Engineering | Industry components | Predictive forecasting | Regression analysis

A Technoeconomic Model for Maritime Applications of Green Power Technologies

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BUSINESS PROBLEM

With increasing demand for carbon-neutral and carbon-lite power generation both within the marine industry and Caterpillar Inc.'s (CAT) broader service areas, it is critical for CAT to understand how emerging technologies might affect their primary markets in the future. Given the variety of industries and diversity of customer needs that CAT serves, the development of tools that allow for a sector-by-sector approach to new technology investigation is critical to understand where and to what degree individual markets will be disrupted by the adoption of new technologies.

APPROACH

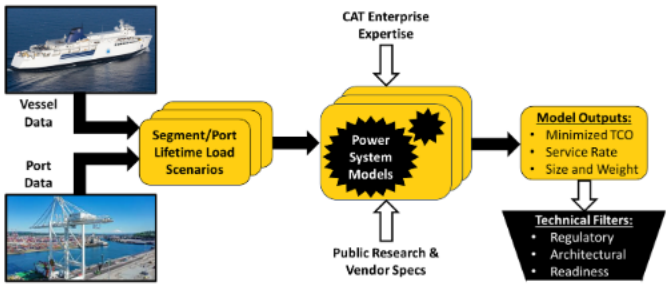
Expand CAT's technoeconomic investigative capabilities into new power technologies by developing a flexible model to predict and compare the competitiveness (discounted total cost of ownership) of small and micro nuclear reactor (S/MMR), hydrogen fuel cell, and battery-electric power systems to incumbent fossil-fuel power sources for a variety of on-water and onshore marine applications.

DATA SOURCES

The model was built from several sources of knowledge. For constructing load profiles and internal combustion engine (ICE) system models, the majority of the data came from CAT and other vendor documentation. For batteries and fuel cells, the data came from supplier data sheets, publications, and CAT experts. For nuclear systems, the data came from publications, textbooks, and academic experts.

Data Types and Format

Data formats predominantly included time series for load profile construction, physical property data sets to build the technical components of the model, and cost data for the economic portion.



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IMPACT

The solution equips CAT with a configurable tool based on first principles, empirical correlations, and reasonable assumptions to assess and compare the performance of several alternative technologies of interest to incumbent fossil fuel power systems in the marine space. The tool predicts total cost of system ownership, lifetime carbon emissions, and component volume and mass based on segment-specific, characteristic input data. In scanning across a diverse set of use cases both within and adjacent to CAT's current marine market, the tool identified opportunities for the adoption of battery technologies in short-trip vessel segments where operations would not be disrupted by an increased need for charging. The tool also identified opportunities for the adoption of nuclear power technologies at large ports and on large cargo ships. However, these use cases are specific and fall outside of what can be considered the core components of CAT's marine business - the model predicts that it will be very difficult to economically decarbonize most of the vessel segments and port archetypes studied using solely the alternative technologies considered. Hybrid diesel-battery powertrains and drop in alternative fuels seem to show more potential in this vein. In addition to the high-level segment analysis conducted for the thesis, the tool may prove useful for individual vessel/port-specific modeling given the bespoke nature of marine power architecture, particularly for larger systems.

DRIVERS	CAT is concerned with informing their long-term technology strategy as markets shift towards incentivizing decarbonization due to numerous international and organizational carbon emission reduction mandates. CAT deals in markets that are reliant on fossil fuels and difficult to decarbonize (e.g., marine power). A structured yet flexible data-driven method for assessing the adoption of green power technologies could guide this strategy.
BARRIERS	Lack of extensive real-world vessel and port operating data in some of the segments that the analysis aimed to explore made it difficult to forecast the power demand requirements for these scenarios with a high level of certainty. Additionally, a lack of recent, public small-scale nuclear power projects made it difficult to forecast the cost of these systems precisely.
ENABLERS	The diversity of the team's knowledge base was a major factor in the success of the project. Specifically on the ICE and electrical system modeling front, having access to experts streamlined model development. The matrix structure of the company made it possible to reach across teams and leverage connections at partner companies and regulators to gain insights into the marine market which further informed the conclusions of the analysis
ACTIONS	Since the tool was designed to inform strategic decision-making, communicating both how the model works and the results of the analysis were crucial to adding value to the company. This communication included several presentations and a Q&A with CAT senior management and several hours of recorded training with CAT simulations team to ensure a complete knowledge transfer.
INNOVATION	Building on several theses that explore applications of nuclear power technologies for large cargo shipping, the solution developed takes a more ground-up approach to demand modeling, allowing for granular case-specific demand modeling rather than making high level assumptions about power usage. The model also includes an innovative simplified radiation shielding calculation method that is computationally inexpensive and scenario agnostic.
IMPROVEMENT	The solution provides CAT with the ability to leverage significantly more data to better inform their predictions on the economic competitiveness and technical fit of alternative power technologies in their primary markets. The configurability of the tool allows for the scanning of uses-cases across multiple segments of the marine industry to identify the aggregated addressable market and business opportunity for a given green power technology.
BEST PRACTICES	Documenting and substantiating the assumptions that contribute to the construction of the model is critically important to both increase confidence in the subsequent results and ensure that other members of the organization understand its function. In future, validating the model using available lifetime cost data for real-world power systems would develop further confidence in its forecasting abilities.
OTHER APPLICATIONS	The logic and architecture of the marine power system model could easily be adapted to compare the application of green power technologies in other areas of CATs business and expand to include a wider area of technologies.