'MATERIAL BALANCE' subsystem interface. At the top, there are dropdowns for 'Plant: Refinery Name' and 'Process Unit: CDU', along with a 'Reporting period: July 2026'. The interface is divided into several sections:

- CALCULATION OPTIONS:** Includes 'Allocation Method' (Mass-based selected, Energy-based unselected) and 'Scope Allocation' (Scope 1, 2, and 3 all selected). An 'Approved tolerance' of $\pm 0.50\%$ is set.
- FEED STREAMS:** A table with columns: No., Feed Name, Flow Rate, t/h, GHG Intensity, kg CO₂e/t, LHV, GJ/t, and Energy Input, GJ/h. It lists three feed streams: Crude Oil, Hydrogen, and MTBE. A summary row shows 'TOTAL / WEIGHTED AVG.' with values: 429.3, 570, 42.90, 18,415.
- PRODUCT & OUTPUT STREAMS:** A table with columns: No., Product / Output, Classification, Flow Rate, t/h, Allocate, GHG Intensity, kg CO₂e/t, LHV, GJ/t, Energy Output, GJ/h, MB Rec., and EB Rec. It lists five streams: Whole Naphtha (Main Product), Kerosene (Commercial Product), Diesel (Co-product), Atmospheric Residue (Intermediate), and Off-gas (By-product). A summary row shows 'TOTAL / WEIGHTED AVG.' with values: 428.6, 598, 42.66, 18,285.
- BALANCE VALIDATION:** Shows 'Material Balance' (Input: 429.3 t/h, Output: 428.6 t/h, Difference: +0.16%, Within tolerance) and 'Energy Balance' (Input: 18,415 GJ/h, Output: 18,285 GJ/h, Difference: -0.71%, Reconciliation required).
- RECONCILIATION:** Shows 'Material: Diesel' and 'Energy: Atmospheric Residue'. A 'VIEW LOG' button is present.
- UNIT PCF SUMMARY:** Shows 'Attributable emissions: 54.8 tCO₂e/h', 'Allocated output: 428.6 t/h', and 'Weighted PCF: 598 kg CO₂e/t'.

At the bottom, there is a status bar with 'Last calculation: 19 Jul 2026, 08:30', 'All data sources connected', and a 'Run Calculation' button.

The feed table may include the following columns:

- Sequential number
- Feed name
- Flow rate
- Total GHG emission intensity, expressed as CO₂ equivalent per unit of mass or energy
- Lower heating value
- Energy introduced into the system

The **feed table** includes a summary row in which total flow rate and total energy input are calculated, while other applicable parameters are aggregated or calculated as weighted averages.

Feed streams are selected from the predefined list maintained within the FEED subsystem. Once a feed type is selected from the drop-down list, the corresponding predefined parameters are populated automatically. Where permitted, users may subsequently adjust unit-specific values or override default parameters.

The **product table** follows a similar structure and may include the following columns:

- Sequential number
- Product or output-stream name
- Stream classification, such as commercial product, main product, co-product, by-product, waste, or intermediate stream

- Flow rate
- Allocation inclusion option, defining whether process emissions are allocated to the stream
- Total GHG emission intensity, expressed as CO₂ equivalent per unit of mass or energy
- Lower heating value
- Energy removed from the system
- Material-balance reconciliation option
- Energy-balance reconciliation option

The material-balance reconciliation option allows a selected stream to absorb minor differences between total input and output flows where an imbalance remains within an approved tolerance. A similar option may be applied to reconcile the unit energy balance. Such adjustments should be traceable, controlled, and clearly identified in the calculation results. Once a product type is chosen from the drop-down list, the corresponding predefined parameters are populated automatically.

The product table also includes a summary row following the same general principle as the feed table. Total output flow and total energy output are calculated, while other relevant parameters are aggregated or calculated as weighted averages.

Calculation and allocation options are selected in a dedicated control panel located to the left of the tables. These options define the methodological basis applied to the process unit, including, for example:

- Mass-based allocation
- Energy-based allocation
- Scope types allocation options

The selected allocation method directly determines how the process unit's attributable GHG emissions are distributed among its output streams. Alternatively, the allocation methodology may be selected once at the Plant Level. In this case, the selected methodology is automatically applied to all process units within the calculation boundary, ensuring methodological consistency and eliminating the need to configure allocation methods individually for each process unit.

The **Utilities** and **Auxiliaries** subsystems at the Process Unit Level follow a design approach similar to the Material Balance subsystem and are primarily presented in tabular form.

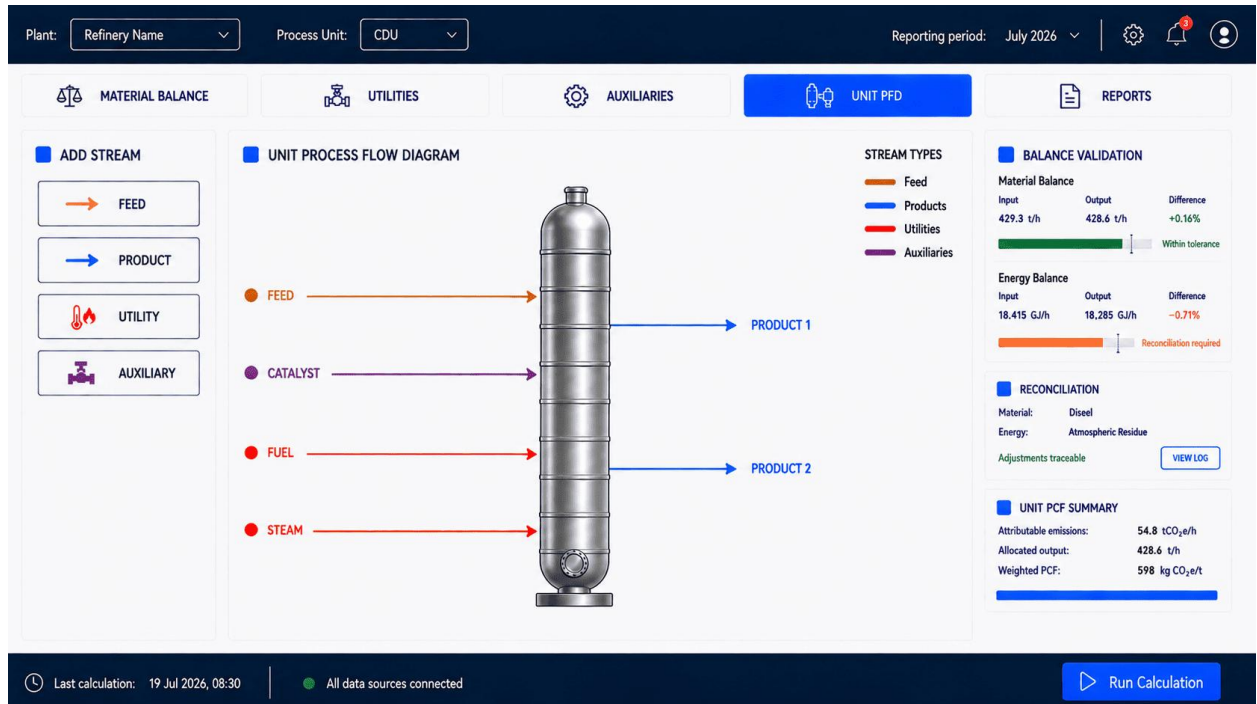
The **Utilities** subsystem includes both input and output streams. Utilities such as steam, electricity, cooling water, fuel gas, hydrogen, and compressed air may be consumed by the process unit, while certain utilities may also be generated or recovered. For example, waste heat may be recovered and converted into steam for subsequent use within the same process unit, elsewhere within the plant, or for export to another production area. The subsystem should therefore support the definition, calculation, and reconciliation of both consumed and generated utility streams.

The **Auxiliaries** subsystem is intended to define auxiliary materials consumed by the process unit, including catalysts, additives, solvents, reagents, adsorbents, and other process chemicals. In most cases, this subsystem requires only input streams because auxiliary materials are consumed or incorporated into the process. Output streams may nevertheless be supported where required.

The **Feed, Products, Utilities, and Auxiliaries** subsystems at the **Plant Level** maintain bidirectional data links with the corresponding **Material Balance, Utilities, and Auxiliaries** subsystems at the **Process Unit Level**. As a result, a stream or production element defined at one level is automatically reflected at the other level.

For example, utility, or auxiliary stream entered at the Process Unit Level is reflected in the relevant Plant Level subsystem and in the overall production model.

This bidirectional relationship simplifies data entry, reduces duplication, and supports consistent construction and maintenance of the plant or product production chain.



The **Unit PFD** subsystem provides a simplified graphical representation of the selected process unit together with its associated material, utility, auxiliary, and product streams. The process unit is displayed using an appropriate schematic symbol, such as a reactor, distillation column, heat exchanger, or other representative process equipment.

In the example presented within this concept design, the Unit PFD includes one feed stream, two product streams, fuel and steam utility streams, and one catalyst stream.

The Unit PFD is generated automatically based on the information defined within the Material Balance, Utilities, and Auxiliaries subsystems. Whenever a stream is created or modified within the corresponding tabular subsystem, it is automatically displayed on the Unit PFD with the appropriate stream classification and graphical representation. Consequently, users are not required to manually redraw the process diagram after modifying process data.

Alternatively, process streams may also be created directly within the Unit PFD. Using the component palette located on the left-hand side of the interface, users can add feed, product, utility, or auxiliary streams to the process unit. During stream creation, the user may either select an existing stream from the corresponding Plant Level registry or define a new stream together with its required calculation parameters.

Streams created or modified within the Unit PFD are automatically synchronized with the corresponding Material Balance, Utilities, or Auxiliaries subsystem, depending on the stream type. Likewise, any subsequent changes made within the tabular subsystems are immediately reflected in the graphical process diagram.

As a result, the Material Balance, Utilities, Auxiliaries, and Unit PFD subsystems maintain fully bidirectional data synchronization. This ensures consistency between graphical and tabular representations, eliminates duplicate data entry, simplifies process model development.

Subsystems of the Plan Level. The **Feed, Products, Utilities, and Auxiliaries** subsystems at the Plant Level are designed for the centralized definition, management, and maintenance of all production streams used throughout the PCF calculation model. These subsystems serve as the master registries for purchased feedstocks, intermediate and finished products, utilities, and auxiliary materials.

When constructing a new PCF model, users may begin by defining the initial inventory of purchased feedstocks, final products, consumed utilities, and auxiliary materials within these Plant Level subsystems. As the production model evolves, additional streams may be created either directly within the Plant Level registries or during configuration of individual Process Units. Regardless of where a stream is created, it is automatically synchronized across the platform through the bidirectional relationships between the Plant Level and Process Unit Level.

The Feed, Products, Utilities, and Auxiliaries subsystems follow the same design principles, data structure, and operating logic as their corresponding Process Unit Level subsystems. Users may therefore define stream properties using either tabular interfaces or graphical process flow diagrams, depending on the type of production element being modeled.

The graphical PFD capability is particularly valuable when utility or auxiliary material is produced within the enterprise rather than purchased from external suppliers. In such cases, the internal production process can be modeled using the same methodology applied to the main production chain. For example, steam may be generated in plant boilers through the combustion of fuel gas. By modeling these supporting production systems, the platform can calculate the corresponding GHG emission intensity of internally produced utilities and auxiliary materials.

The calculated emission intensities are then automatically propagated to all downstream Process Units that consume these internally generated streams. This approach ensures that the Product Carbon Footprint reflects the actual environmental performance of the enterprise rather than relying solely on generic or externally supplied emission factors, thereby improving both calculation accuracy and methodological consistency across the entire production chain.

Enterprise Level. The Enterprise Level extends the capabilities of the PCF Platform beyond individual production facilities by providing enterprise-wide management, analysis, and optimization of Product Carbon Footprints across multiple plants, products, and supply chains. Depending on an organization's business requirements, this level may range from a relatively simple reporting environment to an advanced decision-support platform capable of optimizing production and distribution across the entire enterprise.

For some organizations, the Enterprise Level may primarily function as a corporate reporting layer that aggregates PCF data from multiple manufacturing sites and provides dashboards, sustainability reporting, regulatory compliance, and management analytics. For others, it may evolve into an optimization platform capable of identifying the most suitable production and logistics scenarios to minimize the PCF for specific customers, markets, or geographic regions while satisfying operational and commercial constraints.

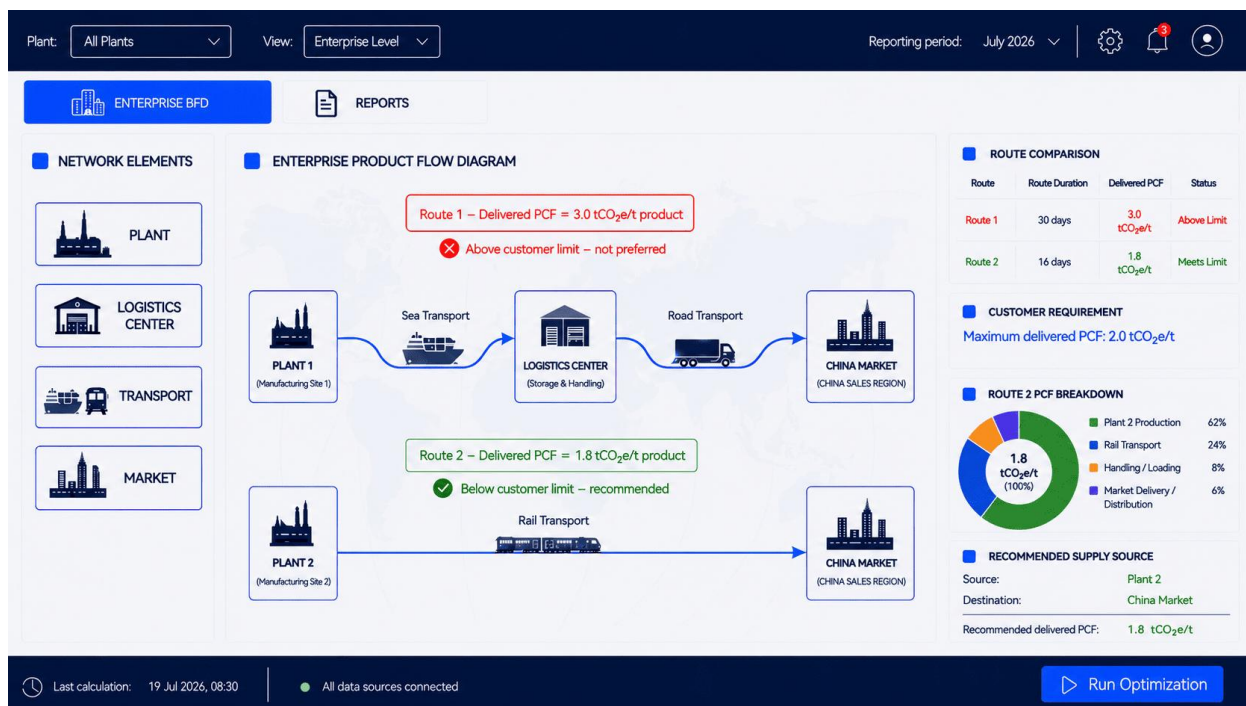
For example, two manufacturing sites may produce the same product but with different overall PCF due to variations in process efficiency, energy sources, feedstock characteristics, transportation routes, or logistics. The Enterprise Level may determine that production from one facility should be allocated to the Asian market while production from another facility should be supplied to North America in order to minimize the delivered PCF for each customer or region. Alternatively, the platform may recommend a different allocation strategy that maximizes overall business value by balancing PCF, logistics costs, production economics, regional pricing, contractual obligations, and profitability. For example, a product with a higher PCF may be supplied to a market without stringent carbon requirements but offering higher margins, while a lower-PCF product is allocated to customers or regions with strict sustainability criteria. Such optimization may simultaneously consider production capacity, transportation costs, market demand, contractual obligations, logistics availability, regional regulations, carbon constraints, and overall enterprise profitability.

The implementation of the Enterprise Level may vary according to the organization's IT architecture and demand to the IT solution. It may be developed as an integral component of the PCF Platform or implemented as a separate enterprise-level application, such as an ERP or supply chain optimization solution, while maintaining seamless integration with the PCF Platform through standardized interfaces. Conversely, organizations operating a single production facility or those without enterprise-wide optimization requirements may derive limited value from this level and may therefore choose not to implement it.

Where implemented, the Enterprise Level may serve as an enterprise-wide aggregator of manufacturing plants, logistics centers, distribution networks, and products, tracking material flows from production through transportation and storage to the final customer. Consequently, the platform is capable of incorporating the GHG emissions associated with internal logistics, transportation of feedstocks, intermediate products, and finished products into the overall PCF calculation.

From a user interface perspective, the Enterprise Level may be represented by a graphical BFD illustrating the complete product life cycle within the organizational boundary from manufacturing plants through logistics centers to the target markets. This provides decision makers with a comprehensive visualization of the supply chain together

with the corresponding Product Carbon Footprint for each production and distribution route.



The concept illustrated in this paper presents two manufacturing plants producing the same product. Product from the first plant is transported by sea to a logistics center and subsequently delivered by road to the Chinese market, resulting in a delivered Product Carbon Footprint of approximately 3.0 kg CO₂e per ton of product. Product from the second plant is transported directly by rail to the same destination, resulting in a delivered Product Carbon Footprint of approximately 1.8 kg CO₂e per ton of product. Although intentionally simplified, this example demonstrates how the Enterprise Level can support supply chain optimization by identifying the most appropriate production source and logistics route to satisfy customer-specific PCF requirements. For instance, if a customer requires a PCF below 2.0 kg CO₂e per ton, the platform would recommend supplying the product from the second manufacturing site.

The final design, architecture, and functionality of the Enterprise Level will ultimately depend on the specific business objectives, organizational structure, and IT landscape of each company. Consequently, it is neither practical nor necessary to define all potential capabilities of this layer within the scope of this Concept Design. As with the previous platform levels, the objective of this document is to present the overall vision, guiding principles, and intended role of the Enterprise Level rather than prescribe its final implementation.

Model Development Process. The PCF Platform consists of the three hierarchical levels described in the previous sections. Development of a plant model or calculation of the PCF for a specific product is performed sequentially by constructing the production chain one process unit at a time.

The recommended starting point is the creation of the initial inventory of purchased feedstocks, utilities, and auxiliary materials required for the first process unit or the beginning of the production chain. Utilities may either be modeled within the platform or, where externally supplied, defined using supplier-specific data and corresponding

emission factors. Similarly, the initial inventory of auxiliary materials should be established before construction of the production model begins. This initial configuration is most conveniently performed within the Feed, Utilities, and Auxiliaries subsystems at the Plant Level.

Once the initial production elements have been defined, the first process unit can be added to the Plant BFD subsystem. The corresponding Process Unit Level is then used to assign feedstocks, utilities, and auxiliary materials to the unit, configure calculation parameters, and define the intermediate product streams generated by the process. The model is subsequently expanded by adding each downstream process unit in sequence. At every stage, the corresponding Process Unit Level is used to introduce new intermediate products, utilities, auxiliary materials, and process streams as required. Alternatively, these production elements may be created directly within the corresponding Feed, Products, Utilities, or Auxiliaries subsystems at the Plant Level, with automatic synchronization maintained between the Plant and Process Unit Levels.

Once the complete production chain has been modeled and all process streams and calculation parameters have been defined, the model may be extended to the Enterprise Level, where production facilities, logistics centers, transportation routes, and customer markets can be connected to establish the complete product supply chain. Implementation of the Enterprise Level is optional and should be determined by the organization's business requirements.

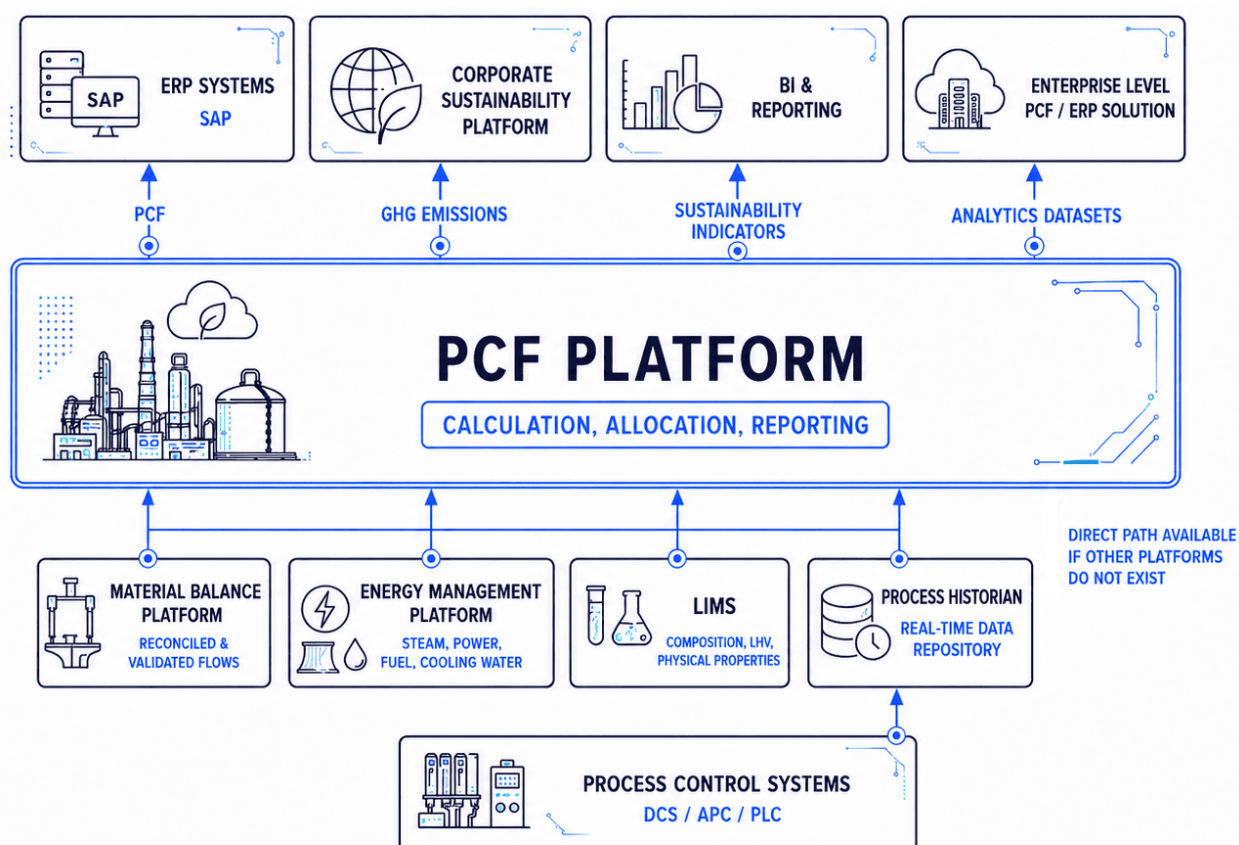
The workflow described above represents the manual model development approach, in which process data such as flow rates, compositions, utility consumption, emission factors, and other calculation parameters are entered and maintained manually by platform users. For organizations requiring a higher level of automation, the implementation process may instead begin with construction of the complete production model followed by integration with enterprise systems such as MES, process historians, and laboratory information management systems (LIMS). During this phase, process streams, equipment, and calculation objects are mapped to operational data tags, enabling automatic acquisition of the information required for PCF calculations.

Nevertheless, a phased implementation approach is generally recommended. The initial deployment should focus on a manually maintained platform that delivers the mandatory functionality and enables rapid realization of business value. Automated data integration can then be introduced in subsequent implementation phases as business requirements evolve and organizational maturity increases. Furthermore, for many organizations, the additional cost and implementation effort associated with full automation may not be justified, making a manually maintained PCF Platform an appropriate and economically attractive long-term solution.

Integration with MES, ERP, and Other Enterprise Systems. When the PCF Platform operates in an automated mode, it can be integrated with a wide range of enterprise information systems to enable automatic acquisition of operational and business data while providing calculated PCF information to downstream business applications.

For refining and petrochemical facilities, the digital architecture typically begins at the process control level, where the Distributed Control System (DCS) or other process control systems generate operational data. These data are transferred to the Process Historian, which serves as the central repository for collecting, storing, and distributing

real-time process information from the control systems as well as from other plant information systems.



The overall digital maturity of industrial companies varies considerably. Consequently, the extent of integration between the PCF Platform and other enterprise systems will depend on the existing IT landscape and the level of digitalization of the organization. The PCF Platform may receive information from several upstream systems depending on their availability and functionality. For example, material flow rates may be obtained from a Material Balance Platform, where process measurements have already been reconciled and validated. Such systems provide balanced values for feedstocks, intermediate products, finished products, and process losses, improving the quality and consistency of PCF calculations.

Similarly, information on steam, electricity, fuel gas, cooling water, and other utilities may be supplied by an Energy Management Platform, which processes operational data received from the Process Historian and calculates utility consumption and generation across the manufacturing site.

Product composition, lower heating values, physical properties, and other laboratory measurements may be obtained from the LIMS.

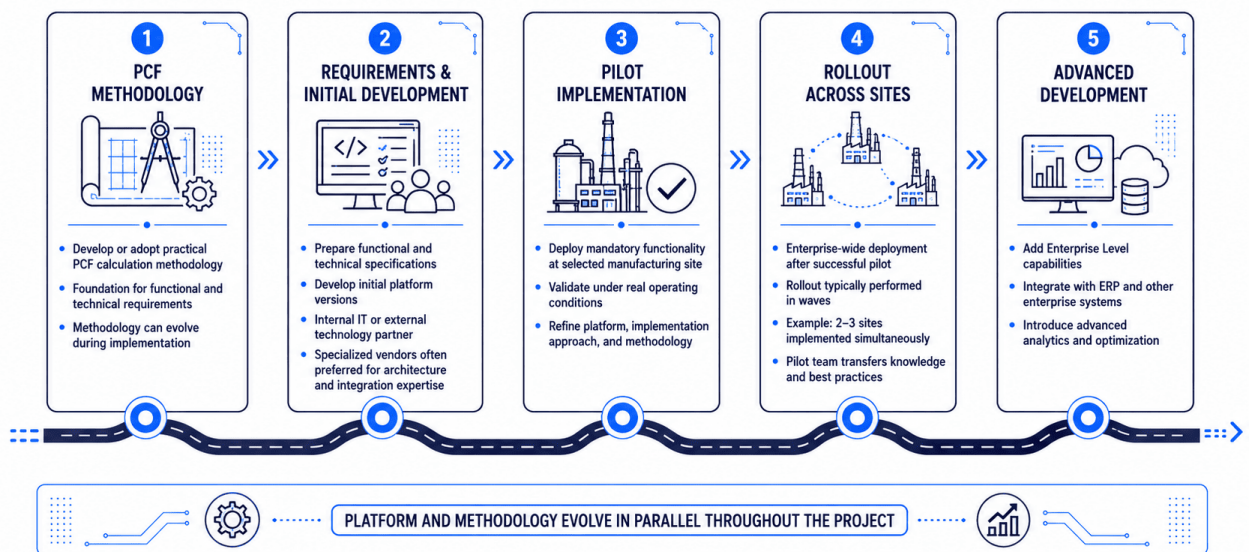
Where some of these intermediate systems are not available, the PCF Platform may alternatively retrieve the required operational data directly from the Process Historian.

In addition to receiving information, the PCF Platform also serves as a source of calculated sustainability information for higher-level enterprise systems. Calculated PCFs, GHG emissions, sustainability indicators, and analytical datasets may be transferred to ERP systems, such as SAP, Corporate Sustainability Platform, business intelligence solutions, or other enterprise reporting applications.

Depending on the selected architecture, the Enterprise Level of the PCF Platform may either be implemented as an integral component of the platform itself or as a separate ERP-level solution that receives calculation results from the Plant Level PCF Platform and combines them with logistics, commercial, procurement, and other enterprise data to support corporate decision-making.

It should be recognized that such a fully integrated architecture represents an advanced level of digital maturity and typically requires significant investment in enterprise integration, data governance, and IT infrastructure. Consequently, organizations may choose to implement the PCF Platform progressively, beginning with a manually maintained solution and expanding toward increasing levels of automation and system integration as business requirements evolve.

Project Implementation and Platform Deployment. Although industrial companies generally share similar organizational structures and business processes, they differ significantly in their operational practices, digital maturity, and IT landscapes. Consequently, the stakeholders, implementation approach, and project organization for deploying a PCF Platform may vary considerably from one company to another. Therefore, the objective of this section is not to prescribe a detailed implementation methodology, but rather to present a high-level view of the principal phases and milestones of a typical PCF Platform implementation project.



The first stage of the project is the development or adoption of a practical **PCF calculation methodology**, provided that such a methodology has not already been established within the organization. This methodology forms the foundation for defining the functional and technical requirements of the future platform. It is not necessary for the methodology to be fully mature before development begins, as it will naturally evolve throughout the implementation process in parallel with the platform itself.

The next stage involves the preparation of the **functional and technical specifications** and the development of the initial platform versions. The platform may be developed either by the organization's internal IT department or in partnership with an external software vendor specializing in industrial digital solutions. The latter approach is often preferable because specialized technology partners typically possess expertise in

enterprise software architecture, industrial system integration, and software development that may not exist within an internal IT organization. As discussed earlier, leading industrial companies, including BASF, have chosen to implement their PCF platforms in collaboration with technology partners.

Once a version containing the mandatory functionality has been developed, the project should proceed to a **pilot implementation** at a selected manufacturing site. The pilot phase provides an opportunity to validate the platform under real operating conditions while simultaneously refining the implementation methodology, improving the platform functionality, and enhancing the underlying PCF calculation methodology.

Following successful completion of the pilot project, the organization may begin **enterprise-wide deployment** of the solution. For large companies, rollout is typically performed in waves, for example by implementing the platform at two or three manufacturing sites simultaneously. The project manager responsible for the pilot implementation may subsequently lead the overall rollout program, while key specialists from the pilot team can participate in each individual deployment project, transferring knowledge, best practices, and implementation experience throughout the organization.

Once the platform has been successfully deployed across the manufacturing network, further development may include implementation of the Enterprise Level, integration with ERP systems and other enterprise information systems, and the introduction of advanced analytical and optimization capabilities described in previous sections of this Concept Design.

The final stage is optional and should be determined by the organization's business priorities, digital strategy, and expected business value. Depending on the company's objectives and level of digital maturity, some organizations may continue expanding the platform toward a fully integrated enterprise-wide decision-support system, while others may conclude development after successfully implementing the mandatory functionality and selected advanced capabilities.

Conclusion. This document presents a high-level Concept Design for an enterprise PCF IT Platform intended for the refining, petrochemical, and chemical industries. It describes the business need, conceptual architecture, methodological foundation, principal functional capabilities, implementation approach, and integration with existing enterprise information systems. The objective of this document is to establish a common vision for the future platform and provide a basis for further discussion among business, engineering, sustainability, and information technology stakeholders.

The proposed architecture and functionality should not be considered a final software specification. Instead, they represent one possible implementation approach based on current industry practices, available technologies, and anticipated business requirements. The final solution should be adapted to the specific objectives, organizational structure, digital maturity, and IT landscape of each company.

As Product Carbon Footprint methodologies, sustainability regulations, and enterprise digital capabilities continue to evolve, the platform should be designed with sufficient flexibility to accommodate future methodological, functional, and technological developments. The architecture proposed in this Concept Design provides a scalable foundation that enables organizations to begin with essential PCF calculation capabilities and progressively expand toward a fully integrated enterprise decision-support platform.

Ultimately, the success of a PCF Platform should be measured not only by its ability to calculate Product Carbon Footprints accurately, but also by its contribution to improving operational efficiency, supporting informed business decisions, accelerating product certification, strengthening customer confidence, and enhancing the organization's long-term sustainability and competitiveness.

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Abbreviation:

BFD	Block Flow Diagram
BI	Business Intelligence
CO₂	Carbon Dioxide
CO₂e	Carbon Dioxide Equivalent
DCS	Distributed Control System
ERP	Enterprise Resource Planning
GHG	Greenhouse Gas
IT	Information Technology
LCA	Life Cycle Assessment / Life Cycle Analysis
LIMS	Laboratory Information Management System
MES	Manufacturing Execution System
PCF	Product Carbon Footprint
PFD	Process Flow Diagram