CALIFORNIA ENERGY COMMISSION

ENERGY RESEARCH AND DEVELOPMENT DIVISION

FINAL PROJECT REPORT

Transforming the Techno-Economics of Decarbonization in California's Bespoke Industrial Sector with the Scalable Front-End Engineering AI — Galileo

August 2024 | CEC-500-2024-091

PREPARED BY:

Courtney McKeon
Skyven Technologies
Primary Authors

Michael Ferreira
Project Manager
California Energy Commission

Agreement Number: EPC-20-018

ACKNOWLEDGEMENTS

Special thanks to the California Energy Commission for its financial and leadership support throughout this project.

PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission, and distribution and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation, and bring ideas from the lab to the marketplace. The EPIC Program is funded by California utility customers under the auspices of the California Public Utilities Commission. The CEC and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas and Electric Company, and Southern California Edison Company—were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The CEC is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the Energy Research and Development Division at ERDD@energy.ca.gov.

ABSTRACT

Industrial decarbonization is pivotal to California's environmental targets, given the sector's substantial contribution of 21 percent to the state's greenhouse gas emissions. However, a significant challenge to achieving widespread adoption of efficiency measures is the unique nature of each industrial facility; this is termed the "snowflake problem." The problem demands tailored solutions and specialized expertise for scoping and front-end engineering (FEE) of decarbonization solutions. Companies lack the in-house proficiency for decarbonization FEE, forcing them to choose alternatives such as the cost and technical analysis time of hiring outside expertise or depending on vendor-driven point solutions, which often lead to unsuitable choices and inaction. To address this, Skyven Technologies developed Galileo, an artificially intelligent FEE system aimed at revolutionizing industrial decarbonization by reducing FEE costs by 90 percent, person-hours by 93 percent, and overall timeline from the first technical call to a completed decarbonization report by more than 99 percent. Galileo has been used to analyze more than 135 manufacturing facilities, identifying more than 4.3 million metric tons of potential greenhouse gas savings and more than $480 million of potential fuel cost savings. Future plans involve expanding Galileo's reach to commercial and residential sectors. This project signifies a significant advancement in accelerating decarbonization efforts across industrial, commercial, and residential domains, underscoring the importance of innovative solutions in meeting California's clean energy goals, as indicated in Assembly Bill 32 (Nunez, Chapter 488, Statutes of 2006), the Global Warming Solutions Act of 2006, and Senate Bill 32 (Pavley, Chapter 249, Statutes of 2016), the California Global Warming Solutions Act of 2016, which requires the California Air Resources Board to ensure that the state’s greenhouse gas emissions are reduced to 40 percent below the 1990 levels by 2030.

Keywords: artificial intelligence, front-end engineering, machine learning, Galileo

Please use the following citation for this report:

McKeon, Courtney. 2024. *Transforming the Techno-Economics of Decarbonization in California’s Bespoke Industrial Sector with the Scalable Front-End Engineering AI — Galileo*. California Energy Commission. Publication Number: CEC-500-2024-091.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Executive Summary

Background

Industrial decarbonization is integral to California's clean energy and climate objectives, as outlined in Assembly Bill 32 (Nunez, Chapter 488, Statutes of 2006) and Senate Bill 32 (Pavley, Chapter 249, Statutes of 2016). These bills require dramatic decreases in the volume of greenhouse gas emissions in the state, as the industrial sector contributes 21 percent of the state's total greenhouse gas emissions according to the California Air Resources Board. The current Scoping Plan under Assembly Bill 32 identifies various measures, like efficiency improvements, fuel switching, electrification, and renewable natural gas use, to mitigate industrial emissions, emphasizing the significance of enhancing industrial efficiency and competitiveness for California's economy. However, a significant challenge exists to achieving mass adoption of industrial efficiency measures in that each industrial facility is highly specific and unique in nature. This issue, dubbed the "snowflake problem," demands tailored decarbonization solutions and specialized knowledge for front-end engineering that involves pre-project scoping, conceptual design, and preliminary savings estimates. Companies lack the internal capability for front-end engineering, leaving them with inadequate options such as the cost and technical analysis time of hiring outside expertise or relying on vendor-offered point solutions, which can be a time-consuming process (taking up to four months to complete) and often leads to inaction or unsuitable choices. Consequently, many industrial firms continue with conventional practices, hindering progress towards decarbonization. Addressing this challenge is crucial, now more than ever, to advance California's clean energy and climate goals effectively and in a timely manner.

Project Purpose and Approach

The purpose of the project was to develop an artificial intelligence system for front-end engineering that learns from past and present industrial decarbonization projects and applies that learning to future projects to achieve transformative improvements in the techno-economics of industrial decarbonization. Skyven Technologies (Skyven) has named this artificial intelligence front-end engineering software system Galileo. The goal of the project was to develop an artificial intelligence system that is capable of automatically generating customer-worthy decarbonization solution reports, thereby reducing front-end engineering costs by a factor of 10 and the front-end engineering timeline by a factor of 4. The intended audience for the project includes industrial facilities across all sectors as well as commercial and residential facilities. The project approach involved building an artificial intelligence system using knowledge representation and reasoning and developing an expert user interface for building and refining models, a non-expert user interface for running an analysis, and machine learning (see Chapter 2, Project Approach, for details).

Key Results

With Galileo, the time it takes from the initial technical call with a customer to a completed decarbonization report is as low as 24 hours, compared to the four months that it would take to generate a similar report by hand; this far exceeds the factor of 4 timeline reduction goal. Additionally, Galileo costs 93 percent less and requires 90 percent fewer person-hours to produce a report than typical hand calculations. To date, Galileo has been used to scope projects at more than 135 manufacturing facilities in a variety of sectors, including chemicals (ethanol, sugar beets, plastics), pulp and paper (paper mill, consumer paper goods), and food and beverage (dairies, breweries, snack products), unlocking more than 4.3 million metric tons of potential greenhouse gas savings (the equivalent of the amount of emissions produced by 934,782 cars in a year) and more than $480 million in potential fuel cost savings for manufacturing facilities. As a validation test for the system, two pilot projects were analyzed using Galileo and the results were compared to best-in-class hand calculations. The annual savings for the decarbonization solutions provided by Galileo were within 0 percent and 13 percent of the hand-calculated results (see Table 4 and Table 5 in Chapter 3).

Knowledge Transfer and Next Steps

To disseminate information about Galileo and foster its adoption, Skyven devised a multi-faceted approach. First, the research team completed a comprehensive whitepaper detailing Galileo's functionality, data insights, and a comparison with traditional calculations for posting to Skyven’s website, along with a complementary blog post. Additionally, Skyven established a dedicated section on its website to highlight Galileo's features and outcomes. While this was initially used as a scoping tool for industrial clients interested in decarbonization solutions, Galileo's potential extends to diverse markets. Skyven envisions licensing Galileo to service providers, industrial assessment centers, and/or governmental bodies to streamline their decarbonization services. Furthermore, a two-sided marketplace model could be implemented in which Skyven offers Galileo runs for free to potential clients and charges vendors for referrals. Looking ahead, Skyven aims to expand Galileo's applicability to commercial and residential sectors, through advancements of the artificial intelligence and knowledge base. Ultimately, Skyven seeks to use Galileo for front-end scoping across industrial, commercial, and residential facilities, employing various deployment strategies, such as charging for runs, licensing, and vendor partnerships.

CHAPTER 1: Introduction

The purpose of the project was to develop an artificial intelligence (AI) software that will drastically reduce the costs, person-hours, and timeline of scoping front-end engineering of decarbonization solutions. The successful development of this software is important and timely in the context of California's clean energy and climate goals for several key reasons, as highlighted below.

Industrial decarbonization is critical to achieving California's goals of reducing greenhouse gas (GHG) emissions, as set forth in Assembly Bill 32 (Nunez, Chapter 488, Statutes of 2006) and Senate Bill 32 (Pavley, Chapter 249, Statutes of 2016). According to the California Air Resources Board's current Scoping Plan under Assembly Bill 32, the industrial sector accounts for 21 percent of California's total GHG emissions. The plan cites a combination of efficiency, fuel switching, electrification, and renewable natural gas as potential measures to reduce industrial emissions. The plan further identifies the importance of enhancements to industrial efficiency and competitiveness to California's economy.
A key barrier to achieving the state's statutory energy goals in the industrial sector is the bespoke nature of industrial energy efficiency and fuel-switching projects. The industrial sector displays exceptional variability and uniqueness from facility to facility — the so-called "snowflake problem." Like a snowflake, every industrial facility is unique. Even two facilities owned by the same company, manufacturing the same product at similar throughput, can be substantially different.

The snowflake problem demands not only bespoke solutions but also the sophisticated knowledge and expertise to conceptualize optimal decarbonization solutions for a facility's unique operations. This conceptual design, feasibility analysis, benefits analysis, and budgetary costing constitute "front-end engineering" (FEE). Industrial manufacturers do not have the expertise to perform front-end engineering and to conceptualize decarbonization solutions that meet challenging financial and operational requirements.

Given the lack of internal expertise, companies today have two options, both of which are insufficient. Option 1 is to hire an expert energy consultant. This option is insufficient because hiring an expert consultant costs $25,000 to $100,000 per facility, involves three to six months of analysis, and produces a report which the facility often does not have the time or resources act on. Option 2 is to select a point solution presented by a vendor. Equipment vendors commonly approach industrial facilities to sell point solutions like solar photovoltaics or combined heat and power, and companies struggle unsuccessfully to judge the quality, fit, and risk of the proposal. The result is that companies in the industrial sector carry on with business as usual without decarbonizing.

To overcome the snowflake problem, Skyven Technologies (Skyven) developed Galileo, an artificial intelligence front-end engineering software system (FEE AI) solution that automates the in-depth technical analysis and front-end engineering of the customer facility, cutting costs by a factor greater than 10 (from $25,000-plus to $1,800 per facility). The cost reduction stems from a 10-time reduction in total engineering hours, from 120 hours to 12 hours, and a reduction in the overall timeline, from the first technical conversation to a decarbonization report, of from four months to one day. Galileo achieved these results by learning from expert users and from prior project data. It applied this learning to guide non-expert users through the analysis, asking for appropriate data at the right time. Galileo automatically evaluates dozens of potential decarbonization measures and chooses the best fit for the facility, instead of trying to fit a suboptimal vendor-provided point solution inappropriately. It generates a customer-worthy engineering report justifying the selection and presenting costs, risks, and expected energy and carbon savings, ultimately making the process of decarbonizing easy, impactful, and lucrative.

With Galileo's rapid, low-cost results, the barrier to explore decarbonization in plants would fade, enabling rapid and widespread adoption of decarbonization projects across California's industrial sector. Since the industrial sector currently accounts for 21 percent of GHG in California, this solution is a multiplicative game changer to help dramatically reduce GHG emissions across the entire state.

CHAPTER 2: Project Approach

Skyven's overall approach to building the FEE AI, Galileo, was to define ontologies for each of the multitude of potential decarbonization measures, the associated plant processes, and the associated types of industrial plants. Rules were then defined that governed relationships with the ontology, and procedures were defined in the expert user interface (UI) for building and refining the analytical models for the calculation or estimation of properties related to a decarbonization solution. These calculations were dependent on values the customer provided in the non-expert/customer UI for running an analysis. To connect the non-expert/customer UI for running an analysis with the expert UI for building and refining the analytical models, the research team developed a knowledge representation and reasoning (KRR) engine to connect the two platforms, perform calculations, and use logic to determine the questions asked during an analysis. The following paragraphs describe the KRR, expert UI, and non-expert UI in more detail.

Knowledge Representation and Reasoning Engine

The KRR engine is the background engine that connects all of the Galileo components to perform analysis and produce results. It gets rules and other components, such as plant type, equipment, question formats, and units, from the Galileo expert UI for refining the analytical models and synchronizes them with the customers inputs from the non-expert/customer UI for running an analysis. The engine determines what information is needed for an analysis and presents the next questions in the non-expert/customer UI to generate the answers. The questions asked in the non-expert/customer UI for running an analysis are thus dynamic and customized based on user inputs (see the User Interface for Running an Analysis section in this chapter for details). The KRR engine then evaluates the customer answers and repeats the process of asking all of the necessary and relevant questions until it can generate solutions and related metrics. The coding language used was python (with a Flask framework and GraphQL), and a Neo4j graph database was used as the database management system.

Every time the Skyven team analyzed a new type of plant, process, or decarbonization solution, the solution was added to the knowledge base ontology, with appropriate relationships, rules, and procedures specified. However, without a dedicated UI for ontology and model building, this would have required knowledge of logic programming and KRR. Therefore, an expert UI for building and refining the analytical models was designed to meet this requirement.

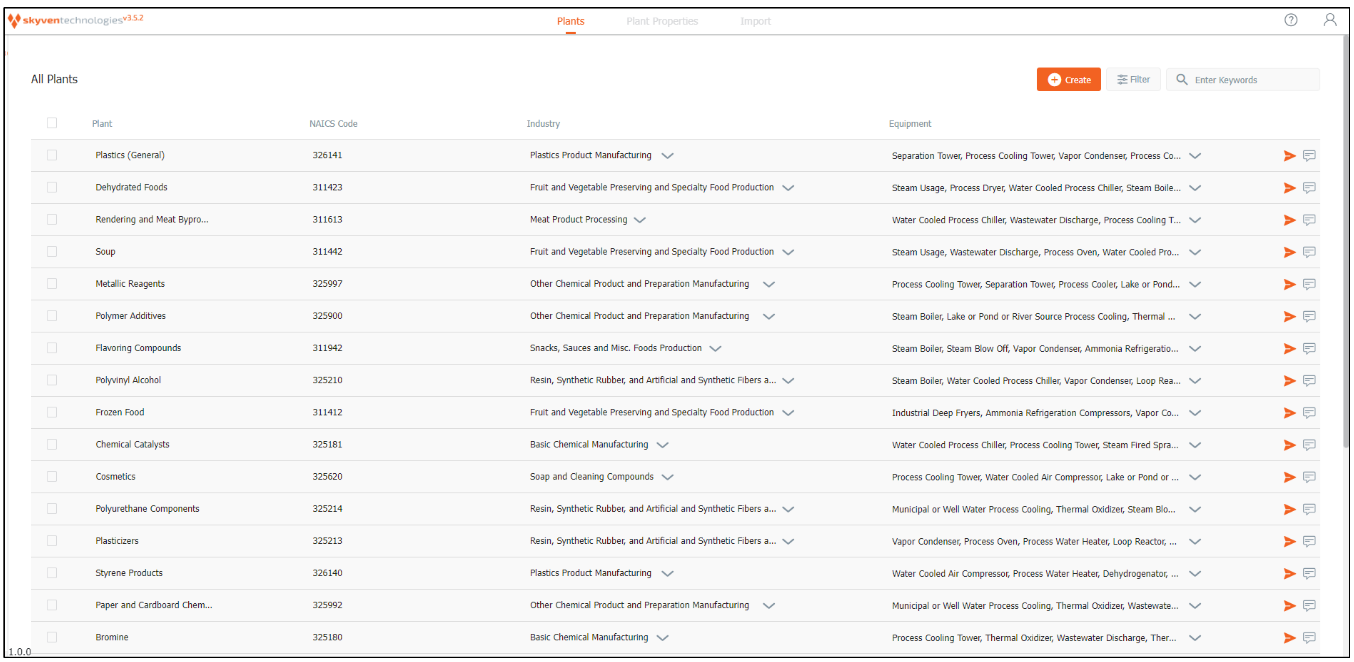
User Interface for Building/Refining Analytical Models

In the UI for building and refining the analytical models, Skyven's engineering team generated generic digital twin models of a wide variety of manufacturing processes and decarbonization solutions and added these models into the software. The models were used as the basis of Galileo's KRR engine. An expert user (defined as a user who is capable of defining the relationships between the equipment and the decarbonization solution and who has intimate knowledge of the user for building and refining the analytical models) specified the properties for each model, including the qualitative or quantitative relationship between the properties. New models were frequently developed and added to Galileo as Skyven worked with manufacturers in new industrial sectors.

This UI consists of several different user windows, including: Plant & Properties, Equipment & Properties, Units, Constants, Components, and Solutions & Properties.

In the Plant & Properties UI window, the expert energy user can input a plant type and its North American Industry Classification System code and link that plant to an industry type and associated equipment. This window is also the location where the expert energy user can define certain plant-level property questions that are asked during the analysis, such as the plant address, operating hours, and electric and fuel consumptions and costs. Figure 1 shows a snapshot of the Plant & Properties UI window.

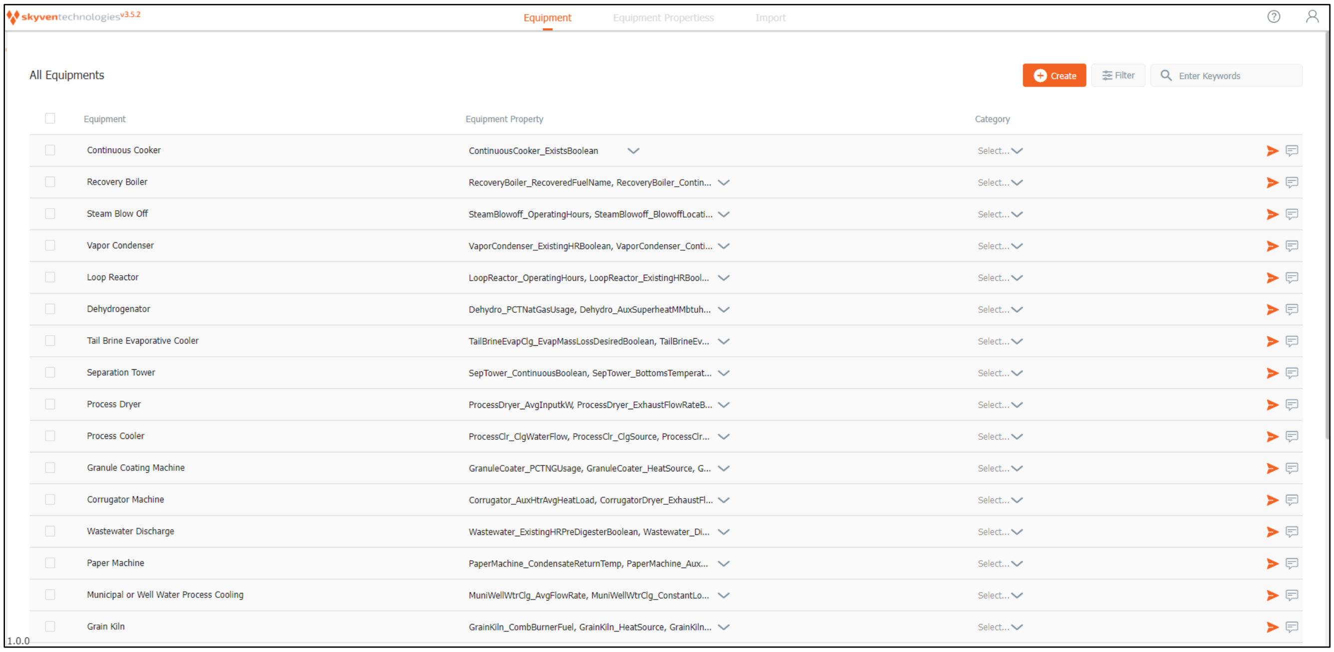
Figure 1: Plant & Properties Expert UI Window



Source: Skyven Technologies, 2024

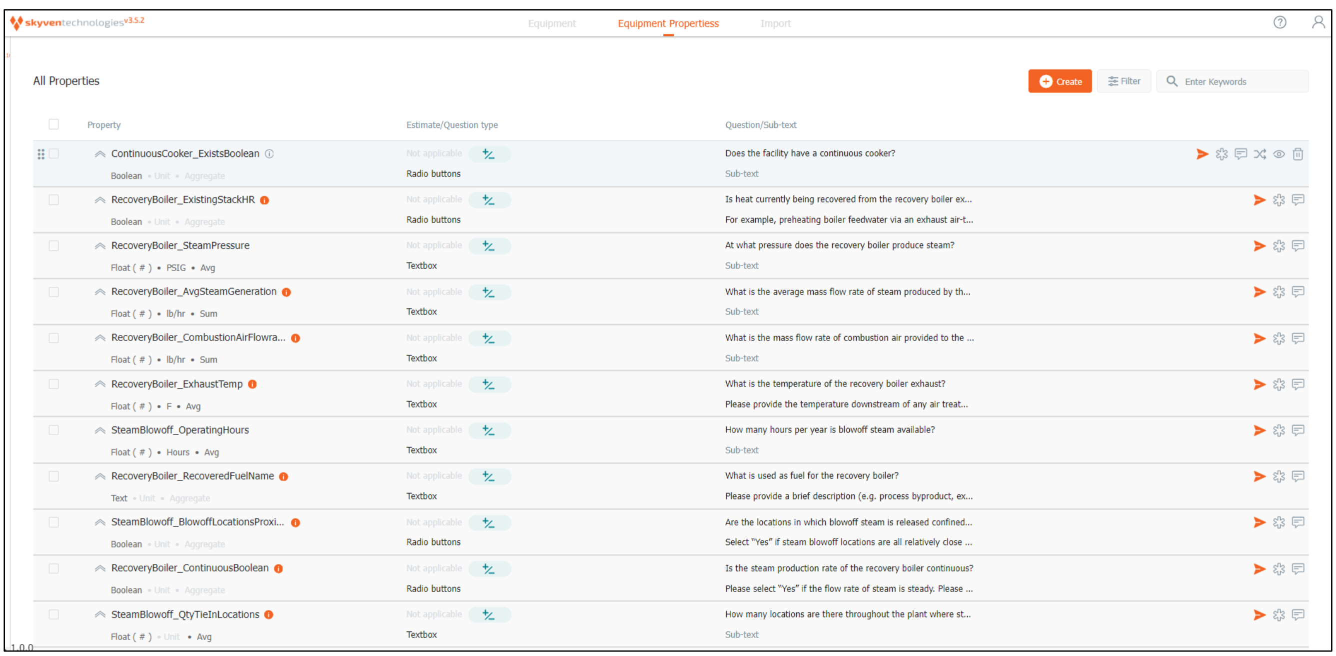
In the Equipment & Properties UI window, the expert energy user can define new pieces of equipment and link that equipment to its associated properties. The expert user can also define the equipment property questions that are asked during the analysis such as process temperatures, flow rates, and operating hours of the equipment. Figure 2 and Figure 3 show snapshots of the Equipment & Properties UI window.

Figure 2: Equipment & Properties Expert UI Window #1



Source: Skyven Technologies, 2024

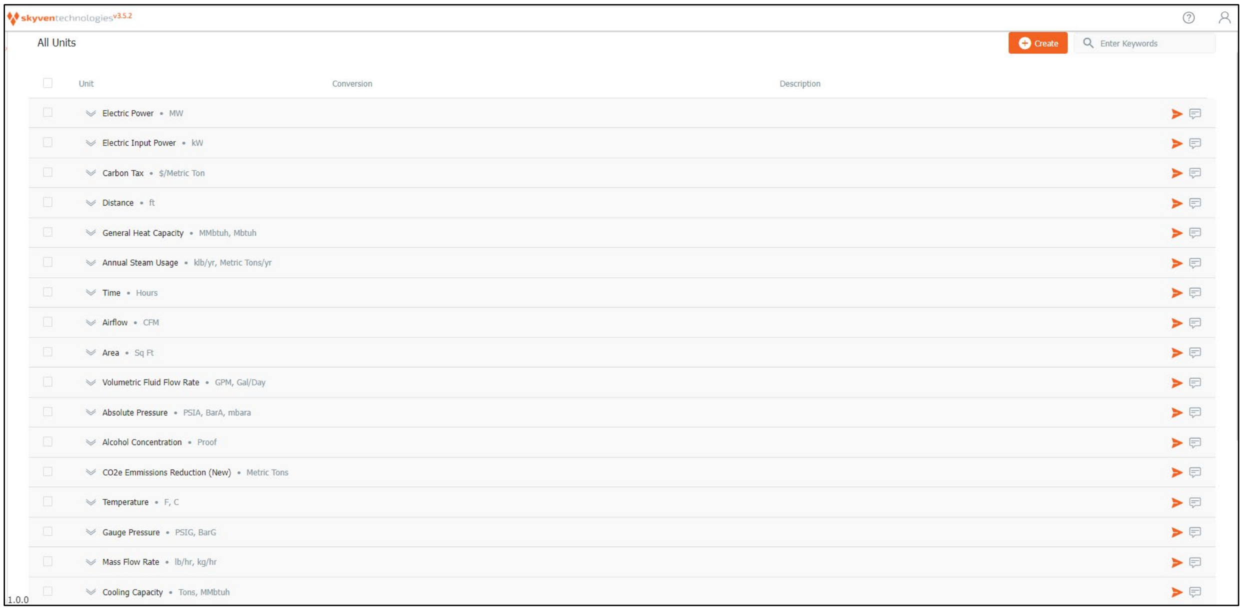
Figure 3: Equipment & Properties Expert UI Window #2



Source: Skyven Technologies, 2024

In the Units UI window, the expert user can define base units for measurements. Additionally, the expert user can define the conversion factors for those measurements to be converted into other commonly used units for ease during the analysis. This logic programming allows for a customer/non-expert user to input a temperature value during the analysis in Celsius and the AI converts this to the base unit of Fahrenheit (as defined by the expert user in the conversion factor section of the Units UI window) before using the value in the specified equations. This allows for all procedures and equations to be standardized regardless of the units the customer/non-expert user provides. Figure 4 shows a snapshot of the Units UI window.

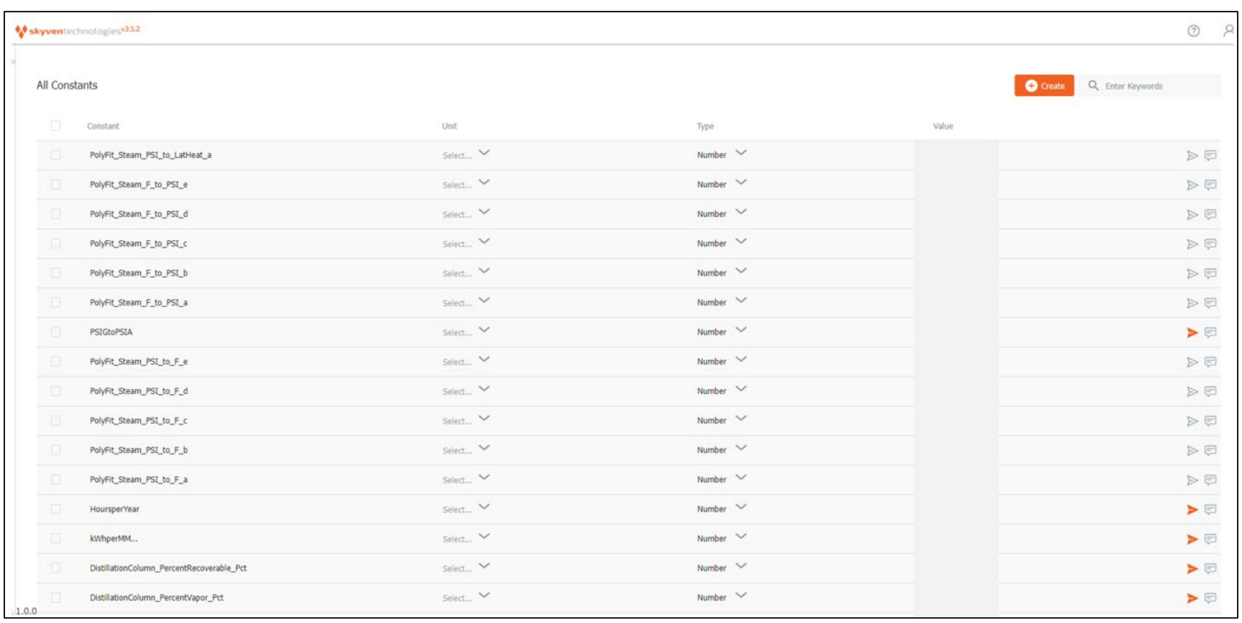
Figure 4: Units Expert UI Window



Source: Skyven Technologies, 2024

In the Constants UI window, the expert user can define constants that are used in the procedures and equations. These constants include, but are not limited to, conversion factors, polynomial fit numbers, and efficiency assumptions. Figure 5 shows a snapshot of the Constants UI window.

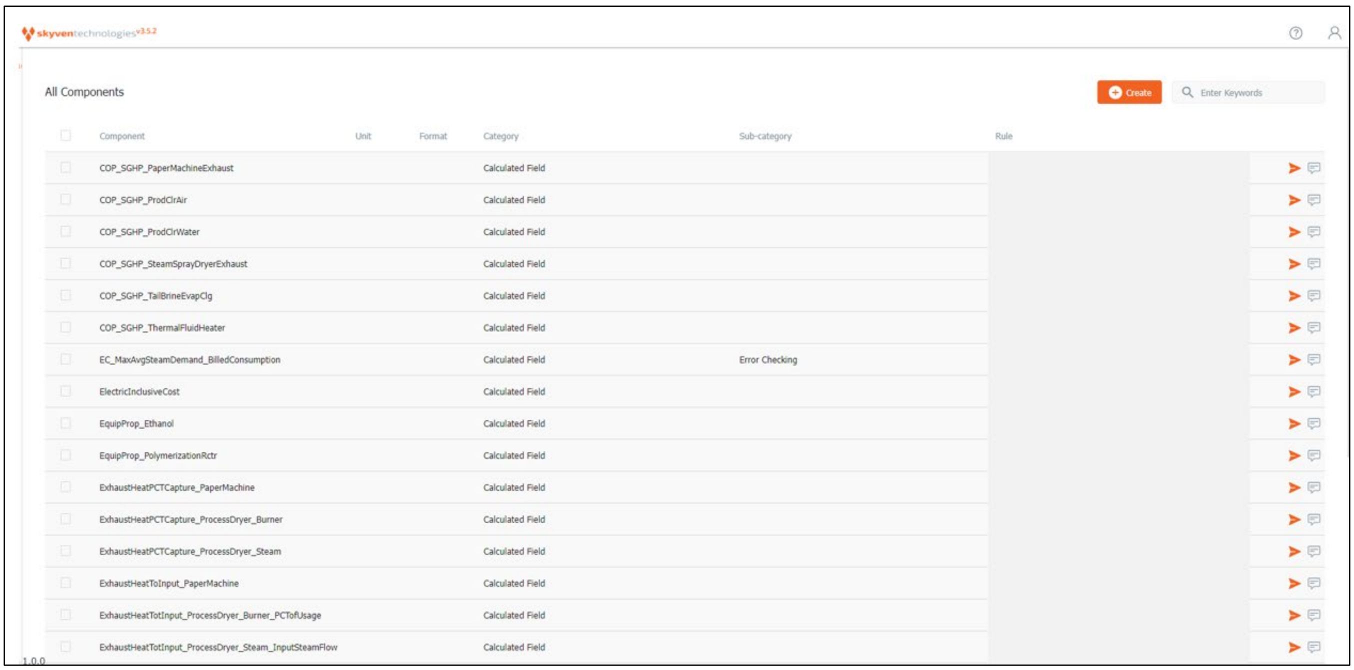
Figure 5: Constants Expert UI Window



Source: Skyven Technologies, 2024

In the Components UI window, the expert user can create interim procedures and equations that will ultimately be used in the final equations that the expert user creates in the Solutions & Properties UI window. The intent of the Components window is to help compartmentalize certain portions of the equations so that it's easier to edit equations as new information is learned over time and it's easier to view and understand the equations in the Solutions & Properties window. Examples of equations that were added to the Components window include calculations of heat available in a specific heat source/piece of equipment, heat exchanger approach temperatures, and flash vessel temperatures. Figure 6 shows a snapshot of the Components UI window.

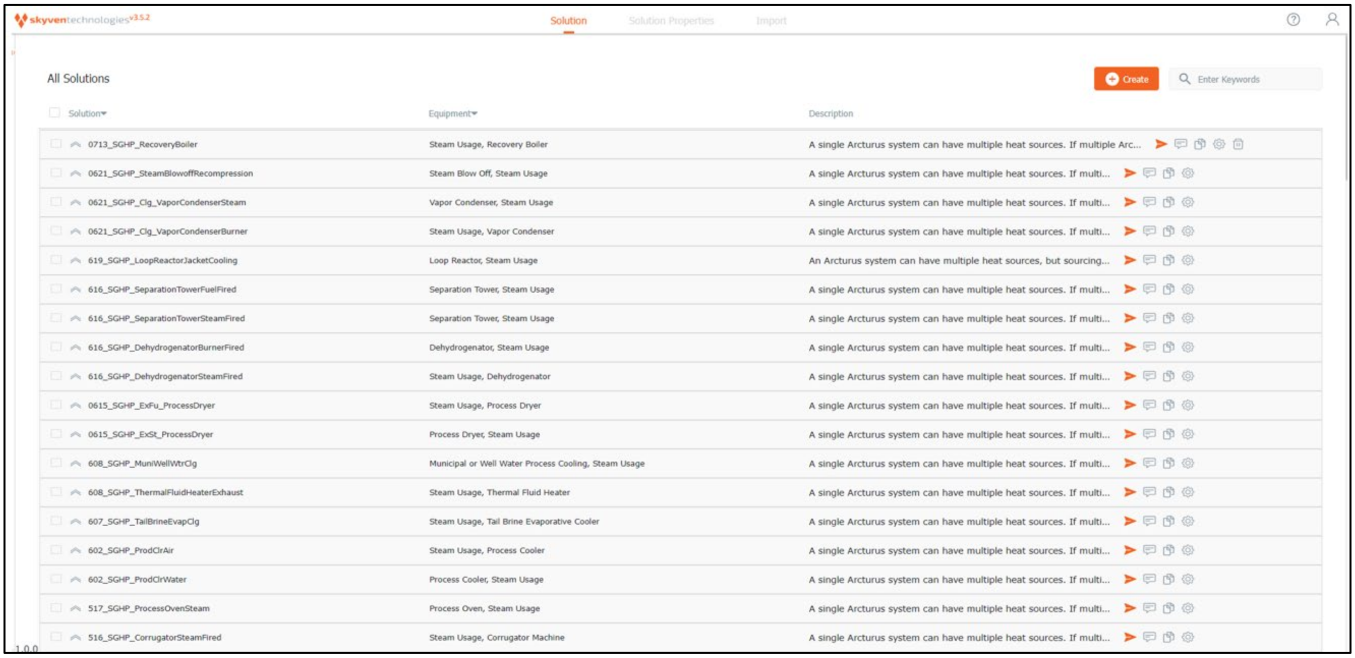
Figure 6: Components Expert UI Window



Source: Skyven Technologies, 2024

In the Solutions & Properties UI window, the expert user can create specific solutions for decarbonization, such as hot water heat pumps, steam generating heat pumps, condensing economizers, and steam traps. Within these solutions, the expert user can create rules using plant properties, equipment properties, constants, and components to calculate technical feasibilities and environmental and economic metrics for a decarbonization solution. Solutions are specifically linked to the equipment & properties window so that solutions show up based on equipment that the customer selects during the run (see the User Interface for Running an Analysis section in this chapter for more details). Technical feasibilities include compatibility checks, such as determining if a heat source is large enough for a certain decarbonization technology or determining if the facility's steam pressure and usage are compatible with a decarbonization solution that produces steam. Environmental and economic metrics may include, but are not limited to, calculations and rules for determining the Scope 1 and Scope 2 emissions, annual fuel usage reduction, annual fuel cost reduction, and, in certain instances, the steam production capacity of the decarbonization technology. In this UI window, the expert user can also identify engineering considerations and other benefits associated with the decarbonization solution. Engineering considerations may include, but are not limited to, checks for consistency of the heat source, discussions of multiple heat sources, footprint and placement considerations for the technology, and refrigerant considerations. Other benefits may include, but are not limited to, electrification benefits, redundancy with existing equipment, and grant funding eligibility. Figure 7 shows a snapshot of the Solutions & Properties UI window.

Figure 7: Solutions & Properties Expert UI Window



Source: Skyven Technologies, 2024

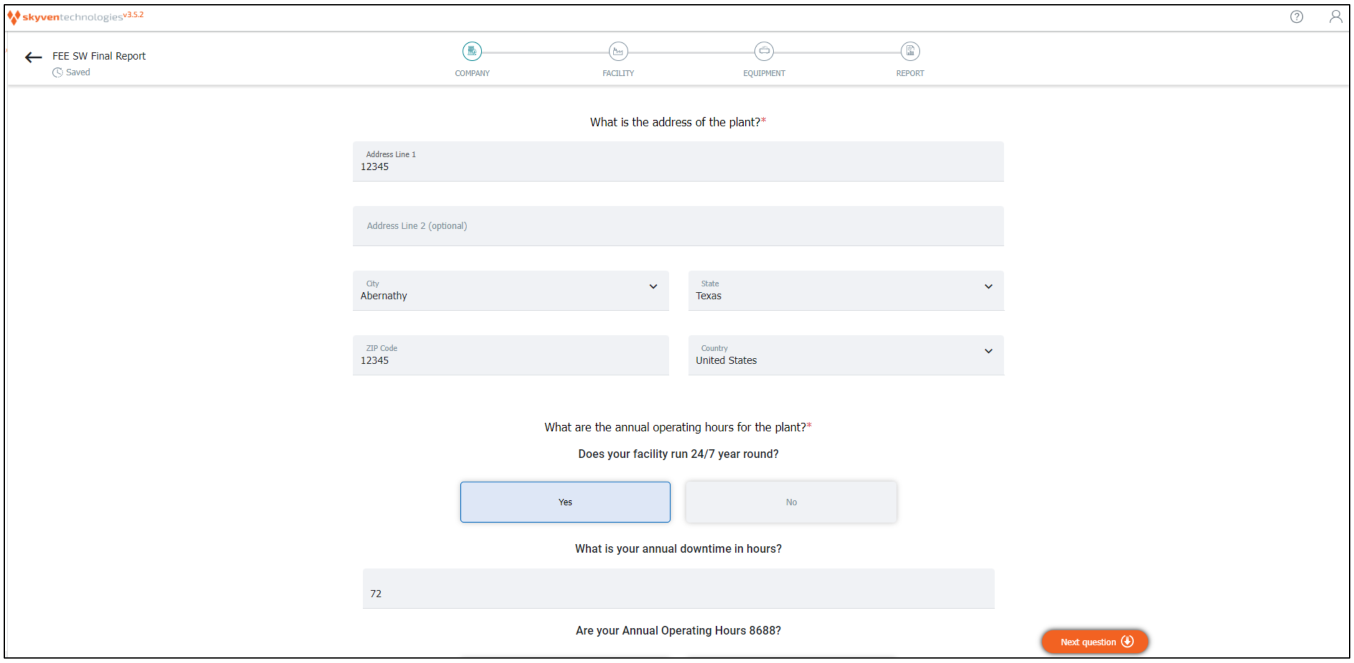
Skyven designed the Plant & Properties, Equipment & Properties, Units, Constants, Components, and Solutions & Properties windows so that an expert user can populate the knowledge base of the AI without needing to understand logic programming or KRR.

User Interface for Running an Analysis

In addition to the UI designed for an expert user to populate the knowledge base, Skyven also developed a UI for running a Galileo analysis and visualizing the decarbonization solution results. To assess potential decarbonization solutions, Galileo asks industrial users questions based on facility metrics. To generate these questions, Galileo's KRR engine translates the models described in the previous section into a question tree, which uses automated reasoning to gather all of the required data for plant analysis. The answers to these questions are used to automatically build a custom model of the facility. This interface was designed to be completed by a non-expert user with the assistance of a Skyven employee. The four different windows in this UI include Company, Facility, Equipment, and Report. The Report window is discussed in further detail in the Results section of Chapter 3.

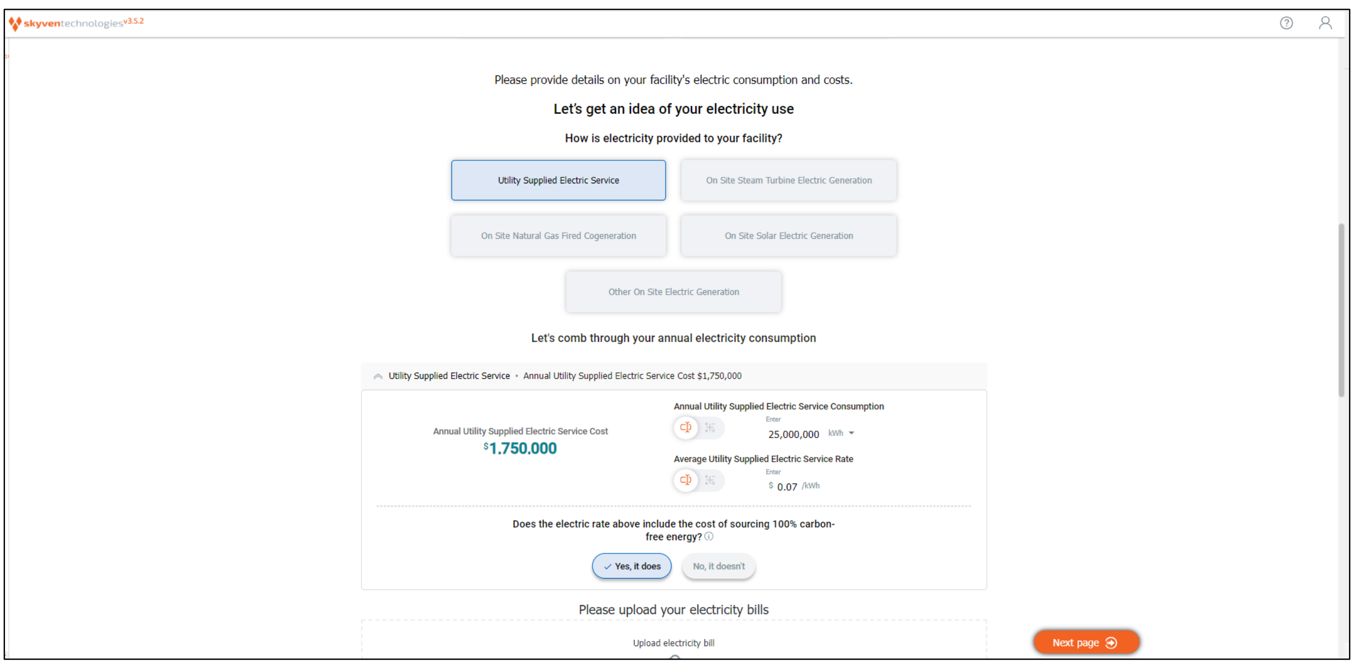
In the Company window, the customer is asked to input information regarding the facility as a whole. This includes plant address, plant operating hours, total annual electric usage and cost, total annual fuel usage and cost, whether the facility is subject to a carbon tax or not, and what percentage of facility steam (if any) is produced by on-site combined heat and power. Figure 8, Figure 9, and Figure 10 show snapshots of the Company UI window.

Figure 8: Company Non-expert UI Window #1



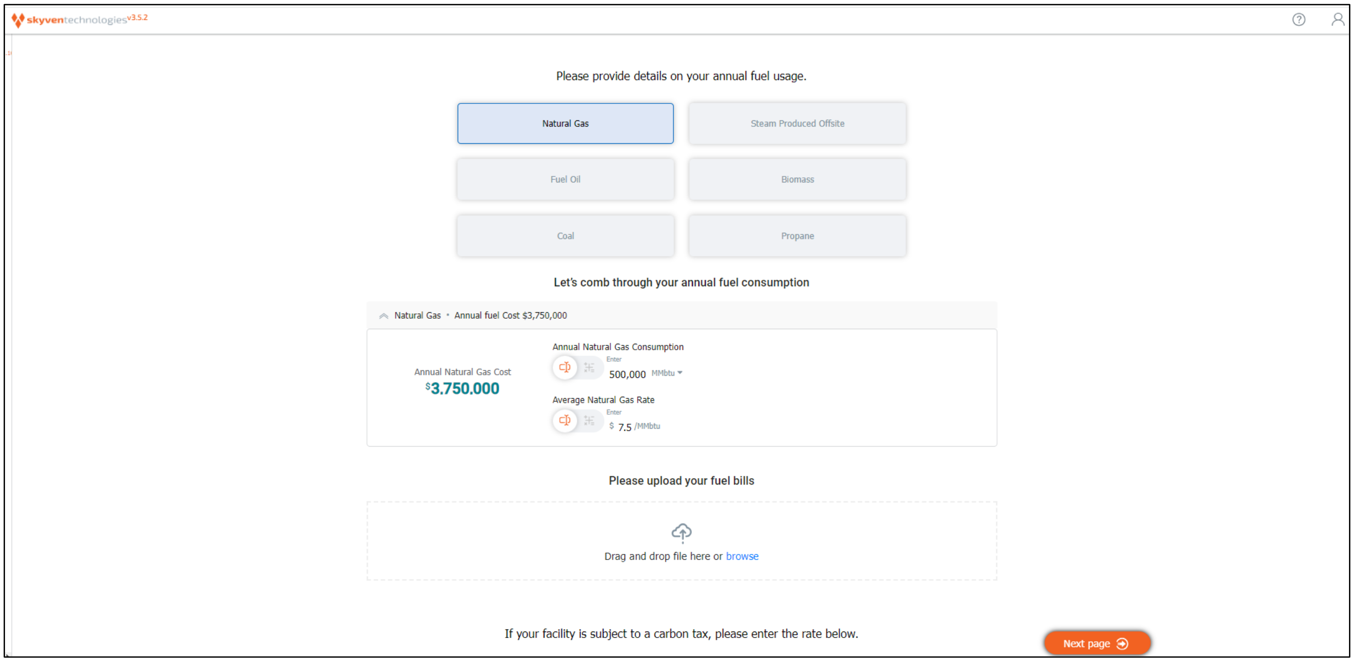
Source: Skyven Technologies, 2024

Figure 9: Company Non-expert UI Window #2



Source: Skyven Technologies, 2024

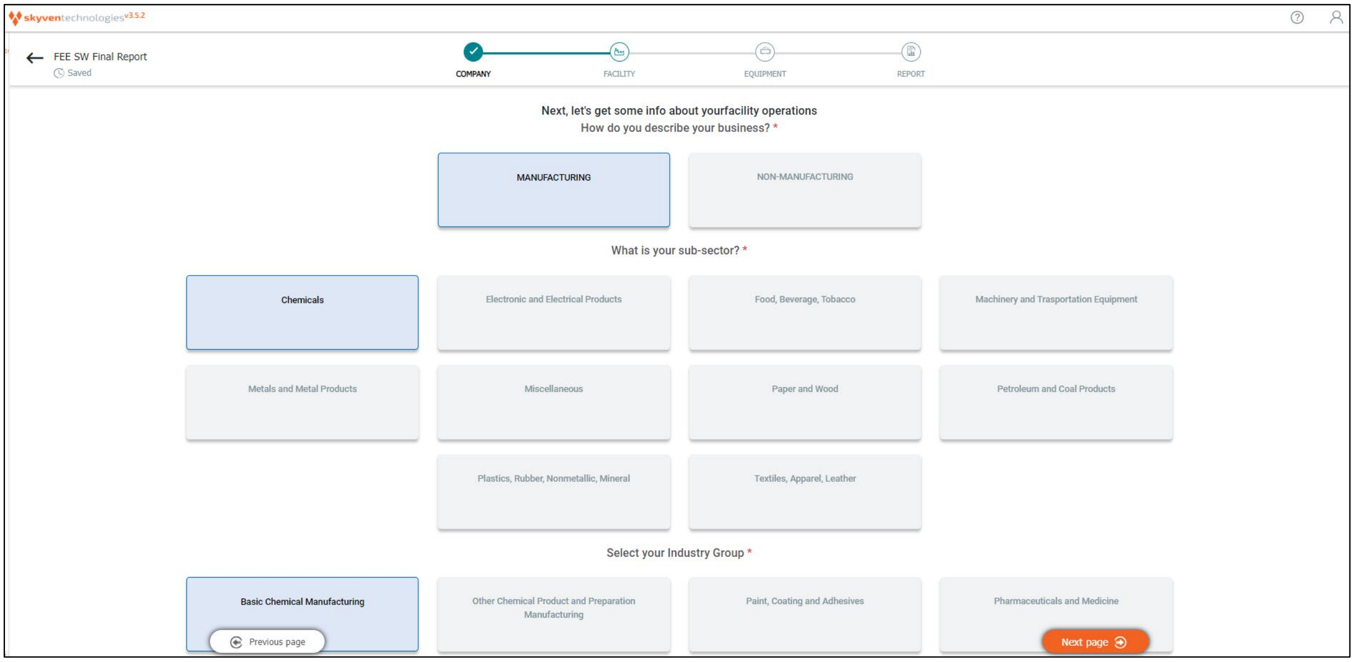
Figure 10: Company Non-expert UI Window #3



Source: Skyven Technologies, 2024

In the Facility window, the customer is asked to select the type of facility, starting with whether or not the business would be described as manufacturing or non-manufacturing. The customer is then asked to select the subsector that best describes the business. Some examples of non-manufacturing business subsectors are district heating, hospitals, and office buildings; some examples of manufacturing business subsectors are chemicals, food and beverage, paper and wood, and plastics. After selecting the subsector, the customer is asked to select the industry group that best describes the business. Some examples of industry groups associated with the subsector for chemicals are basic chemical manufacturing, paint and adhesives, resin and fibers, and pharmaceuticals and medicine. Figure 11 shows a snapshot of the Facility UI window.

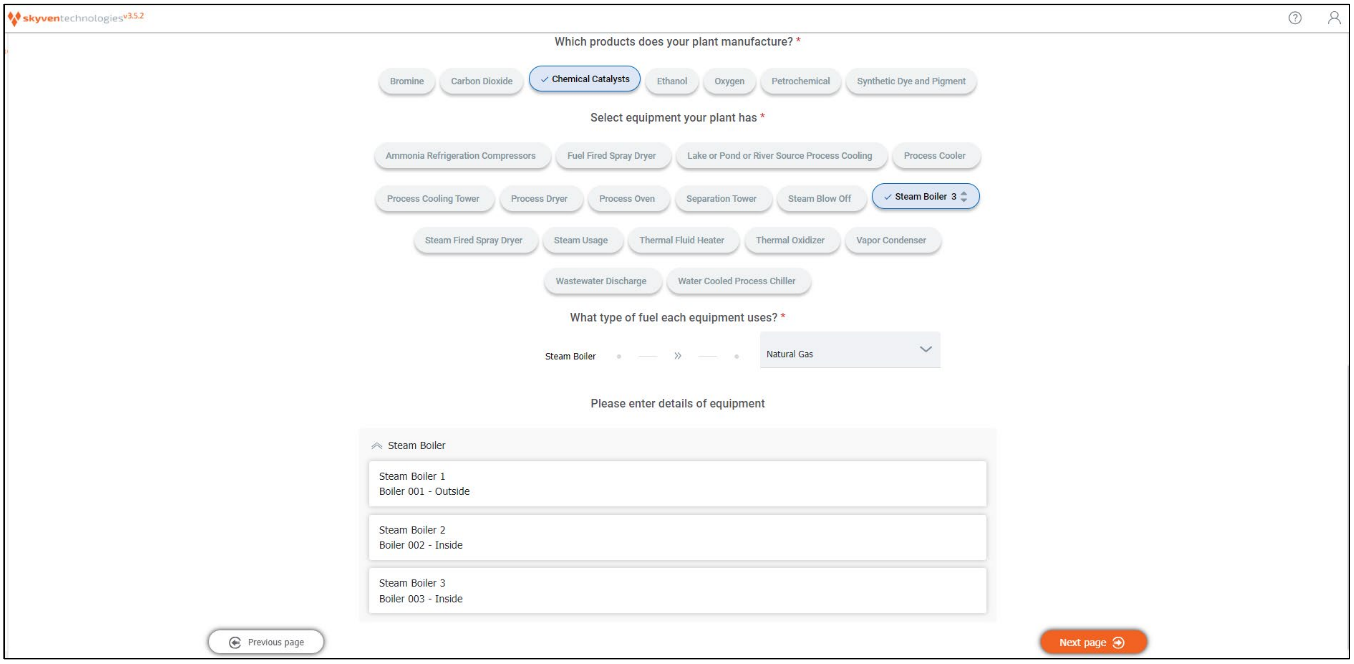
Figure 11: Facility Non-expert UI Window #1



Source: Skyven Technologies, 2024

After selecting the industry group, the customer is asked to select the products that the plant manufactures. This can be a multiple-selection answer if a facility manufactures more than one product. Examples of products associated with the industry group for basic chemical manufacturing are chemical catalysts, ethanol, petrochemicals, and synthetic dye and pigment. After selecting the products, the customer is asked to select the plant equipment. The equipment that shows up by plant type is set by the expert user in the Plant & Properties expert UI window. Examples of equipment associated with the production of chemical catalysts are ammonia refrigeration compressors, fuel-fired and steam-fired spray dryers, process ovens, steam boilers, and vapor condensers. A feature allows for the selection of multiples. For example, if the facility has three steam boilers on site, the customer can select a quantity of (3) when selecting the steam boiler equipment. After selecting all of the equipment associated with the facility, the customer is asked to select which type of fuel each piece of equipment uses. This selection is linked to the electric and fuel inputs that the customer selects in the Company window. For example, if the customer selects natural gas for the fuel type and utility-supplied electric service for the electricity type, the customer would then have to choose between natural gas and utility-supplied electric service as the "type of fuel" each piece of equipment uses. Finally, this window has a section for the customer to add descriptions of each piece of equipment. For example, if there are three steam boilers at the site, the customer can specify the name or location of the boiler in this section for ease of communication and future reference. Figure 12 shows a snapshot of the Facility UI window.

Figure 12: Facility Non-expert UI Window #2

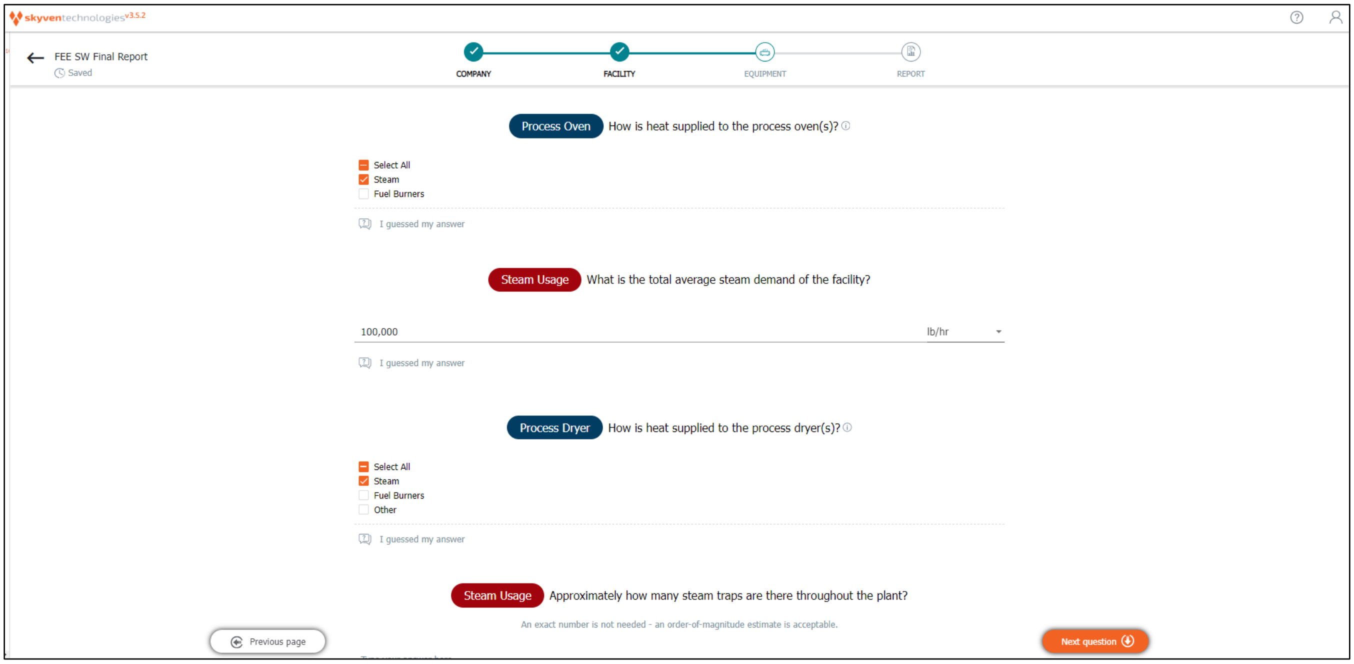


Source: Skyven Technologies, 2024

In the Equipment window, the Galileo software asks questions related to the equipment selected on the Facility window. These questions are designed to quantify the amount of energy going to the equipment and the amount of heat that could possibly be recovered. The order of the questions is determined by the KRR engine and logic programming, as questions are asked in the order of how often they are referenced or used in the knowledge base calculations. For example, the quantity of steam the facility uses is an important metric in determining the quantity of savings that a particular decarbonization solution can provide. Therefore, this question often appears as one of the first few questions when a customer selects steam boiler and steam usage as equipment. The questions are linked to the equipment type and are set by the expert user in the Equipment & Properties expert UI window.

Using the information entered by the user in the Company, Facility, and Equipment windows, Galileo carries out conceptual engineering calculations on the configured digital twin models developed in the knowledge base by the expert user. Based on these calculations, Galileo uses automated reasoning to quickly generate a user-friendly report with two to five decarbonization solutions; these solutions quantify the energy savings and environmental benefits, the engineering considerations, the technical feasibilities, and other benefits. See the Results section of Chapter 3 for more information on the report. Figure 13 shows a snapshot of the Equipment UI window.

Figure 13: Equipment Non-expert UI Window



Source: Skyven Technologies, 2024

Machine Learning

The machine learning (ML) model was coded in python and uses a gradient boosting algorithm that builds a strong predictive model by combining weaker models (specifically, decision trees) to provide highly accurate predictions. The ML model was designed to estimate the full material cost of equipment, which would allow for further economic analysis within Galileo.

The first step in building the ML model involved collection of cost data for equipment. The raw data were then cleaned, formatted, and organized for the ML model. This involved acquiring the dataset in CSV, XLSX, or HTML format, importing essential libraries (such as NumPy, pandas, and matplotlib), handling missing values in the dataset, encoding categorical data, and scaling features to ensure uniformity. Finally, XGBoost (extreme gradient boosting) was used for the model building and training phase. This involved developing an XGBoost regression model, evaluating the model through K-fold cross validation to assess mean absolute error and mean absolute percentage error, choosing the best-fit model, and refining and improving the model as necessary.

Currently, there were limited data available to train the model (see the Results section of Chapter 3 for details). However, once there were sufficient data available, the ML model will be further refined and thus more capable of accurately predicting implementation costs based on historical data.

Building Up Software Features

New features are added to the KRR engine and updated on the UIs as they are identified by Skyven's expert users. Skyven is continually developing software to provide both the expert and the non-expert user with the most technically accurate and user-friendly experience possible, and it is constantly looking for ways to improve Galileo. Some of these improvements include: adding the Components UI window so that solutions can be more easily followed by the expert user, adding the Units UI window so that the customer can enter values in whatever units are available, adding an information icon on the equipment questions so that the expert user can add additional clarifying information for the customer to view when answering questions, and adding a feature to export the Galileo report to an Excel workbook.

Next Steps

Galileo offers significant value to customers by performing rapid initial analyses of their existing equipment and by presenting a range of decarbonization options and preliminary estimates of potential savings. If one of the decarbonization options presented by Galileo is attractive to the customer, Skyven and the customer will work to establish an agreement through a contract that will enable detailed engineering and front-end engineering level two analyses to be completed.

Once detailed engineering proves the economic and technical feasibility of a decarbonization solution, the project can be executed and operated under Skyven's Energy-as-a-Service model. Under this model, the customer pays no upfront capital costs for the equipment (which is funded through investments and third-party financing); instead, the customer pays only for the verified savings provided by the equipment, as measured by the installed metering equipment.

CHAPTER 3: Results

To date, Skyven has run Galileo with more than 135 different facilities, unlocking more than 4.3 million metric tons of potential GHG savings and more than $480 million in potential fuel cost savings for manufacturing facilities. Galileo is currently capable of analyzing 76 different industrial facility types, 67 different pieces of equipment, and 60 different decarbonization solutions making for more than 4,000 different combinations.

Reductions in Time Frame, Person-Hours, and Costs

The time it takes from the initial technical call with a customer to a completed decarbonization report using Galileo is as low as 24 hours. Compared to the four months that it would take to generate a similar report by hand, Galileo has well exceeded the goal of decreasing the timeline by a factor of 4. The four-month metric came from the timeline it took to complete the analysis for Pilot Plant A. Table 1 summarizes the difference.

Table 1: Timeline — Galileo Versus Manual Calculations

	Manual Calculations	Galileo	Percent Decrease
Timeline (hours)	2,904	24	99.2%

Source: Skyven Technologies, 2024

A total of 12 hours of Skyven employee time is required to generate a decarbonization report. Compared to the 120 hours that it would take to generate a similar report by hand, Galileo has met the goal of decreasing the person-hours required to perform the analysis by a factor of 10. The 120-hour metric came from analysis of the time it took to perform manual calculations for Pilot Plant A. Table 2 illustrates the difference between Galileo and the manual calculations.

The following is a breakdown of the total person-hours required for a Galileo run:

- 1 employee x 1 hour (introductory call/prep meeting with client — schedule Galileo run)
- 1 employee x 4 hours (Galileo prep work)
- 3 employees x 2 hours (Galileo run)
- 1 employee x 1 hour (Galileo report review/finalization)

Table 2: Person-Hours — Galileo Versus Manual Calculations

	Manual Calculations	Galileo	Percent Decrease
Timeline (hours)	120	12	90%

Source: Skyven Technologies, 2024

At an average of $150 per hour per employee, the current total of scoping and conceptualizing projects using Galileo is $1,800. Compared to the $25,000 that it would take to generate a similar report, Galileo has exceeded the goal of decreasing the costs to perform the analysis by a factor of 10, as shown in Table 3. These figures came from an analysis of the costs required to perform calculations for Pilot Plant A, including person-hours and overhead costs.

Table 3: Cost — Galileo Versus Manual Calculations

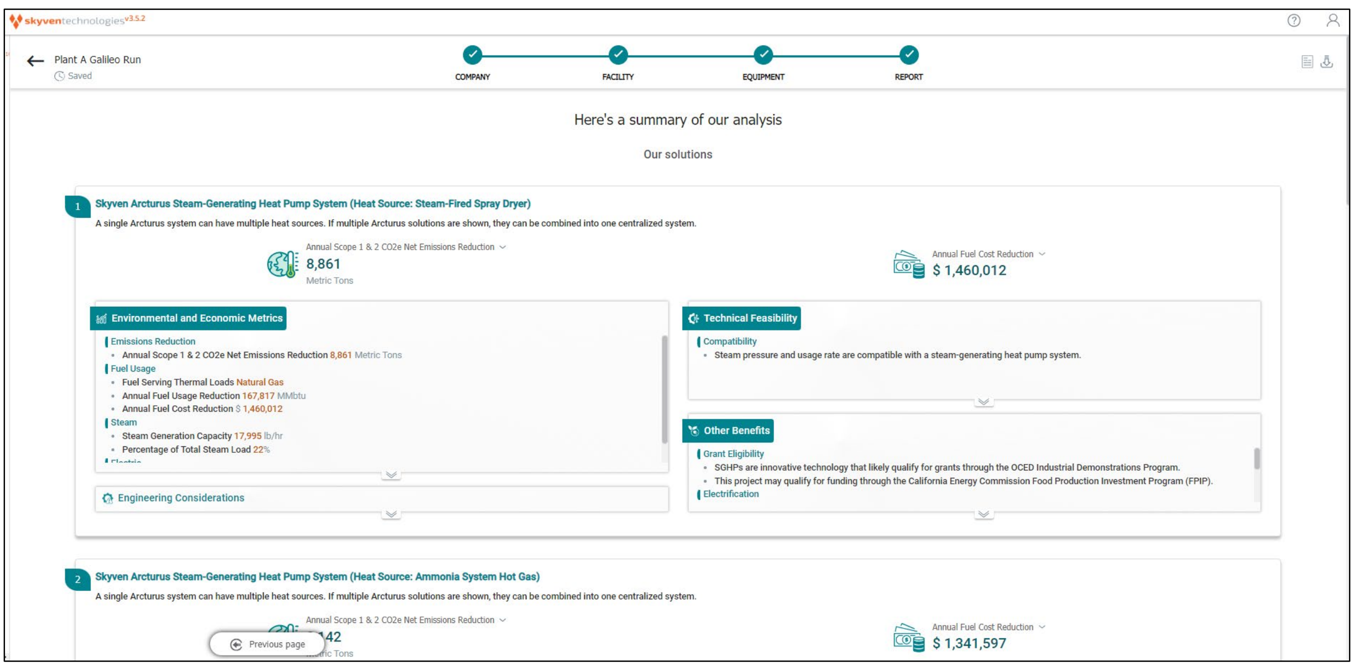
	Manual Calculations	Galileo	Percent Decrease
Timeline (hours)	$25,000	$1,800	93%

Source: Skyven Technologies, 2024

Galileo — Analysis Window and Reports

After the customer works through all of the questions on the Equipment window of the analysis AI window, a decarbonization report showing between two and five profitable decarbonization solutions appears. For each decarbonization solution, Galileo shows environmental and economic metrics calculated from the customer's inputs, such as emissions reduction, fuel usage, steam generation capacity, and electric consumption. Additionally, each solution shows the associated engineering considerations, technical feasibilities, and other benefits as specified by the expert user in the knowledge base. Figure 14 illustrates this window.

Figure 14: Report Non-expert UI Window



Source: Skyven Technologies, 2024

Additional features on this page include an option for the user to export the results to a PDF report or to an Excel spreadsheet. Examples of the PDF reports can be found in the appendices.

Pilot Plants — Galileo Reports Compared to Hand Calculations

To validate the Galileo software, two pilot plants were run through the Galileo analysis and the results were compared to manual hand calculations.

Pilot Plant A is a real dairy plant in California. For Pilot Plant A, manual analysis was conducted for a condensing economizer and steam traps. Skyven worked with ConDex (a condensing economizer vendor) on the condensing economizer analysis and with Steam Management (a steam trap maintenance and monitoring company) on the steam trap analysis. Table 4 shows the comparison of the yearly savings calculated by the Galileo software, measured in one million British thermal units (MMBtu), compared to the manual calculations.

Table 4: Pilot Plant A — Galileo Versus Manual Calculations

	Galileo Software Report	Manual Calculations	Percent Difference
Condensing Economizer (Yearly MMBtu Savings)	51,351	59,211	14%
Steam Traps (Yearly MMBtu Savings)	30,327	30,616	1%

Source: Skyven Technologies, 2024

Detailed manual calculations for Pilot Plant A can be found in Appendix A. The full Galileo report for Pilot Plant A can be found in Appendix B.

Pilot Plant B is a real ethanol manufacturing facility in Kansas. For Pilot Plant B, a manual analysis was performed for a steam generating heat pump system using rectifier condensers as the heat source. Skyven worked with S&B Engineers and Contractors Ltd. on the steam generating heat pump manual calculations. Table 5 shows the comparison of the yearly savings calculated by the Galileo software versus the manual calculations.

Table 5: Pilot Plant B – Galileo Versus Manual Calculations

	Galileo Software Report	Manual Calculations	Percent Difference
SGHP – Rectifier Column (Steam Capacity – pounds per hour)	46,000	46,000	0%
SGHP – Rectifier Column (Electricity Usage – kilowatt-hours)	30,111,722	27,370,000	10%

Source: Skyven Technologies, 2024

The Galileo software calculated the exact same steam capacity (46,000 pounds per hour) as that calculated by manual calculations because both calculation methodologies encountered the same maximum steam generation capacity. That is, the maximum amount of steam that could be used in this plant was entered by the customer in response to a Galileo question as 46,000 pounds per hour. Detailed manual calculations for Pilot Plant B can be found in Appendix C. The full Galileo report for Pilot Plant B can be found in Appendix D.

Machine Learning Results

Skyven used ML to estimate equipment costs within the Galileo system. The Skyven team began working on the framework for this ML technology and pilot tested the ML capabilities using quotes received from various equipment manufacturers. At this time, the number of quotes and therefore the amount of data the ML system has to work with is relatively small, so there is a rather large range in terms of accuracy. In the screenshots in Table 6 and Table 7, the information shown in blue and light green was received via equipment manufacturer quotes and fed into the ML system to train it. The Skyven team then re-ran the system with the information in blue as the inputs and received predicted cost estimates from the ML system (in dark green). The accuracy between the ML system and the equipment manufacturer quotes is shown in orange in Table 6 and Table 7.

Table 6: Machine Learning Accuracy — Heat Pump Equipment

No	Total Motor Horsepower	Number of Stages	Low-Side Temperature (°F)	High-Side Temperature (°F)	COP	Heat Capacity (MMbtuh)	Date Quote Received	Full-Build Material Cost	Predict	Accuracy (%) (MAPE)
1	650	2	76	173	6.08	5.00	6/1/2022	$972,149	$972,148.8125	0.0000192871668849117
2	800	1	75	175	4.81	8.80	11/18/2020	$796,690	$796,689.9375	0.0000078449585158594
3	900	1	90	170	3.49	7.13	2/20/2023	$660,000	$642,453.8125	2.6585132575757600000
4	700	1	90	170	4.45	6.48	2/20/2023	$640,000	$639,999.9375	0.0000097656250000000
5	900	1	85	170	3.53	7.43	2/20/2023	$660,000	$642,453.8125	2.6585132575757600000
6	700	1	85	170	4.43	6.50	2/20/2023	$640,000	$639,999.9375	0.0000097656250000000
7	500	1	65	150	4.08	5.77	11/10/2022	$546,075	$546,074.9375	0.0000114453142883304
8	725	2	42	180	3.12	5.00	5/17/2022	$875,000	$874,999.93750	0.0000071428571428571
9	400	1	90	170	4.33	4.61	2/28/2023	$475,000	$474,999.96875	0.0000065789473684211
10	400	1	85	170	4.33	4.61	2/28/2023	$475,000	$474,999.96875	0.0000065789473684211
11	550	1	70	175	3.98	4.99	6/10/2022	$600,000	$700,311.06250	16.7185104166667000000
12	600	1	80	180	5.1	5.7	3/8/2023	$640,278	794236.0625	24.0455025004764000000
13	400	1	90	170	6.0	4.7	3/8/2023	$540,000	593698.9375	9.9442476851851900000
14	900	1	70	180	4.2	7.5	3/8/2023	$800,000	796689.9375	0.4137578125000000000

Source: Skyven Technologies, 2023

For heat pump equipment, the accuracy of the ML ranged from 0 percent to 24 percent. This is acceptable due to limited data.

Table 7: Machine Learning Accuracy — Heat Recovery Steam Generating Equipment

No	Exhaust Stream Flow (SCFM)	Exhaust Stream Entering Temp (°F)	Steam Generation Capacity (lb/hr)	Generated Steam Pressure (PSIG)	Date Quote Rec	Full-Build Material Cost	Predict	Accuracy (%) (MAPE)
1	1,990	1,530	2,770	150	3/3/2022	$211,853.00	$296,275.9688	39.8497867625193000000
2	6,398	750	2,914	58	8/1/2022	$169,043.98	$169,043.9844	0.0000000000000000000
3	9,545	500	2,381	29	11/22/2021	$341,213.00	$341,212.9063	0.0000274755065018039

Source: Skyven Technologies, 2023

The estimates had a large deviation of about 40 percent, resulting from limited data available for training the model.

Technical Advisory Committee Comments

During the technical advisory committee meeting, one of the committee members asked how the manual hand calculations compared to the finalized results of the project. There were no projects ultimately installed at Pilot Plant B. However, both the condensing economizer and the steam trap projects at Pilot A were installed.

Table 8 shows the percentage difference between the manual calculations and the actual performance of the steam trap and the condensing economizer projects at Pilot Plant A.

Table 8: Pilot Plant A — Manual Calculations Versus Actual Performance

	Manual Calculations	Actual Performance	Percent Difference
Condensing Economizer (Yearly MMBTU Savings)	59,211	47,452	-22%
Steam Traps (Yearly MMBTU Savings)	30,616	42,929	+33%

Source: Skyven Technologies, 2024

It is important to note that the actual performance value for the condensing economizers was extrapolated to a year's worth of data. The yearly value was extrapolated from data collected in September 2022, when the condensing economizer was running at full capacity (the project had not been operating for several months due to changes in the steam boilers at the site). The difference in the values stems from the extrapolation of the existing data on the condensing economizers and the conservative estimates of the steam trap savings in the hand calculations. Additional data collected on this equipment in the coming months/years will help address/alleviate these differences.

Challenges

Skyven's biggest challenge is obtaining more cost data so that the ML cost model can be further refined. Currently, the model includes about 20 equipment manufacturer quotes, but something on the order of 1,000 or more is needed for improved accuracy. Skyven is also working to develop a feature that can estimate the answers to a question that the customer cannot answer, based on previously submitted data from similar industries/customers. To do this, more data points are needed here as well, again, more on the order of 1,000 rather than the 100-plus currently in the system.

CHAPTER 4: Conclusion

A large barrier to achieving California's clean energy and climate goals is the specific and unique nature of industrial facilities, which requires bespoke decarbonization solutions. The current options for scoping and FEE of decarbonization solutions are either to hire costly and time-consuming outside energy consultants or to seek vendor-specific solutions. These options are insufficient and often lead to inaction by the facility and continuation of the status quo. Therefore, Skyven developed a FEE AI system that is capable of analyzing a facility and, using input provided by the customer, automatically generating a decarbonization proposal with between two and five solutions; these solutions include economic and environmental benefits as well as engineering considerations, technical feasibilities, and other benefits.

Skyven has used Galileo with more than 135 different facilities across various sectors, such as chemical (ethanol, sugar beets, plastics), pulp and paper (paper mill, consumer paper goods), and food and beverage (dairies, breweries, snack products), resulting in the identification of more than 4.3 million metric tons of potential GHG savings and more than $480 million in potential fuel cost savings for manufacturing establishments. Galileo's current capabilities include analyzing 76 distinct industrial facility types, 67 different pieces of equipment, and 60 diverse decarbonization solutions, totaling more than 4,000 unique combinations. From the initial technical call with a customer to a finalized decarbonization report, Galileo can produce results in as little as 24 hours, a stark contrast to the four months required for a similar report generated manually. Furthermore, production of decarbonization reports using Galileo costs 93 percent less and necessitates 90 percent fewer person-hours compared to typical hand calculations.

Skyven devised a diverse approach to sharing information about Galileo and promoting its adoption. A detailed whitepaper outlining Galileo's capabilities, data insights, and a comparison with traditional methods was finalized for posting on Skyven's website, accompanied by a corresponding blog post. Additionally, Skyven created a dedicated section on its website to showcase Galileo's features and achievements. While Galileo was initially developed as a scoping tool for industrial clients interested in decarbonization solutions, its potential extends across various sectors. Skyven plans to offer licenses for Galileo to service providers, industrial assessment centers, and/or governmental bodies to enhance their decarbonization services. Furthermore, Skyven envisions a two-sided marketplace model, where Galileo runs are provided free to potential clients while vendors pay for referrals.

Looking forward, Skyven aims to broaden Galileo's reach to include commercial and residential sectors through advancements in AI and the knowledge base. Ultimately, Skyven intends to use Galileo for decarbonization assessments across industrial, commercial, and residential properties, using various strategies such as charging for runs, licensing, and forming partnerships with vendors.

GLOSSARY AND LIST OF ACRONYMS

Term	Definition
AI	artificial intelligence — technology that enables computers and digital devices to learn, write, create, and analyze
FEE	front-end engineering — an engineering design approach that focuses on the technical requirements as well as the rough cost savings for a project
FEE AI	artificial intelligence front-end engineering system
KRR	knowledge representation and reasoning — a field in artificial intelligence that focuses on how to represent information in a way that a computer system can use to make decisions with human like reasoning
ML	machine learning
MMBtu	million British thermal unit
Skyven	Skyven Technologies
UI	user interface — the point of human-computer interaction and communication

References

CARB (California Air Resources Board). 2017 (Nov). *California's 2017 Climate Change Scoping Plan*. California Air Resources Board. Available at https://ww2.arb.ca.gov/sites/default/files/classic/cc/scopingplan/scoping_plan_2017.pdf.

Nunez. 2006 (Sep 27). "AB 32 - Air pollution: greenhouse gases: California Global Warming Solutions Act of 2006." California State Legislature, Assembly Bill 32, Chapter 488, Statutes of 2006. Available at http://www.leginfo.ca.gov/pub/05-06/bill/asm/ab_0001-0050/ab_32_bill_20060927_chaptered.html.

Pavley. 2016 (Sep 8). "SB 32 - California Global Warming Solutions Act of 2006: emissions limit." California State Legislature, Senate Bill 32, Chapter 249, Statutes of 2016. Available at https://legiscan.com/CA/text/SB32/id/1428776.

Project Deliverables

The following is a list of all of the products produced under this agreement:

- KRR Framework Test Plan and Report
- Wireframe Plans
- UI Development and Test Plan
- Report for Pilot Plant A
- Report for Pilot Plant B
- Technology Transfer Plan and Report
- Critical Project Review (CPR) Report
- Quarterly Progress Reports (QPR)

These project deliverables, including the CPR and QPR interim project reports, are available upon request by submitting an email to pubs@energy.ca.gov.

ENERGY RESEARCH AND DEVELOPMENT DIVISION

APPENDIX A: Pilot Plant "A" and "B" Hand Calculations and Galileo Reports

August 2024 | CEC-500-2024-091

APPENDIX A:
Pilot Plant "A" and "B" Hand Calculations and Galileo Reports

Condensing Economizer:

Heat recovery system in the ***condensing*** mode.

Fuel: Natural Gas

Gas side:	Gas type	Boiler Flue
	Total flow rate	91,422 lb/hr
	Inlet temperature	296 °F
	Outlet temperature	115 °F
	Dew point	127 °F
	H_2O vapor by weight @ inlet	9.2 %
	H_2O vapor flow @ inlet	8,410 lb/hr
	H_2O vapor flow @ outlet	5,801 lb/hr
	H_2O condensed	2,609 lb/hr
	Specific heat @ avg. temperature	0.264 Btu/lb·°F
	Pressure drop	1.38 inch w.c.
	Fouling factor	0.001 hr· ft^2· F/Btu
	Maximum velocity at inlet temperature through the new free area	17.6 fps
Liquid side:	Fluid type	Water
	Total flow rate	66,000 lb/hr
	Inlet temperature	80 °F
	Outlet temperature	181 °F
	Pressure drop	15.61 psi
	Fouling factor	0.001 hr· ft^2· F/Btu
	Velocity at average temperature	4.54 fps

Sensible Heat Load: 4,175,568 Btu/hr

Latent Heat Load: 2,621,024 Btu/hr

TOTAL HEAT RECOVERED (with 2% losses) 6,796,592 Btu/hr

There are 8,712 operating hours, therefore the Condensing Economizer can save up to 59,211 MMBTU/year.

Steam Traps:

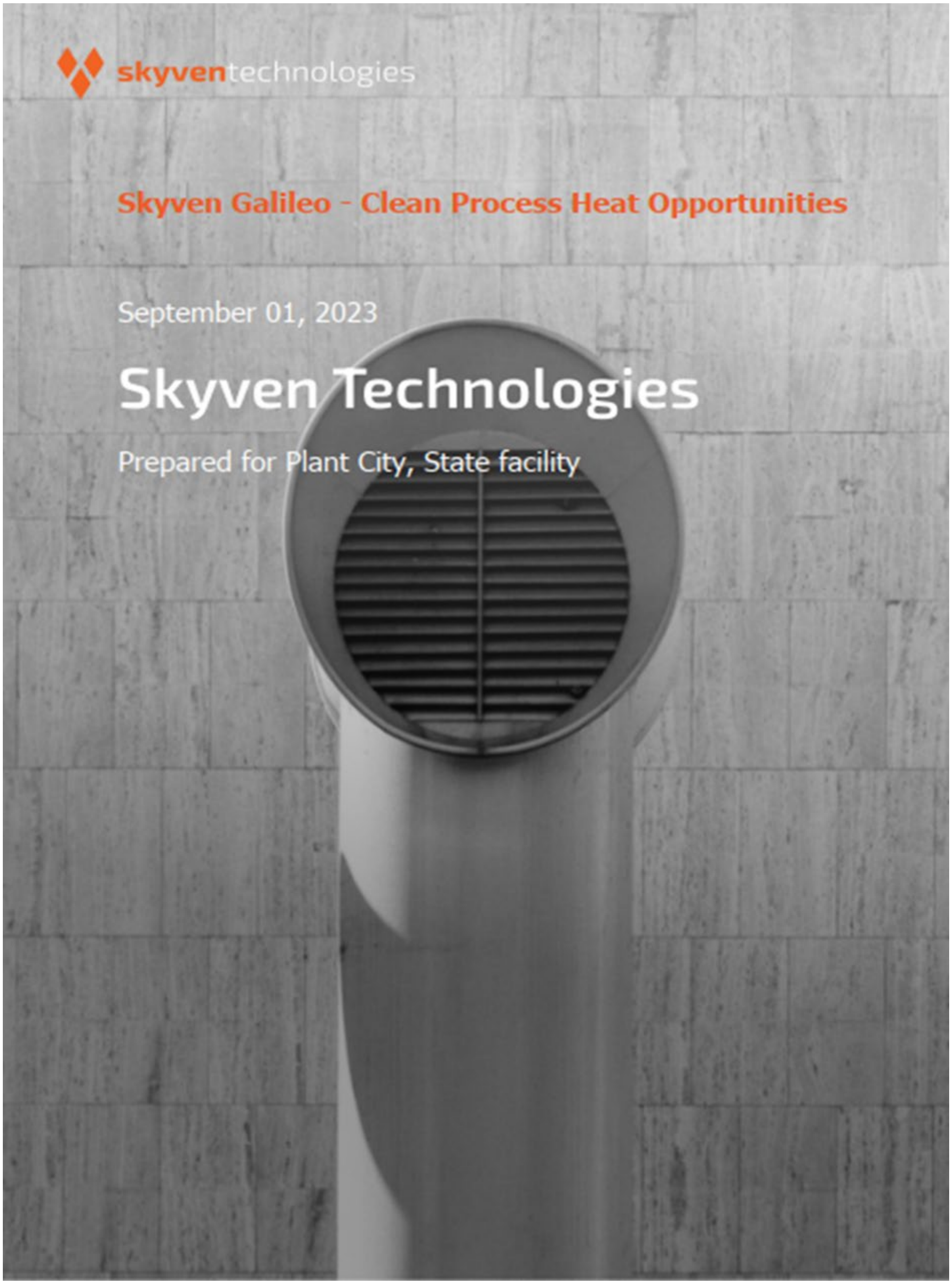
Tag # - Location	Steam Leak Average Prior to Fix (klbs/hr)	Steam Leak Average Post Fix (klbs/hr)	Steam Saved (klbs/hr)	Steam Saved (klbs/month)	Thermal Energy Savings (MMBtu/month)
Tag 2 - Boiler Room	0.028	0.006	0.021	15.472	15.472
Tag 4 - Boiler Room	0.194	0.043	0.151	109.010	109.010
Tag 8 - Boiler Room	0.035	0.008	0.027	19.654	19.654
Tag 10 - Boiler Room	0.078	0.017	0.061	43.670	43.670
Tag 11 - Boiler Room	0.004	0.001	0.003	2.130	2.130
Tag 9 - Butter	0.009	0.002	0.007	5.230	5.230
Tag 10 - Butter	0.006	0.001	0.004	3.123	3.123
Tag 16 - Plant 6 (Size 2)	0.474	0.104	0.370	266.383	266.383
Tag 16 - Plant 6 (Size 1.5 #1)	0.217	0.048	0.169	121.830	121.830
Tag 16 - Plant 6 (Size 1.5 #2)	0.321	0.071	0.250	180.343	180.343
Tag 20 - Receive	0.024	0.005	0.019	13.737	13.737
Tag 14 - Butter	0.041	0.009	0.032	22.903	22.903
Tag 73 - Plant 8 (Size 2)	1.479	0.325	1.153	830.427	830.427
Tag 73 - Plant 8 (Size 1)	0.099	0.022	0.077	55.647	55.647
Tag 73 - Plant 8 (Size 0.5)	0.004	0.001	0.003	2.424	2.424
Tag 70 - Plant 7 (Size 0.5 #1)	0.004	0.001	0.003	2.261	2.261
Tag 70 - Plant 7 (Size 0.5 #2)	0.005	0.001	0.004	2.800	2.800
Tag 67 - Plant 7	0.005	0.001	0.004	2.796	2.796
Tag 66 - Plant 7	0.022	0.005	0.017	12.089	12.089
Tag 70 - Plant 8	0.133	0.029	0.103	74.465	74.465
Tag 23 - Receive	0.025	0.006	0.020	14.079	14.079
Tag 22 - Receive (Size 0.75 #1)	0.035	0.008	0.027	19.554	19.554
Tag 22 - Receive (Size 0.75 #2)	0.008	0.002	0.006	4.614	4.614
Tag 22 - Receive (Size 0.75 #3)	0.077	0.017	0.060	43.325	43.325
Tag 24 - Pipe Chase	0.022	0.005	0.017	12.168	12.168
Tag 27 - Pipe Chase	0.076	0.017	0.059	42.438	42.438
Tag 28 - Pipe Chase	0.063	0.014	0.049	35.246	35.246
Tag 29 - Pipe Chase	0.075	0.016	0.058	42.048	42.048
Tag 26 - Pipe Chase	0.014	0.003	0.011	7.960	7.960
Tag 32 - Pipe Chase	0.020	0.004	0.015	11.134	11.134
Tag 39 - Pipe Chase	0.032	0.007	0.025	18.245	18.245
Tag 40 - Pipe Chase	0.022	0.005	0.017	12.253	12.253
Tag 38 - Pipe Chase	0.013	0.003	0.010	7.377	7.377
Tag 41 - Pipe Chase (Size 1)	0.039	0.009	0.031	22.127	22.127
Tag 41 - Pipe Chase (Size 0.75)	0.025	0.005	0.019	14.010	14.010
Tag 44 - Pipe Chase	0.020	0.004	0.015	11.121	11.121
Tag 80 - Plant 8	0.006	0.001	0.005	3.619	3.619
Tag HEX - Plant 7	0.790	0.174	0.616	443.656	443.656
				Monthly Total (MMBTU/month)	2551.367
				Yearly Total (MMBtu/year)	30,616

ENERGY RESEARCH AND DEVELOPMENT DIVISION

APPENDIX B: Pilot Plant "A" Galileo Report

August 2024 | CEC-500-2024-091

APPENDIX B:
Pilot Plant “A” Galileo Report



skyventechnologies

Skyven Galileo - Clean Process Heat Opportunities

September 01, 2023

Skyven Technologies

Prepared for Plant City, State facility

Introduction

The following report determines projects to significantly reduce CO2 from the Pilot Plant A site in Plant City, State. Included is the following key information gathered during the meeting to inform the results:

Site Information

- Site operates 8,712 hours a year

Natural Gas

- Annual Natural Gas Usage: 8,739,664 Therm
- Average Natural Gas Rate: $0.87 per Therm
- Annual Natural Gas Cost: $7,603,507.68

Solutions

3 Condensing Economizer on Steam Boiler(s)

Install condensing economizer(s) to preheat boiler makeup water using heat recovered from boiler exhaust stack gas.

Annual Scope 1 & 2 CO2e Net Emissions Reduction
2,711
Metric Tons

Annual Fuel Cost Reduction
$ 446,751

Environmental and Economic Metrics

Emissions Reduction
- Annual Scope 1 & 2 CO2e Net Emissions Reduction – **2,711** Metric Tons

Fuel Usage
- Fuel Serving Thermal Loads – **Natural Gas**
- Annual Fuel Usage Reduction – **51,351** MMbtu
- Annual Fuel Cost Reduction – $ **446,751**

Technical Feasibility

Compatibility
- Install condensing economizer(s) to preheat boiler makeup water using heat recovered from boiler exhaust stack gas.
- The steam boiler makeup water is a viable heat sink.

Engineering Considerations

Condensing Flue Gas
- Condensing economizer and associated equipment will be designed to resist corrosion from water condensing out of flue gas.

Other Benefits

Grant Eligibility
- This project may qualify for funding through the California Energy Commission Food Production Investment Program (FPIP).

Solutions

5 Intelligent Steam Traps and Active Monitoring/Repair

Install IOT steam traps with automatic remote monitoring and repair or replace failed traps.

Annual Scope 1 & 2 CO2e Net Emissions Reduction
1,601
Metric Tons

Annual Fuel Cost Reduction
$ 263,844

Environmental and Economic Metrics

Emissions Reduction
- Annual Scope 1 & 2 CO2e Net Emissions Reduction – **1,601** Metric Tons

Steam
- Steam Demand Offset – **3,252** lb/hr
- Percentage of Total Steam Load – **4** %

Fuel Usage
- Fuel Serving Thermal Loads – **Natural Gas**
- Annual Fuel Usage Reduction – **30,327** MMbtu
- Annual Fuel Cost Reduction – $ **263,844**

Technical Feasibility

Compatibility
- Existing steam trap audit schedule does not identify and repair all failed traps.
- The quantity of steam traps is high enough to justify installing a remote monitoring system.

Engineering Considerations

Remote Connectivity
- Steam traps communicate with remote monitoring systems via cellular data link, avoiding any need to tie into the plant network.

Other Benefits

System Performance
- Properly operating steam traps help prevent water hammer and other undesirable conditions.

Grant Eligibility
- This project may qualify for funding through the California Energy Commission Food Production Investment Program (FPIP).

CALIFORNIA
ENERGY COMMISSION

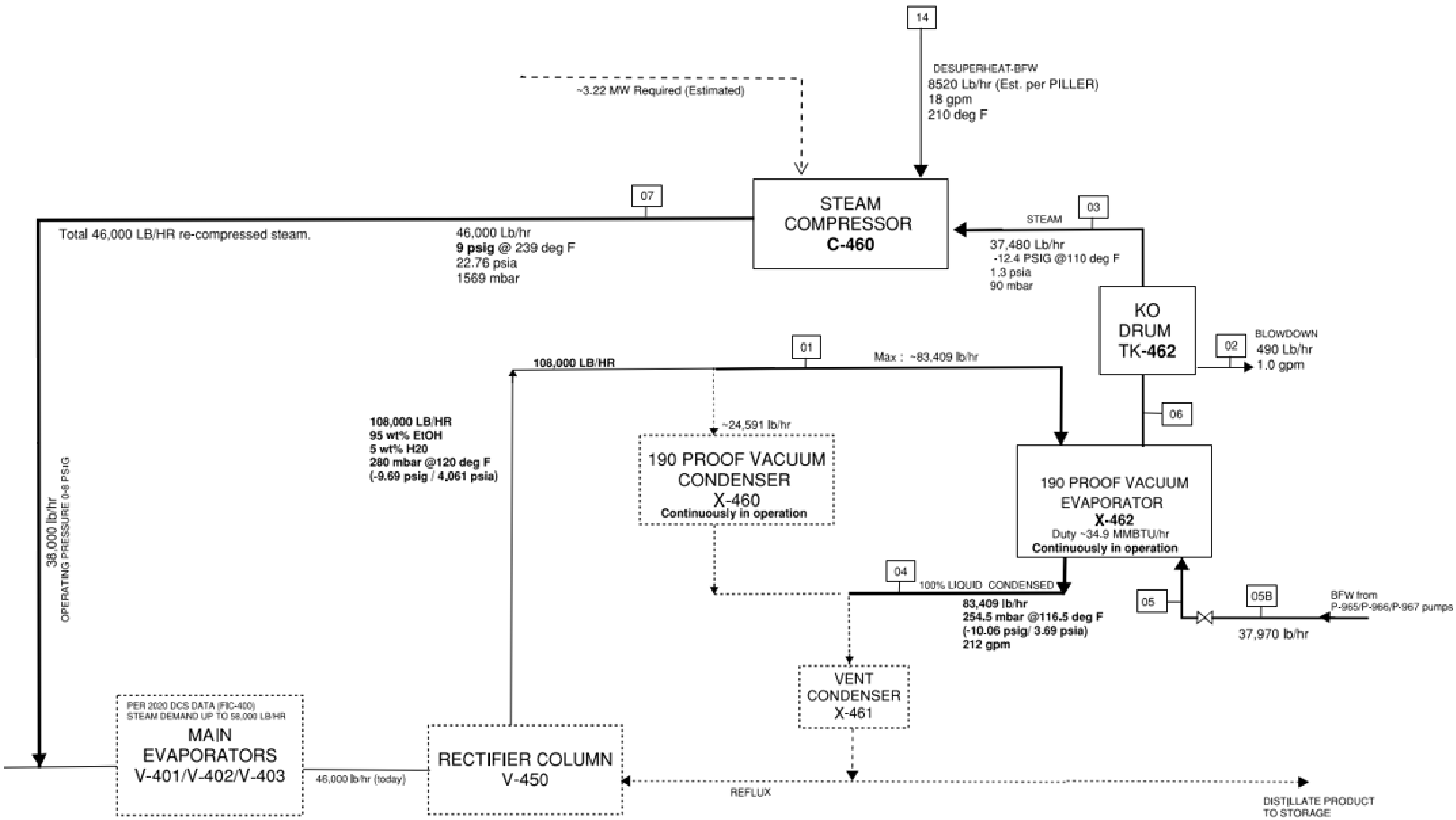
CALIFORNIA NATURAL RESOURCES AGENCY

ENERGY RESEARCH AND DEVELOPMENT DIVISION

APPENDIX C: Pilot Plant “B” Manual Calculations

August 2024 | CEC-500-2024-091

APPENDIX C:
Pilot Plant "B" Manual Calculations



CALIFORNIA ENERGY COMMISSION

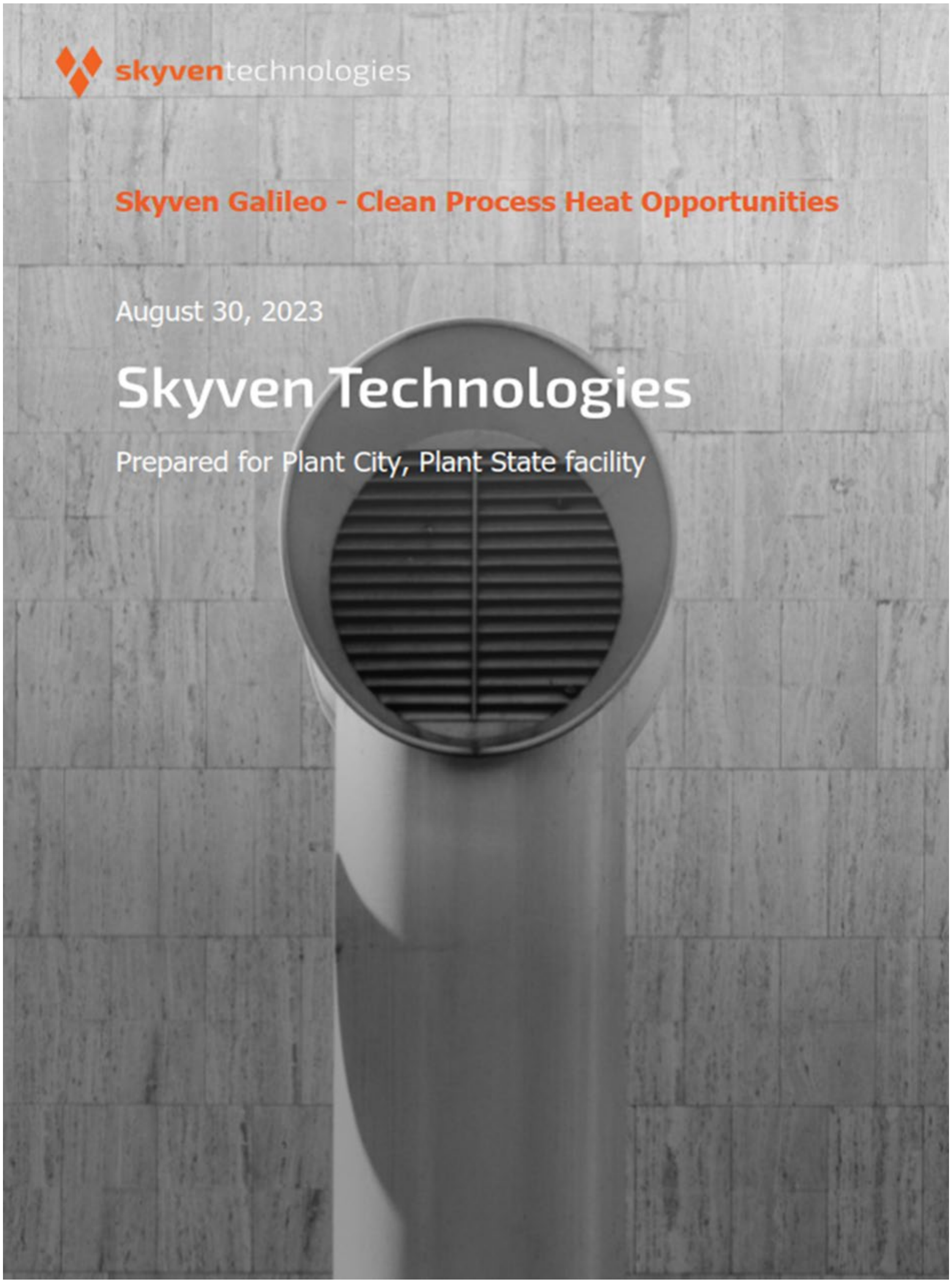
CALIFORNIA NATURAL RESOURCES AGENCY

ENERGY RESEARCH AND DEVELOPMENT DIVISION

APPENDIX D: Pilot Plant “B” Galileo Reports

August 2024 | CEC-500-2024-091

APPENDIX D:
Pilot Plant "B" Galileo Reports



Introduction

The following report determines projects to significantly reduce CO2 from the Pilot Plant B site in Plant City, State. Included is the following key information gathered during the meeting to inform the results:

Site Information

- Site operates 8,500 hours a year

Natural Gas

- Annual Natural Gas Usage: 814,300 MMbtu
- Average Natural Gas Rate: $3.52 per MMbtu
- Annual Natural Gas Cost: $2,866,336

Solutions

2 Skyven Arcturus Steam-Generating Heat Pump (Heat Source: Rectifier Condensers)

An Arcturus system can have multiple heat sources, but sourcing heat from the condenser may decrease the heat available from cooling equipment.

Annual Scope 1 & 2 CO2e Net Emissions Reduction
24,604
Metric Tons

Annual Fuel Cost Reduction
$ 1,640,275

Environmental and Economic Metrics

Emissions Reduction
- Annual Scope 1 & 2 CO2e Net Emissions Reduction – **24,604** Metric Tons

Fuel Usage
- Fuel Serving Thermal Loads – **Natural Gas**
- Annual Fuel Usage Reduction – **465,987** MMbtu
- Annual Fuel Cost Reduction – $ **1,640,275**

Steam
- Steam Generation Capacity – **46,000** lb/hr
- Percentage of Total Steam Load – **61** %

Electric
- Annual Electric Usage Increase – **30,111,722** kWh

Technical Feasibility

Basic Fit
- Steam pressure and usage rate are compatible with a steam-generating heat pump system.

Engineering Considerations

Heat Source - Rectifier Condenser
- Heat can be recovered directly from the condenser at a higher temperature than from centralized cooling systems.
- Arcturus operating COP improves with higher temperature heat sources.

Multiple Heat Sources
- The Skyven Arcturus SGHP can utilize waste heat from multiple sources.
- Additional engineering is required to determine the best combination of heat sources to use.
- Heat available from condenser(s) can't be double-counted with heat from centralized cooling system serving the condenser(s).

Solutions

2 Skyven Arcturus Steam-Generating Heat Pump (Heat Source: Rectifier Condensers) (cont.)

Engineering Considerations (cont.)

Footprint

- The steam generating heat pump has a large footprint. Additional analysis is required to determine ideal placement.

Other Benefits

Grant Eligibility

- SGHPs are innovative technology that likely qualify for grants through the OCED Industrial Demonstrations Program.

Electrification

- Electrically-driven heat source allows for sourcing of renewable electricity.
- Skyven Technologies can facilitate installation of solar PV electric generation to avoid increase in Scope 2 emissions.
- If on-site solar PV is not feasible, renewable energy credits shall be purchased to offset increase in Scope 2 emissions.
- Skyven covers the cost of the increase in electric usage due to the heat pump.

Redundant with Existing Equipment

- SGHP system will be installed in parallel with the existing equipment, keeping existing steam generation equipment as backup.