

COLLEGE OF ENGINEERING

NAVAL ARCHITECTURE & MARINE ENGINEERING

UNIVERSITY OF MICHIGAN

Modelling Power Barge Energy Pathways Under Uncertainty for Reducing Port Emissions

SISDO – Webb Institute

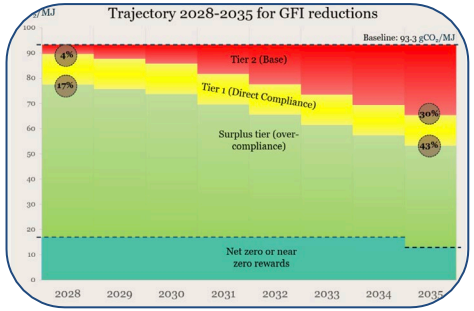
10 November 2025

Joseph Burgoyne, University of Michigan

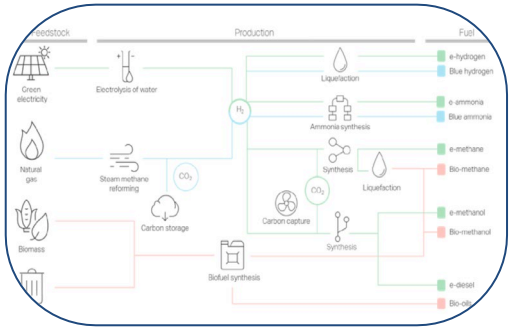
Agenda

1. Decarb Decision-Making Problem
2. Our Lab & Individual Focus
3. Port of Detroit
4. Academic Investigation
5. Techno-Economic-Environmental Model
6. Scenario Exploration
7. Decision Support
8. Conclusions

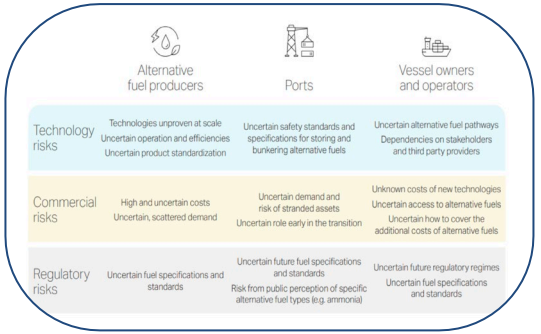
The Maritime Industry's Decarbonization Challenge



Need to act now in an industry not easy to change



There are a lot of options, with varying levels of maturity



Key stakeholders must deal with uncertainty and dynamic conditions

UM Focus: Bridging Academic Rigor with Commercial Reality

Focus

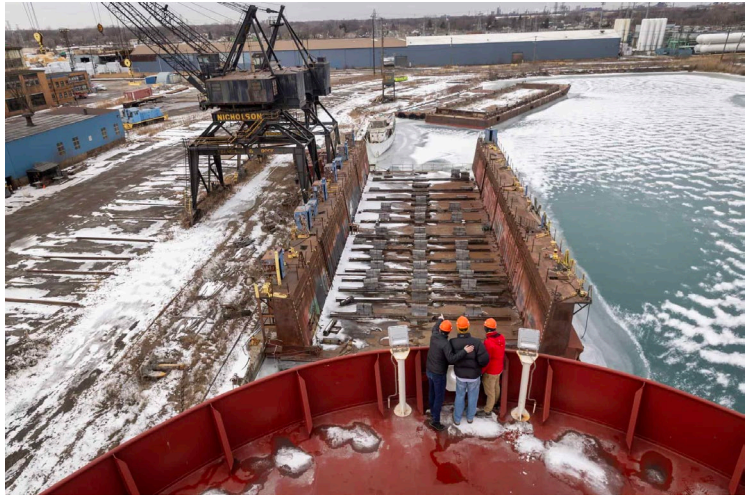
- Leverage academic rigor for more decision-ready tools & guidance for maritime stakeholders

Status Quo

- Generalized studies, disconnected analyses, hidden assumptions, blanket factors

Motivations and Thesis

- Increase specificity + context + visible uncertainty → defensible confident action

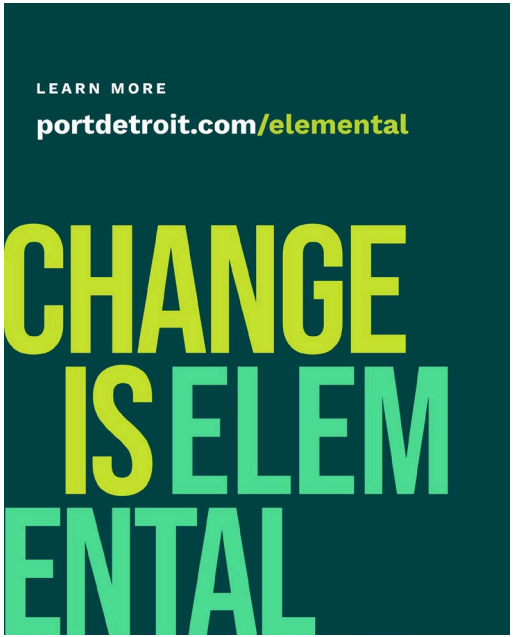


Great Lakes Maritime Initiative

Port of Detroit

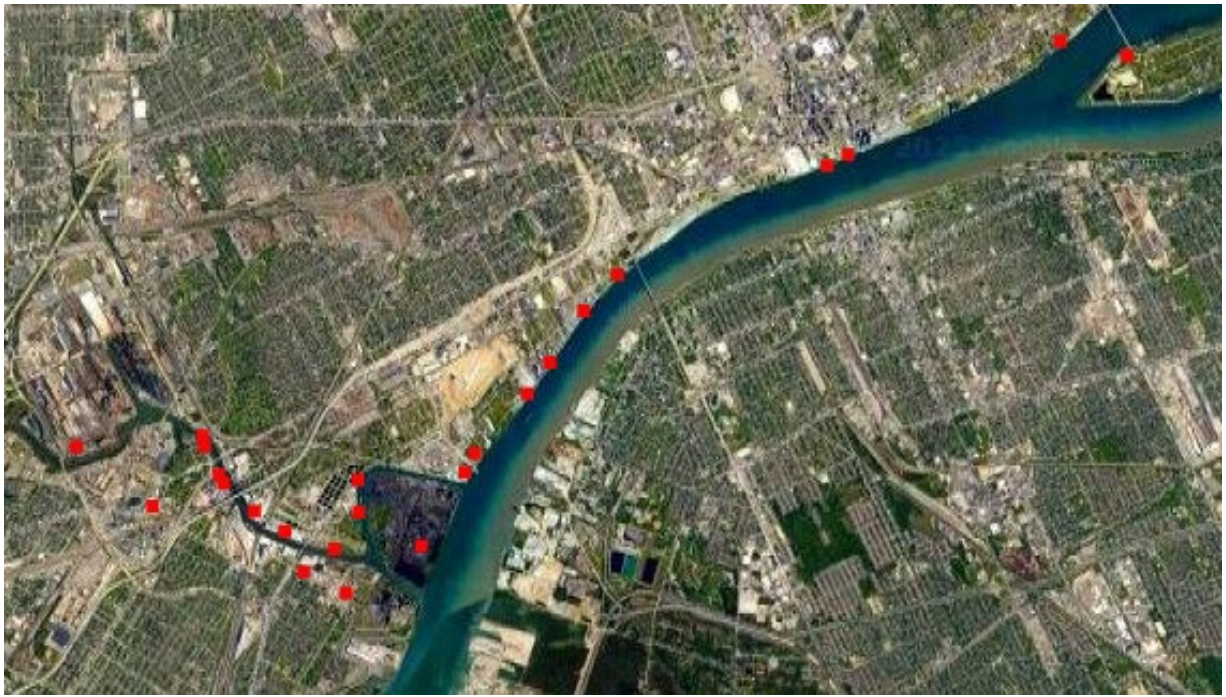


Zug Island Steel & Coke Production on the Detroit River
DetroitPBS



Detroit/Wayne County Port Authority Decarbonization Plan

Port of Detroit Terminals



Port of Detroit: Unique Environment & Challenge

The Port Authority seeks to be a leader in sustainability

- Air quality concerns prompt interest in **cold-ironing solutions**
- Distributed network of terminals results in **shore power** being **cost-prohibitive**
- Drives interest in mobile powering solution

Port contracted UofM & ABS for a feasibility study

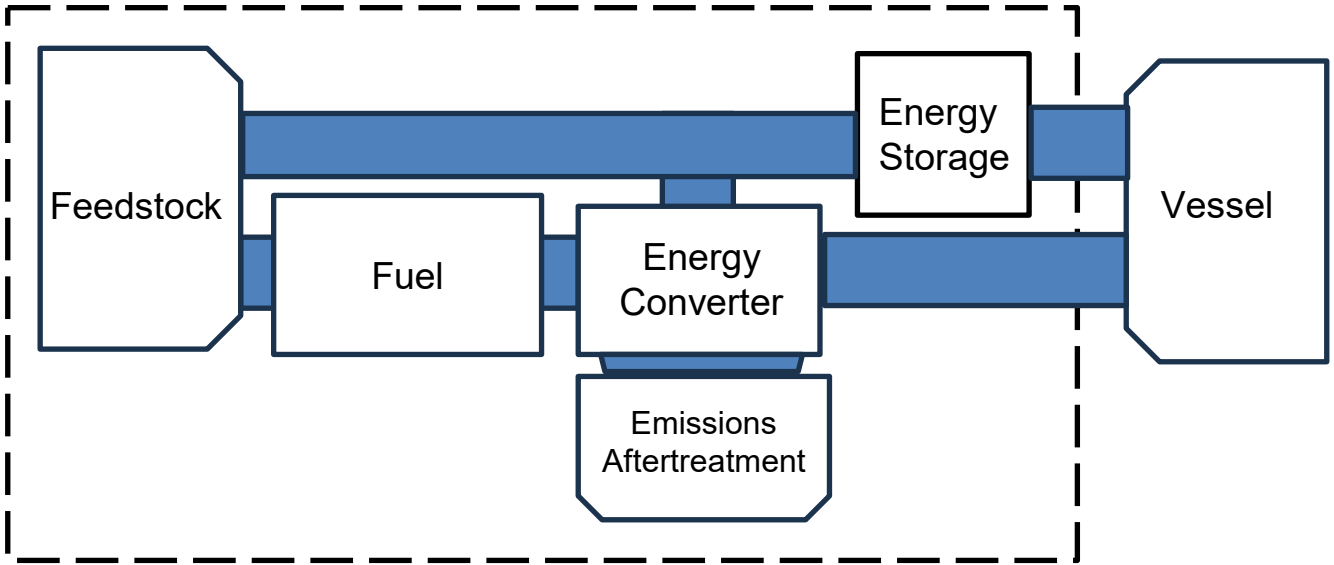
- ABS Role: Characterize vessel activity & power demand
- UofM Role: Assess **energy pathway feasibility** for mobile power barge



Distributed Port of Detroit Terminals in red

Port Detroit Authority Official Website

Assessing Feasibility: Energy Pathway Characterization



Feasibility Study Grounded in Research

Why academia was brought in

- Port challenge requires **technical depth** *and* **system -level reasoning**
- UM-ABS collaboration leverages **academic perspective** and **rigor** with **commercial experience** and **workforce**
- Decarbonization choices span **technology, economics, and policy** – no single right answer

How to manage deep uncertainty?



NAVAL ARCHITECTURE & MARINE ENGINEERING

ABS

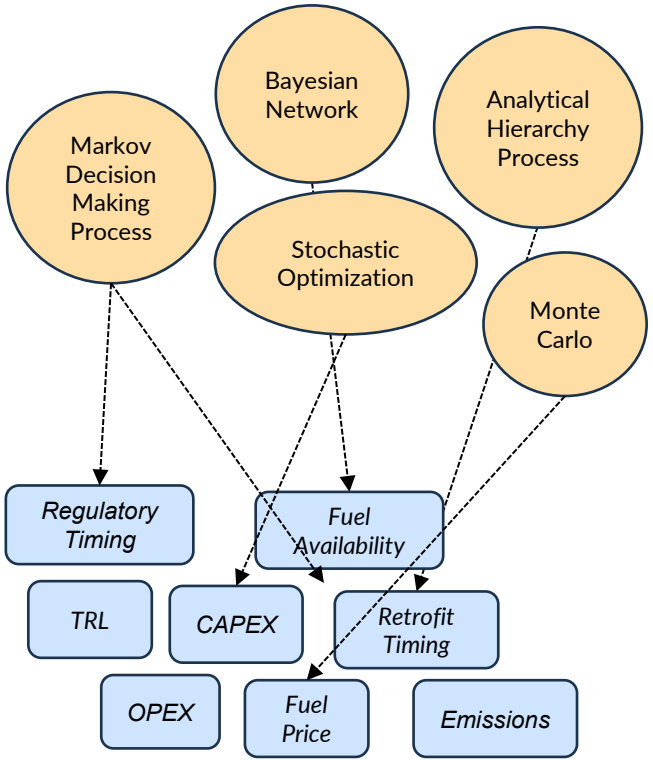
Literature Review Approach: Mapping Methods to Uncertainties

Academia's Natural Role

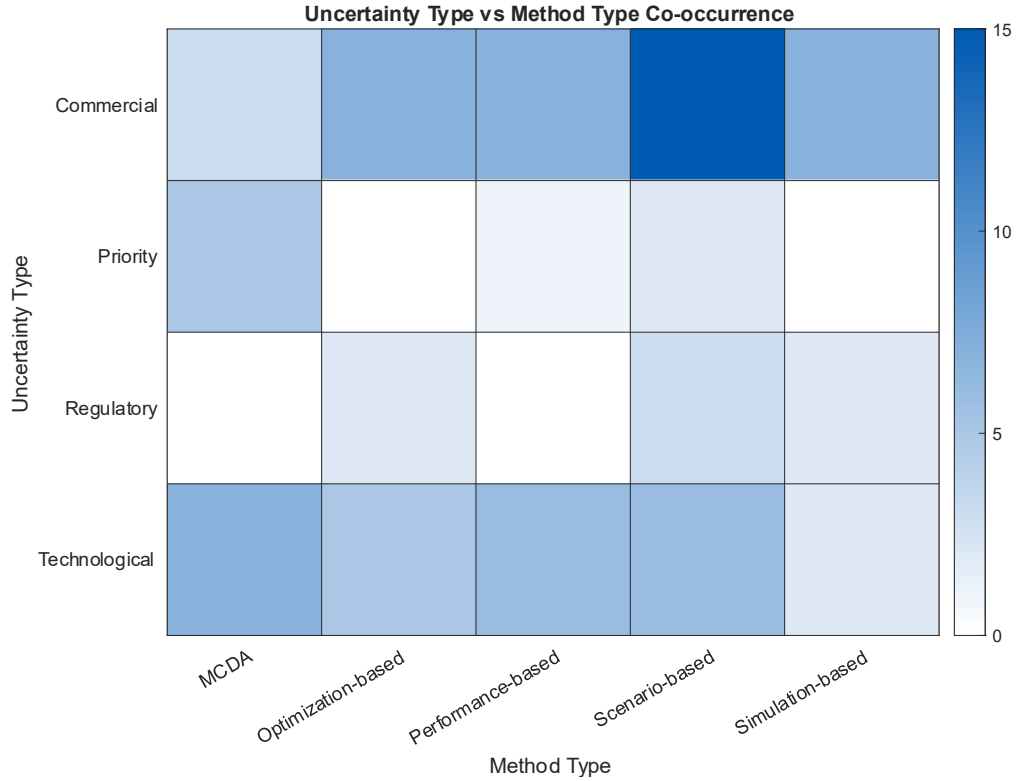
- Well-suited for sifting through complexity and extracting patterns
- History of decision-making under uncertainty

Our Approach

- Review of 60+ papers addressing uncertainty in maritime decarbonization and sustainable planning
- Mapped how different methods have been applied to different uncertainties
- Goal: Increase visibility into what methods exist and where they might help address specific uncertainties



Method to Uncertainty Mapping



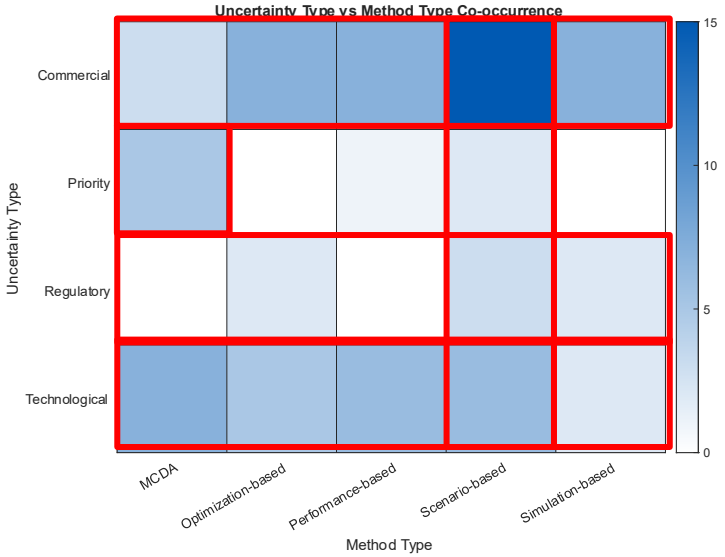
Academic Uncertainty Acknowledgement Trends & Gaps

Noticed Patterns

- Commercial uncertainty requires exploratory methods for volatile, unpredictable markets
- MCDA dominates for stakeholder preference elicitation
- Increasing implicit hybridization of methods
- Maturity of technology alters method choice

Port of Detroit Relevance

- Performance-based TEA for comparing different energy pathways
- Scenario exploration for deep uncertainties regarding fuel availability and future CONOPS



From Research Insights to Applied Modeling Needs

Research insights for **modelling under deep uncertainty**

- Traditional optimization alone misses **contextual trade -offs**
- Need for **exploratory, performance -based** frameworks

Port of Detroit Modelling Requirements

- Compare multiple energy pathways on cost, emissions, and technical feasibility
- **Explicitly handle unknowns and uncertainty**
- Deliver outputs that reflect ranges and robustness, not point estimates

Assessing Feasibility: Techno -Economic -Environmental Model

Interdependent Pillars of Feasibility

- These pillars interact and constrain each other
- Must be assessed holistically to capture system-level effects

Hard vs. Soft Constraints

- Hard gates: TRL, space & weight
- Soft factors: cost competitiveness, supply chain risk

Context is Paramount

- ”Feasible” and “optimal” solutions vary by stakeholder context & priorities

Environmental
Well-to-Wake emissions
Local air quality

Economic
CAPEX
OPEX

Technical
Power adequacy
Technology readiness
Physical compatibility
Availability

Assessing Feasibility: Pathway Configuration Explosion

Balance of fidelity

- Aim for the level that enables decisions, not excessive detail

Intentional scoping

- Incorporate stakeholder priorities/timeline in scoping
- i.e., omit detailed design considerations or group redundant fuel production methods

Early quality gates for scenario planning

- Power adequacy, TRL, size, and weight

Transparent exclusions

- Document omissions and reasoning so they can be revisited as context changes.

Interested in “Hydrogen Power Barge”

Production Methods, 4x

Transport modes, 3x

Onboard storage states, 3x

Conversion Methods, 3x

Emissions Aftertreatment Systems (NA)

Electrical Bus, 2x

= **288 Barges !!!**

Assessing Feasibility: Making Uncertainty Visible

Parameter Ranges

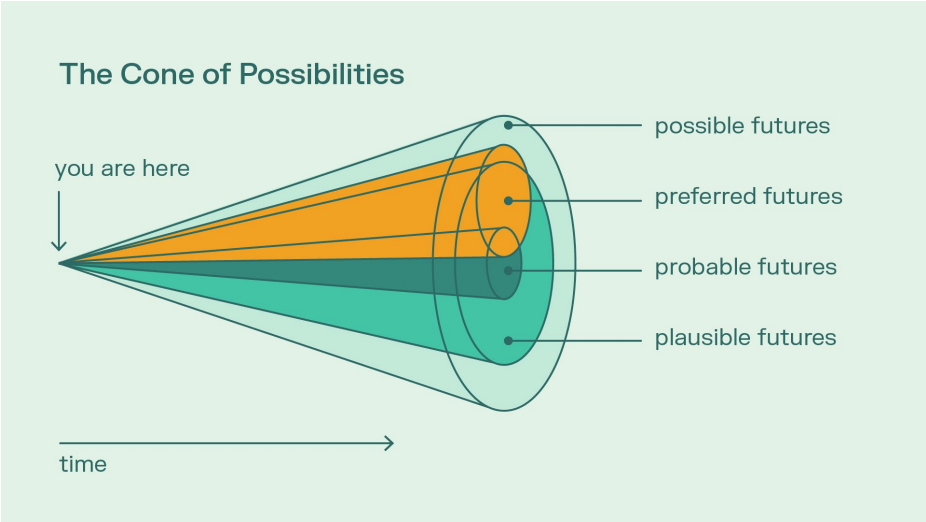
- Bounded values (efficiency 50-60%, Natural Gas $3-9 MMBtu

Scenario Analysis

- Multiple plausible futures (grid costs & mix, port projected change in activity)

Sensitivity Analysis

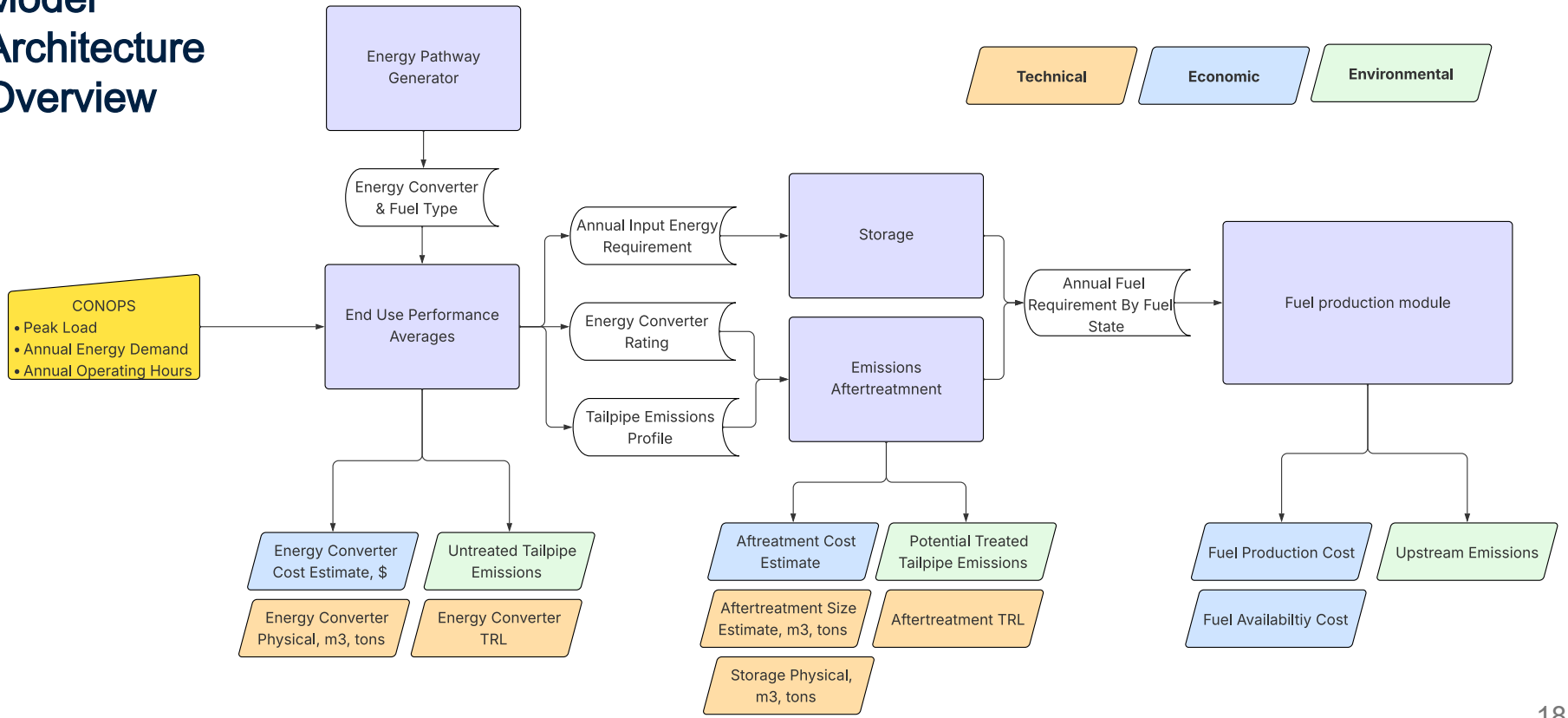
- Identifying make-or-break variables and ranges



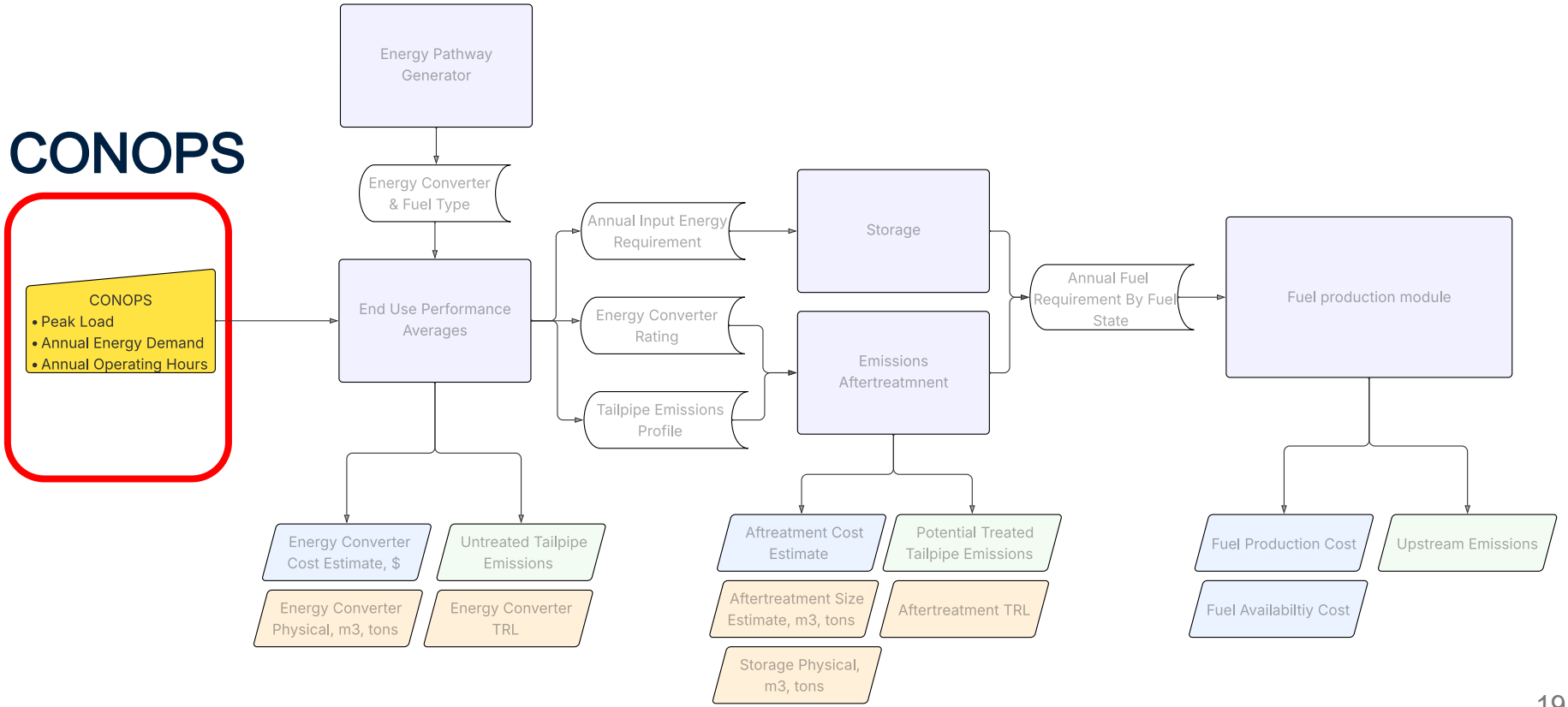
Speculative Design and a Cone of Possibilities, Delve

Point estimates create false precision → fragile decisions optimized for a singular imagined future

Model Architecture Overview



CONOPS


CONOPS
• Peak Load
• Annual Energy Demand
• Annual Operating Hours
Energy Pathway Generator
Energy Converter & Fuel Type
End Use Performance Averages
Annual Input Energy Requirement
Energy Converter Rating
Tailpipe Emissions Profile
Storage
Emissions Aftertreatmnent
Annual Fuel Requirement By Fuel State
Fuel production module
Energy Converter Cost Estimate, $
Untreated Tailpipe Emissions
Energy Converter Physical, m3, tons
Energy Converter TRL
Aftreatment Cost Estimate
Potential Treated Tailpipe Emissions
Aftertreatment Size Estimate, m3, tons
Aftertreatment TRL
Storage Physical, m3, tons
Fuel Production Cost
Upstream Emissions
Fuel Availabiltiy Cost

Primary Input: CONOPS

Describes **how and when** the barge will need to operate around the port

Defines **load profiles, capacity factors,** and **annual energy demand**

- Derived from AIS data, electrical test data, stakeholder input, and assumptions

Serves as model's **front -end input**

- Establishes total energy demand as basis of converter sizing and downstream analysis

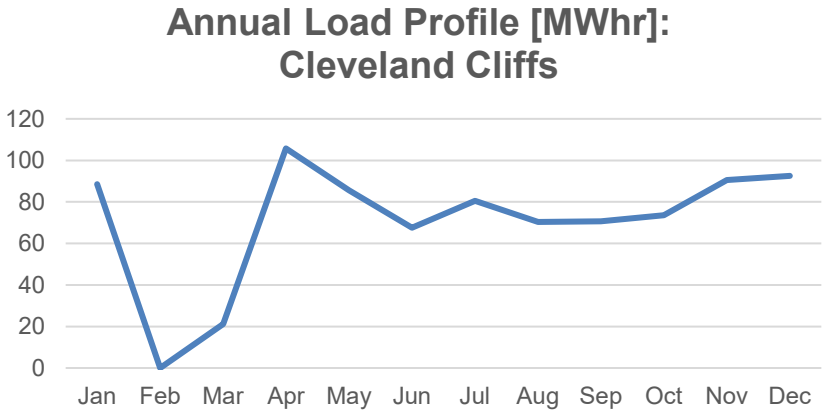
Ship Activity at Cleveland Cliffs

Ship Name	Monthly Hours	Vessel Type
EVERLAST	0	Tug
HERBERT C JACKSON	123	Dry Bulk
HON JAMES L OBERSTAR	288	Dry Bulk
IVER BRIGHT	1	Tanker
KAYE E BARKER	114	Dry Bulk
LEE A TREGURTHA	368	Dry Bulk
NEW YORK	1	Tug
STR WILFRED SYKES	23	Dry Bulk

Primary Input: CONOPS

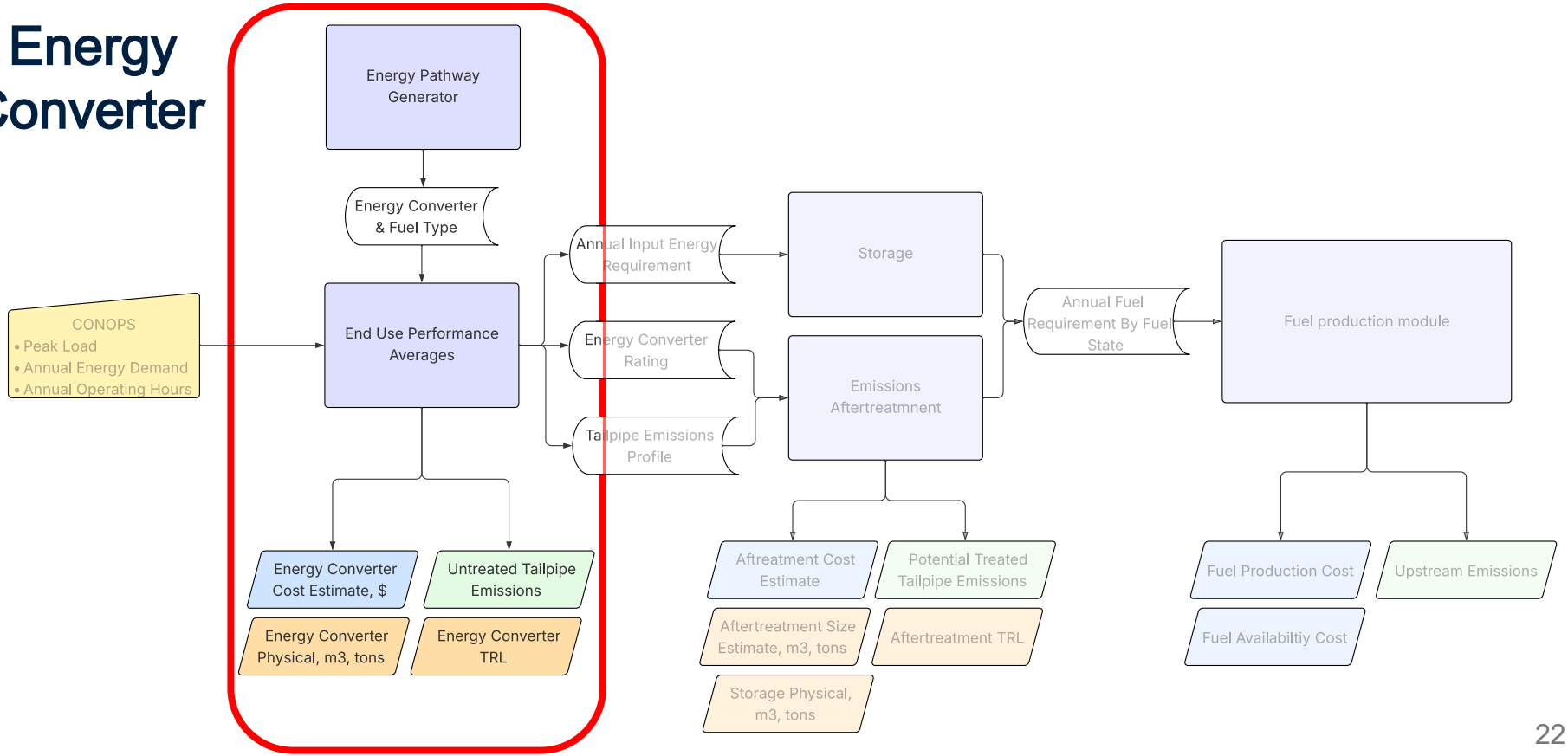
Anticipated Power Req. in Port (kW)		
Ship Type	**Hotel**	**Unloading**
Tug	150	0
Dry Bulk	300	900

Power requirements by ship type and activity state



Integrate with AIS data and assumptions to form terminal load profile

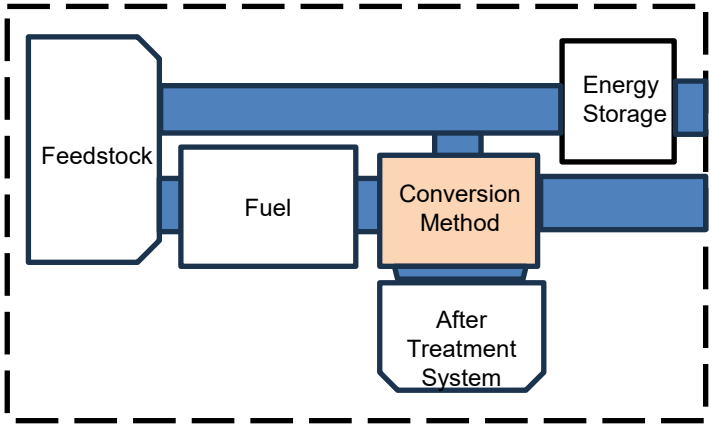
Energy Converter



Energy Converter: Demand to Potential Performance

Translates **port energy demand** to **converter performance**

- Builds **representative energy converters** (ICE, FC, battery) by **fuel type**
  - Averages performance within target power range
  - Carries uncertainty bounds to fuel requirements and TTW emissions
- Defines **untreated tailpipe profile and characteristics**
  - **Efficiency, emissions, sizing, and cost**



Technologies Under Evaluation: Working List

Fuel Type	I.C.E	Fuel Cell	Battery	Turbine
Bio-diesel				
LNG				
Methanol				
Hydrogen				
Ammonia				
LFP				
LTO				
Nuclear				

Converter Module: H2 Fuel Cell, LNG I.C.E.

Using a test case CONOPS

- Target power = 1000 kW
- Job Duration = 8 hours
- Capacity Factor = 0.35

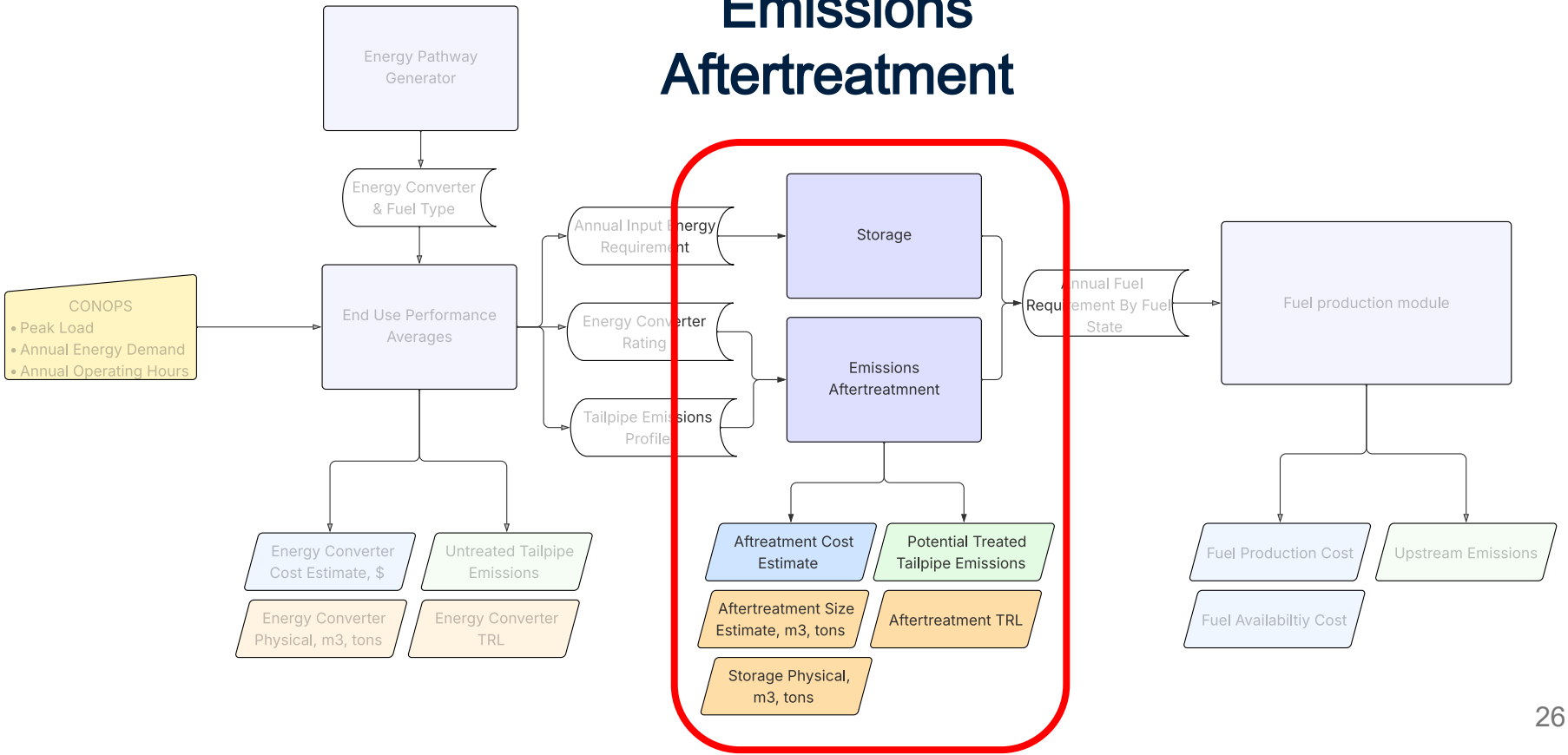
Pathway generator sizes closest to 85% MCR, assuming continuous port side operations

- Stacks fuel cells and batteries
- Efficiency is “best available” data

Full emissions profile acknowledged, just not displayed as minimal SOX and PM for LNG

		LNG_ICE	H2_FC_PEM
Performance	*Efficiency*	44.0 ± 2.0	51.0 ± 2.5
	*Rated Power**	1145	1125
	%MCR	87%	89%
Annual Fuel Requirement [t]		532	181
Annual Emissions	*CO2 [t]*	1380	0
	CH4 [kg]	7052	0
	NOx [kg]	3679	0
	CO [kg]	3373	0
Physical	*Footprint [m2]*	8.71	1.08
	Height [m]	3	2
	No. Units	1	5
CAPEX	*Low [$M USD]*	1.03	3.94
	High [$M USD]	1.72	5.85

Emissions Aftertreatment



Emissions Aftertreatment

Translates raw emissions profile and power demand into treated exhaust performance

- Identifies applicable aftertreatment systems by reading untreated tailpipe emissions
- Applies representative pollutant - specific reduction efficiencies
- Assigns energy penalty factors for efficiency losses/active requirements

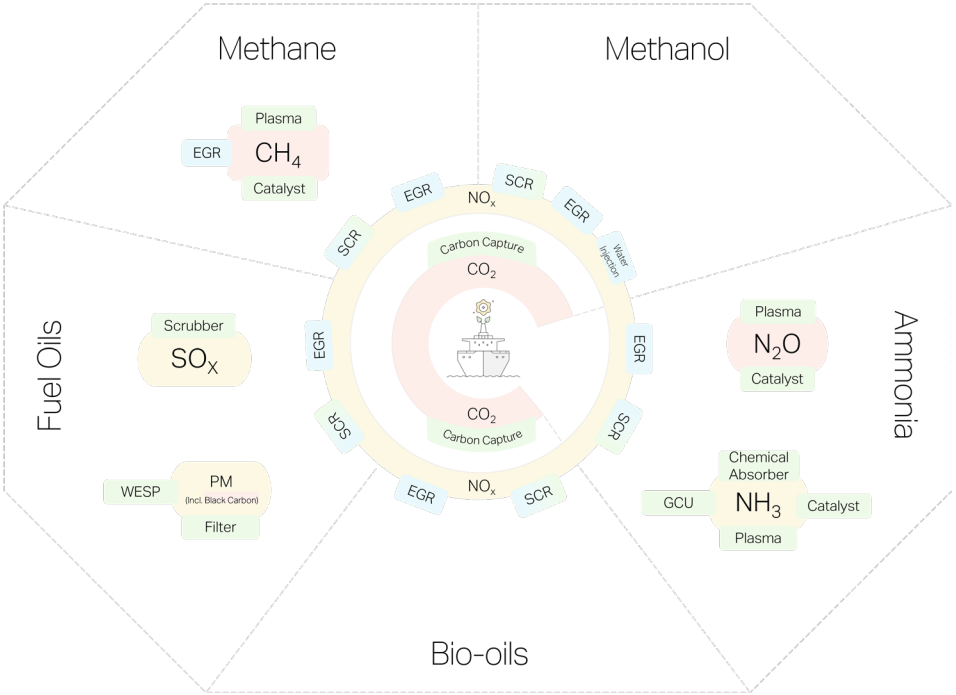
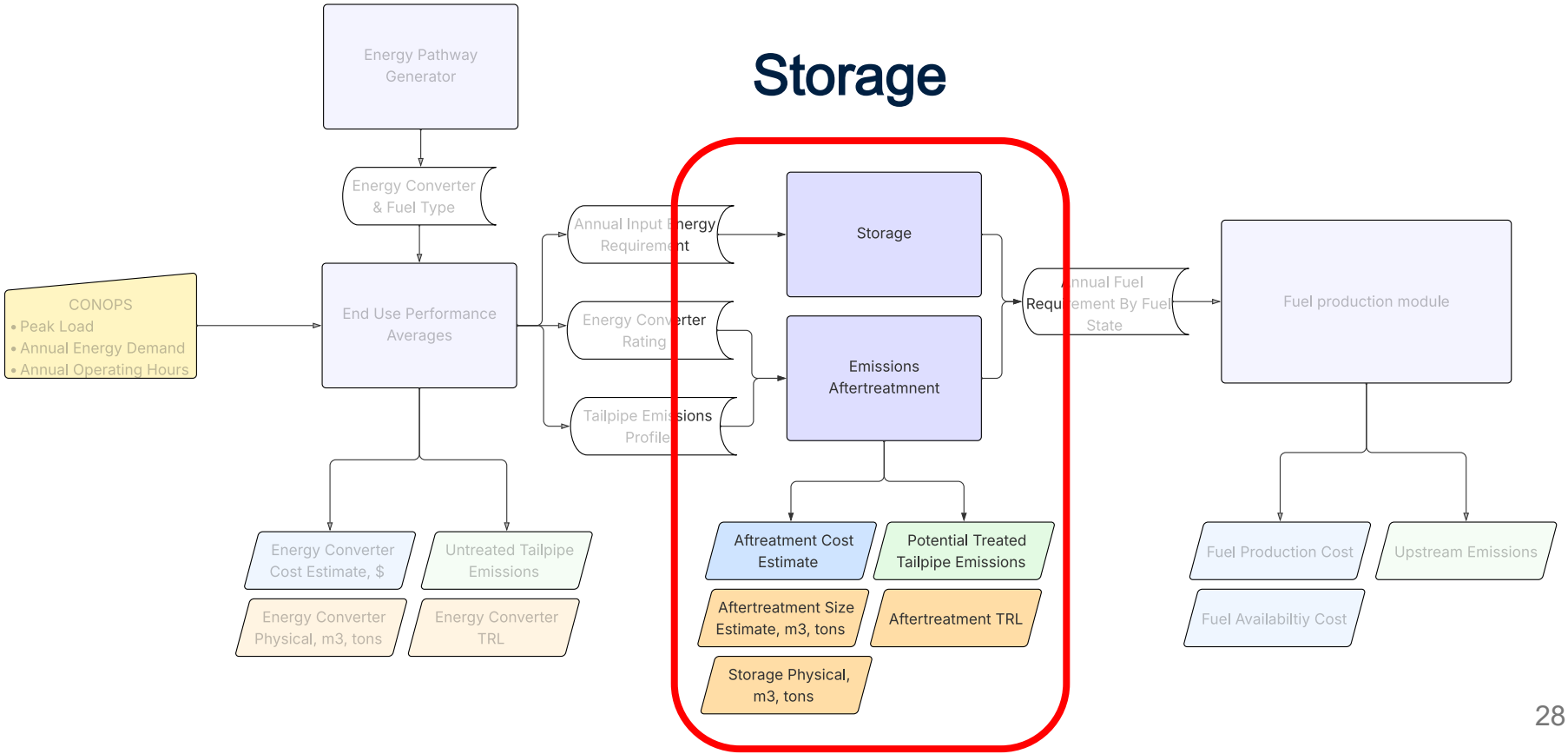


Figure from Maersk-McKenney Center for Zero Carbon Shipping: Determining the Role of Onboard Emissions Reduction Technologies Report, 2022

Storage


Energy Pathway Generator
Energy Converter & Fuel Type
CONOPS
• Peak Load
• Annual Energy Demand
• Annual Operating Hours
End Use Performance Averages
Annual Input Energy Requirement
Energy Converter Rating
Tailpipe Emissions Profile
Storage
Emissions Aftertreatmnent
Annual Fuel Requirement By Fuel State
Fuel production module
Energy Converter Cost Estimate, $
Untreated Tailpipe Emissions
Energy Converter Physical, m3, tons
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Potential Treated Tailpipe Emissions
Aftertreatment Size Estimate, m3, tons
Aftertreatment TRL
Storage Physical, m3, tons
Fuel Production Cost
Upstream Emissions
Fuel Availabiltiy Cost

Storage

Translates energy buffer requirements to storage configuration

- Evaluates applicable storage states by fuel type (ambient, pressurized, cryogenic)
- Determine storage volume and mass from target refueling period

Limited scope currently

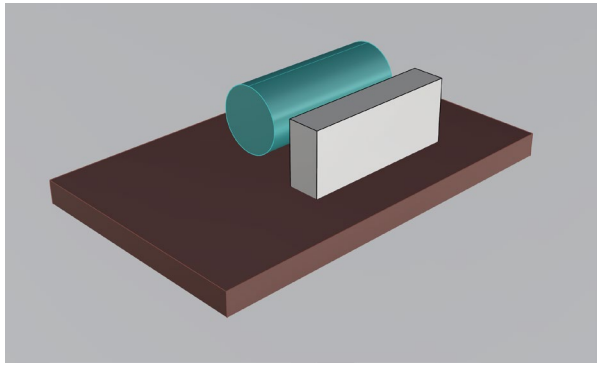
- Developing auxiliary systems – footprint, cost, weight
- Developing tank costing

15 Day Refueling Period

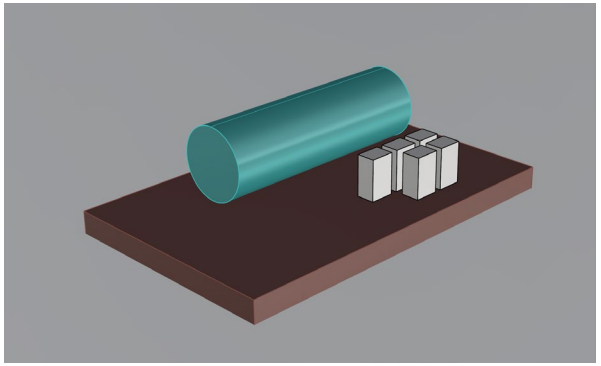
	LNG_ICE	H2_FC_PEM		
		350 bar	*700 bar*	*Liquid*
Volume [m3]	49	332	185	104
Weight [t]	22	7.5	7.5	7.5
Energy Penalty %	1.5	0.5	1	4

Storage: Immediate Technical Check & Visualization

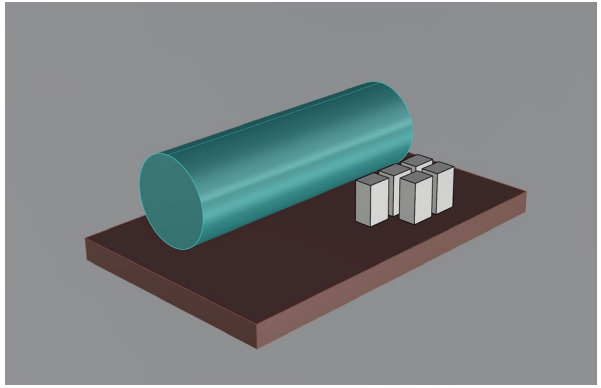
LNG – ICE
-
$49m^3$



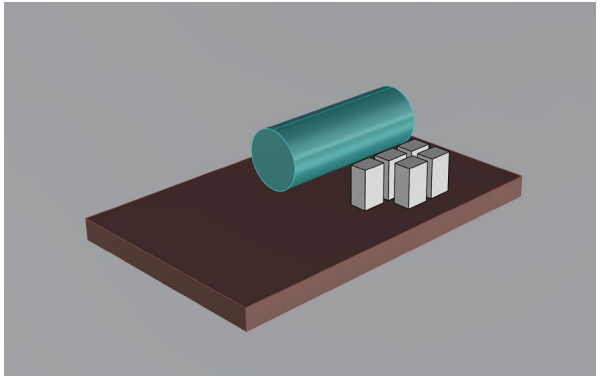
H2 - FC
700 Bar
-
$185m^3$



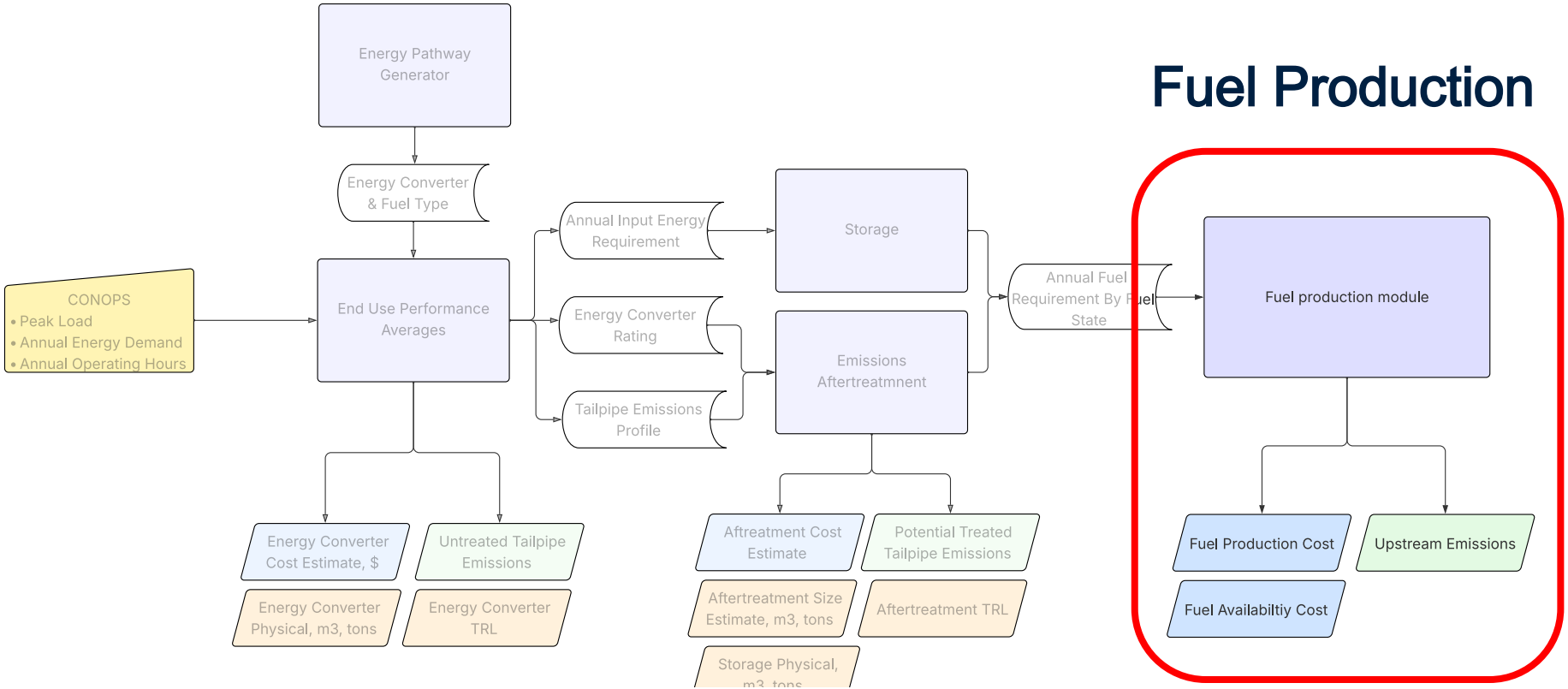
H2 - FC
350 Bar
-
$332m^3$



H2 - FC
Liquid
-
$104m^3$

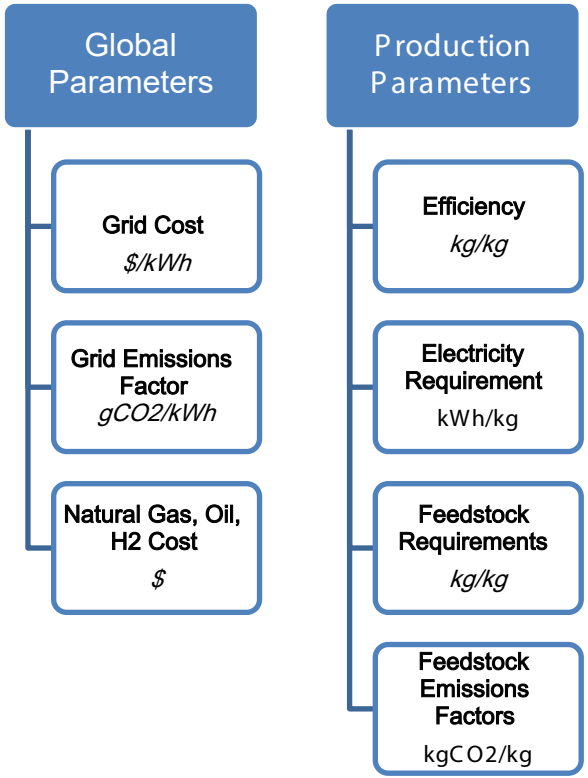


Fuel Production

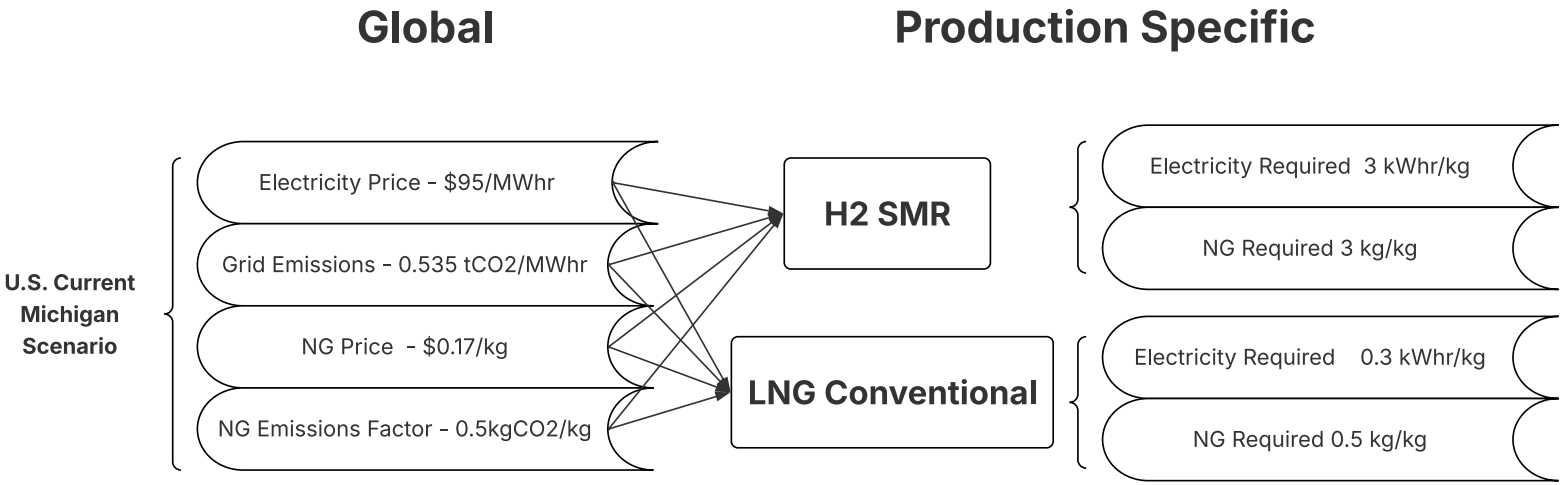


Fuel Production

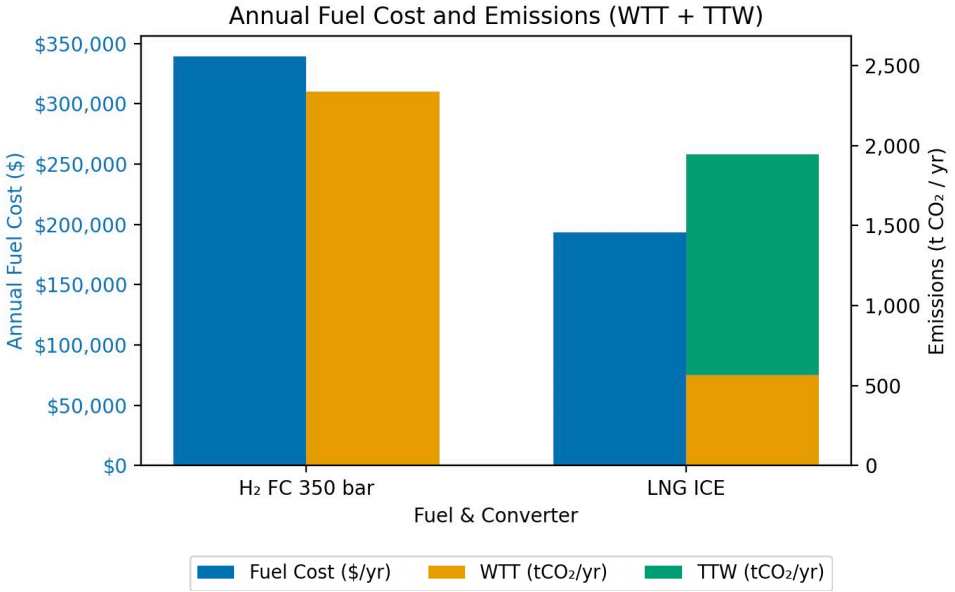
- Focuses on **production methods** , not color labels
- **Global inputs:** grid emissions factor, and grid pricing, scenario overrides
- **Production -specific inputs:** costs and emissions through feedstocks, and process efficiencies
- **Nonsense production pathways are obvious** (H2 by electrolysis with ”grey” grid results in HIGH WTW emissions)
- **High fidelity fuel production allows for regional scenario exploration**



Fuel Production: Hydrogen vs. LNG Inputs



Fuel Production: Hydrogen FC vs. LNG I.C.E



Annual Fuel Cost and Emissions

Pathway	Annual Fuel Cost [$]	WTT [tCO2/yr]	TTW [tCO2/yr]
H2, FC, 350 Bar	339,400	2,336	0
LNG ICE	193,200	567	1379

Calculated using steam methane reforming for gaseous hydrogen

Fuel Production: High Fidelity for Fuel Scenarios

Regional realities matter

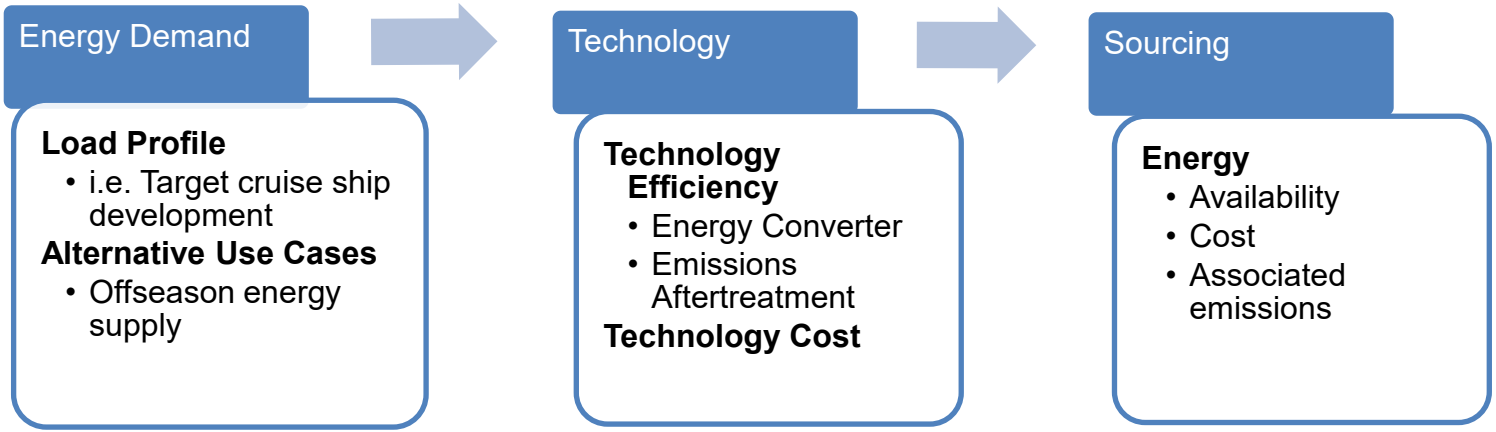
- SE Michigan grid ~= Norwegian grid
- Local feedstock availability can set hard production limits

Implicitly testing fuel “colors” through testing

- Production methods
- Feedstock emissions
- Electricity emissions

Can solve for critical pricing of alternatives

Scenario Building Across Full Spectrum of Model



Can build out test matrices to reflect and test port strategies and tolerances across entire model structure

Managing Stakeholder Narratives & Curiosities

"We have local grey hydrogen - how bad would that be if we used it in the interim before green development?"

"What if lakers end up adopting LNG? Should we prepare with a dual-fuel option?"

"We want to encourage cruise growth in the Great lakes"

"There's local wastewater treatment with bio-gas we could utilize for potential fuel production"

Voicing Potential Scenarios Through Model Inputs

Stakeholder Question	Energy Demand	Technology	Sourcing
H2 Grey-Green Bridge		• Range of FC Efficiencies	• Hydrogen emissions factor • Availability timelines
Waste Water Bio-gas Synergy	• Variable for Offtake Conditions		• Bio-gas cost • Infrastructure shared capital cost
Great Lakes LNG			• LNG pricing • Availability Timelines
Cruise Terminal Growth	• Increase in cruise terminal demand		

Scenarios: From Narrow Modelling to Decision Support

Reveal when options are context - dependent

- Some pathways may only work if infrastructure or policy conditions align

Support risk and robustness analysis

- Success rate across defined scenarios and associated cost of failure

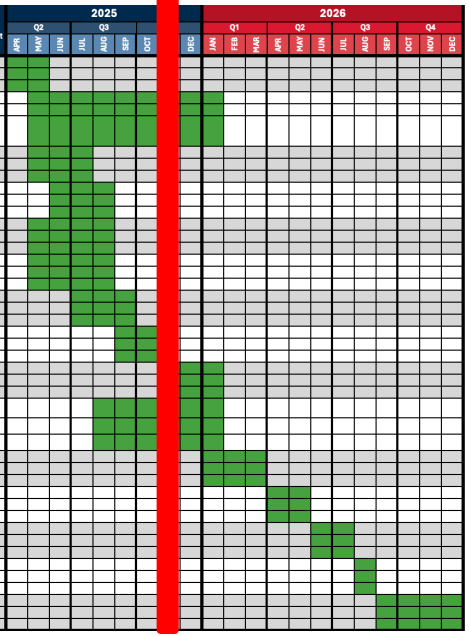
However, human input is required

- Need to construct scenario from human insight and stakeholder input
- Must translate qualitative insights into quantitative parameters

Project Status and Evolution

Current Position

ABS/UM Tasking	Activity Description	Associated Deliverable	Participant	Department	Percent Involvement
0	Project Kickoff and Initiation		ABS	Technology	25%
				Sustainability	25%
			University of Michigan		50%
1	Research, Design and Planning for Power Barge Operations	ABS Task 1 Report detailing literature review summary, findings, and proposed operational profiles for review and selection by the Port of Detroit	ABS	Technology	25%
				Sustainability	25%
			University of Michigan		50%
1.1	Detailed Regulatory Review of Existing Standards		ABS	Technology	50%
				Sustainability	50%
			University of Michigan		0%
1.2	Conduct Stakeholder Workshops to Collect Input (Virtual) and define the operational profile roadmap and the notional concept of operations (CONOPS)		ABS	Technology	10%
				Sustainability	65%
			University of Michigan		25%
1.3	Techno-Economic Assessment Methodology: Developing a comprehensive techno-economic assessment methodology to evaluate various technology, energy, and fuel solutions for a zero-emission power barge concept tailored to the Port of Detroit	University of Michigan Task 1 Report	ABS	Technology	5%
				Sustainability	5%
			University of Michigan		90%
1.4	Social and Environmental Impact Metric: Incorporating social and environmental impact metrics into the assessment methodology to ensure a holistic evaluation of potential solutions	University of Michigan Task 2 Report	ABS	Technology	5%
				Sustainability	5%
			University of Michigan		90%
1.5	Analyze Receiving Ship Requirements Based on Port of Detroit Fleet Servicing Needs		ABS	Technology	20%
				Sustainability	70%
			University of Michigan		10%
1.6	Develop the Operational Profile for Power Barge Operations within the Port		ABS	Technology	25%
				Sustainability	65%
			University of Michigan		10%
1.7	Mapping the NTQ Process for novel technology implementation for proposed power barge profile		ABS	Technology	100%
				Sustainability	0%
			University of Michigan		0%
1.8	Zero-Emissions Power Barge Assessment: Conducting a techno-economic assessment using the developed methodology to identify concepts for a zero-emission power barge that are economically viable, technically feasible, and socially responsible, based on the unique operational profile of the Port of Detroit	University of Michigan Task 3 Report	ABS	Technology	5%
				Sustainability	5%
			University of Michigan		90%
2	Conduct a HAZID/HAZOP and risk assessment workshop with port stakeholders on the defined operational profile (2 day in-person workshop in Michigan conducted by ABS)	ABS Hazard Register	ABS	Technology	90%
				Sustainability	0%
			University of Michigan		10%
3	Conduct a Port-wide Maritime Electrification Study to calculate the potential emissions reductions with proposed power barge deployment	ABS Task 3 Report summarizing findings	ABS	Technology	0%
				Sustainability	100%
			University of Michigan		0%
4	Power Barge Implementation and Procurement Plan detailing supplier mapping, proposed path towards classification and statutory approval	ABS Task 4 Report summarizing Path towards commercialization	ABS	Technology	50%
				Sustainability	50%
			University of Michigan		0%
5	Conduct Knowledge-Sharing Workshops with Stakeholders (2 consecutive day in-person workshops in Michigan, ABS and UM to co-host)	ABS Workshop Summary to be provided 30 days after event	ABS	Technology	25%
				Sustainability	25%
			University of Michigan		50%
6	Final Reporting	ABS Final Report of Findings	ABS	Technology	50%
				Sustainability	50%
			University of Michigan		0%



Beyond Detroit: Scalable for Maritime Decisions

Immediate Applicability

- Other Ports: Customize CONOPS, fuel availability, local constraints
- Vessel powering evaluation and design
- Quantifying demand for alternative fuels/energy in different applications

Further Development

- Current state: complete view of relevant pathways and trade -offs, requires significant input and iteration
- Next Phase: Decision tool that can select ”optimal” energy pathway for stakeholder context and strategy
- Vision: Stakeholders set priorities, tool surfaces strongest options

Thank You – Questions?

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