HYDROGEN TECH WORLD CONFERENCE 2025

CONSULTING ENGINEERS

ENHANCING TECHNO-ECONOMIC FEASIBILITY IN POWER-TO-X PROJECTS THROUGH SYSTEM MODELLING AND OPTIMIZATION

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Agenda

01

ILF at a Glance

ILF CONSULTING ENGINEERS PROVIDES COMPREHENSIVE ENGINEERING SERVICES FOR MAJOR INDUSTRIAL AND INFRASTRUCTURE PROJECTS.

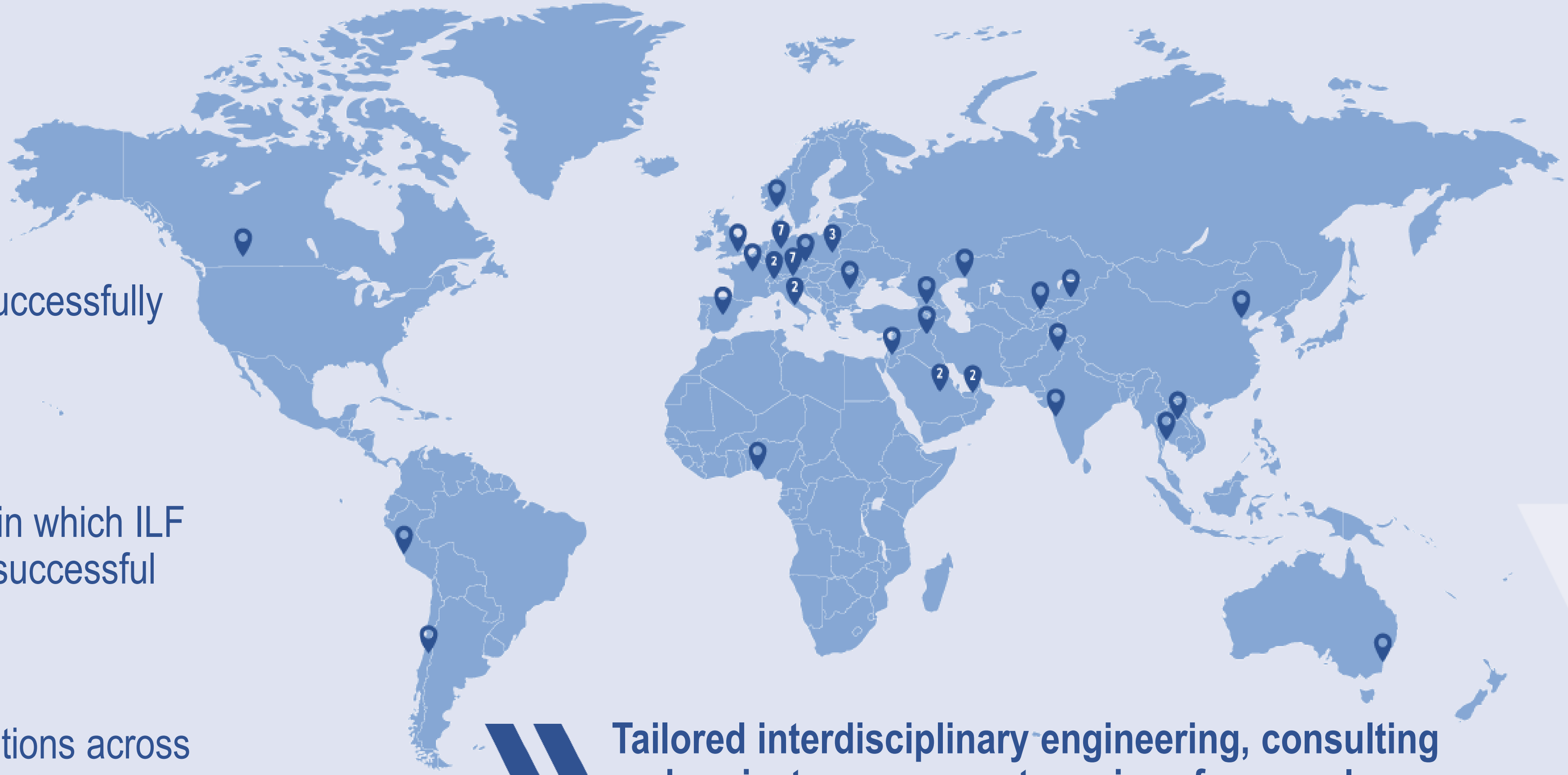
ILF CONSULTING ENGINEERS

ILF in numbers

11,000+
» Projects successfully executed

150+
» Countries in which ILF has been successful

45+
» Office locations across five continents



3,000+
» Employees worldwide

400+
» Million € revenue

55+
» Years of experience

Tailored interdisciplinary engineering, consulting and project management services for complex industrial infrastructure projects

PTX OPTIMIZATION PROJECTS

ILF'S PROVIDES ENGINEERING AND CONSULTING SERVICES IN VARIOUS BUSINESS AREAS WHICH COVER THE ENTIRE VALUE CHAIN OF POWER-TO-X PROJECTS.

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Green Molecule Economy - ILF is your reliable partner for future oriented projects

Renewable Energy

- ILF offers optimized, state-of-the-art solutions for a **wide array of energy transition initiatives.**
- ILF has **deep expertise in energy & climate protection** including solar and wind power.

Hydrogen

- ILF is **actively involved in process industry** and energy related projects.
- ILF's expertise covers the **full value chain** of **hydrogen energy from sourcing to exports.**

Power to X

- ILF offers **tailored solutions** for the implementation of P2X projects & cost benchmarking for production, treatment, transportation, use and storage.

ILF'S EXTENSIVE PROJECT EXPERIENCE ACROSS ALL PROJECT PHASES PROVIDES VALUABLE INSIGHTS FROM DIVERSE PERSPECTIVES, DRIVING SUCCESSFUL OPTIMIZATION PROJECTS.

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<table>
<tr><th>Project Life Cycle</th><th>APPRAISE</th><th>SELECT</th><th>DEFINE</th><th>EXECUTE</th><th>OPERATE</th><th>CLOSE</th></tr>
<tr><td rowspan="5">CONSULTING</td><td>Market Analysis</td><td colspan="2">Financial Advisory</td><td colspan="2">Lender‘s Technical Advisory (TA)</td><td></td></tr>
<tr><td>Master Planning</td><td colspan="4">Transaction Advisory, Due Diligence (DD)</td><td></td></tr>
<tr><td colspan="2">Institutional Analysis</td><td colspan="2">Institutional Strengthening</td><td>O&M* Consultancy</td><td></td></tr>
<tr><td>Project Screening</td><td colspan="2">Public Private Partnership (PPP) Advisory</td><td>Dispute Resolution</td><td>Optimisation Studies</td><td></td></tr>
<tr><td>Pre-Feasibility</td><td colspan="2">Environmental Social Impact Assessment (ESIA)</td><td></td><td></td><td></td></tr>
<tr><td></td><td colspan="3">Energy System Modelling & Optimization</td><td></td><td></td><td></td></tr>
<tr><td rowspan="5">ENGINEERING</td><td colspan="4">Owner‘s Engineer</td><td>Integrity Assessment</td><td>Decommissioning</td></tr>
<tr><td></td><td colspan="3">Engineering Procurement Construction Management (EPCM)</td><td></td><td></td></tr>
<tr><td>Feasibility Study</td><td>Conceptual Design</td><td>Basic Design</td><td>Guide Design</td><td>Rehabilitation</td><td></td></tr>
<tr><td></td><td>Selection Studies</td><td>FEED*</td><td>Detailed Design</td><td>Modification Design</td><td></td></tr>
<tr><td></td><td></td><td>Permit Engineering</td><td>Design Review</td><td>O&M* Support</td><td></td></tr>
<tr><td rowspan="5">PROJECT MANAGEMENT</td><td>Project Organisation</td><td colspan="3">Project Management Consultancy (PMC)</td><td>Operations Superviss.</td><td></td></tr>
<tr><td></td><td colspan="3">Risk Management</td><td></td><td></td></tr>
<tr><td></td><td colspan="3">Stakeholder Management</td><td></td><td></td></tr>
<tr><td></td><td>Execution Planning</td><td>Procurement</td><td>Supply Chain Mngmt</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td>Construction Superv.</td><td></td><td></td></tr>
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FEED = Front End Engineering Design
FS = Feasibility Study
O&M = Operations and Maintenance

02

Why Energy System Modelling & Optimization for PtX projects

WHAT IS A PTX SYSTEM?

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System Components – Design Variables

» Renewable power

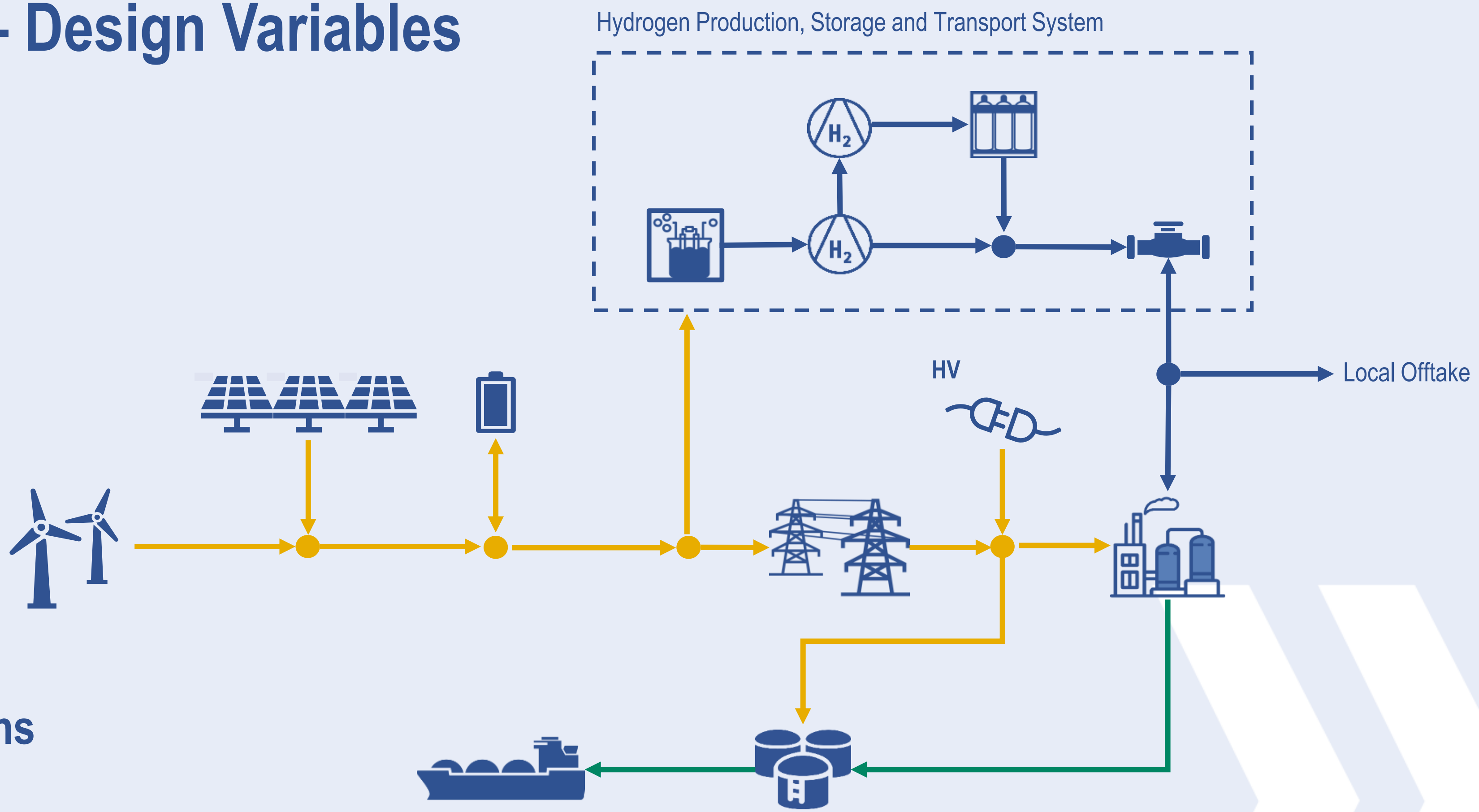
» Energy Storage

» Hydrogen Plant

» Hydrogen Storage

» Synthesis Plant

» Alternative Transport Options



WHY DO WE USE OPTIMIZATION FOR GREEN MOLECULE PRODUCTION? – IT IS A PROCESS TO SOLVE THE GREATEST CHALLENGES FACED BY THE SECTOR.

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New Technical Challenges For The Industry

» **Fluctuating renewable power**

» Process plant **load constraints**

» **Storage** requirements

» **Architecture** selection and **capacity** definition

» **Sustainability / low carbon** compliance

» **Project development** challenges

Simulation & Optimization – the Solution

» **Compares quantitatively** various system architectures

» Defines **optimal system capacities**

» Simulates optimal **operations respecting the technical feasibility**

» Validates the project **business case**

…whilst minimizing **total lifespan cost!**

PROJECT DEVELOPMENT STRATEGY THAT INCLUDES MODELLING AND OPTIMIZATION PRACTICE SINCE THE EARLY PHASES MINIMIZES RISK AND MAXIMIZES VALUE

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	FEL 1 - Appraise	FEL 2 - Select	FEL 3 - Define
Traditional Project Development Risks	» Undefined system architecture, capacity, and production targets » Ambiguous levelized cost of production » Low confidence in project performance	» Lack of operational modelling leads to poor sizing decisions » Limited capability of comparing alternative concept option » Low confidence in performance	» High risk of wasted effort on suboptimal concept » Unclear production and cost projections » Low confidence for investment decision
+ System Modelling and Optimization Iterations	» Early performance mapping of architectures » Accurate levelized cost modelling » Early assessment of techno-economic feasibility based on digital twin modelling	» Quantitative comparison of alternatives » Engineering hours spent for the optimal design only » Confirmation of project performance based on digital twin modelling	» Validation of concept prior to FEL-3 engineering » Lower risk of required conceptual changes during execution » Detailed performance modeling for investment decision

03

Methodology and Case Studies

MODEL AND RESULTS ARE AS GOOD AS THE INPUT ASSUMPTIONS…

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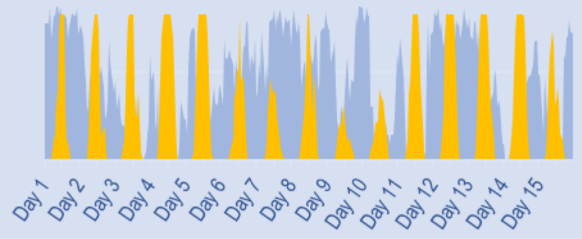
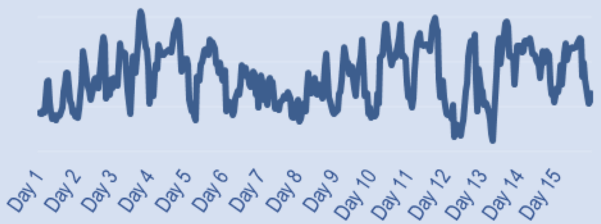
Inputs

RES capacity factor profiles



Electricity price profiles

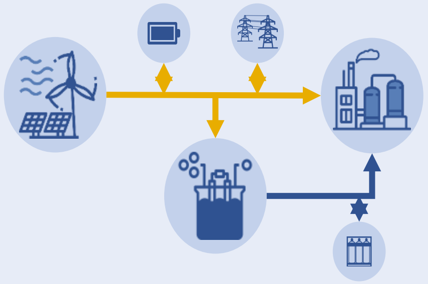


Input parameters and constraints

- Plant efficiencies & load flexibilities
- OPEX/CAPEX, financial assumptions
- Transmission Capacities
- Technical parameters & constraints
- Max. number of shutdowns
- Degradation of facilities…

Digital Twin

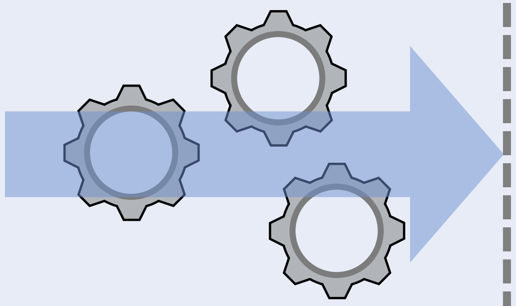
The model replicates realistic operations



While reflecting the relevant techno commercial inputs

Optimizer

Optimization to meet business case objectives



i.e., Levelized cost of production minimization, production target

Results & Visualization

Optimized

Optimized to achieve modelled objective

- Facility Capacities
- RFNBO compliance
- Total production / production profiles
- Plant utilization
- KPIs

CASE STUDY 1 – EARLY ADOPTION OF OPTIMIZATION AND MODELLING METHODOLOGIES - LCOA ANALYSIS OF GREEN AMMONIA PRODUCTION OPTIONS

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Project Information

Cost and Market Driven Approach

FEL 1 - Appraise	FEL 2 - Select	FEL 3 - Define
» FEL 1	» FEL 2 study	» FEL 3 (FEED)

Client	Confidential
Time Frame	2025
Project Info	Up to 3.5 GW PV Solar Grid connection for aux. consumptions c.a 1 MTPA ammonia
Service	FEL-0 Levelized cost and optimization study of different production options ILF in-house PtX optimization and modelling tool

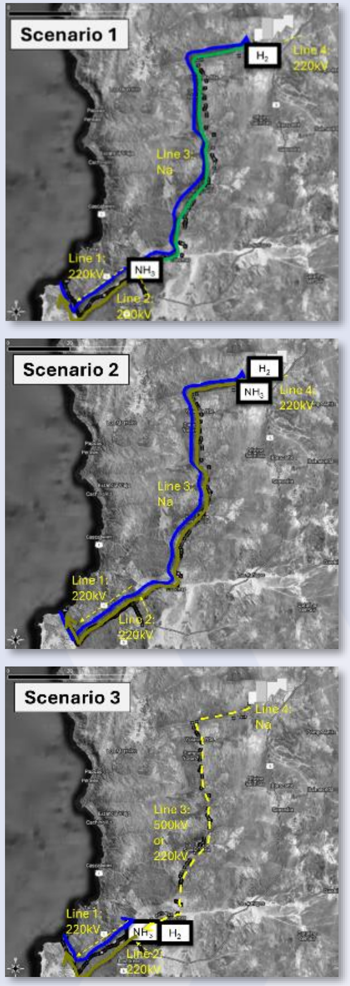
Added value:

- » Early performance mapping of architectures
- » Accurate levelized cost modelling in early stage
- » Higher confidence for decision gate

CASE STUDY 1 – ILF CONDUCTED A MODELLING AND OPTIMIZATION STUDY TO ANALYZE THE LEVELIZED COST OF PRODUCTION FOR THREE MAIN ARCHITECTURE OPTIONS

Scenarios

Scenario	Upstream Block	Connection Upstream/ Downstream Block	Downstream Block	Port
Scenario 1		H2 Pipeline		Ammonia Secondary Storage + Offtake Port Facilities
Scenario 2		Ammonia Pipeline		Ammonia Secondary Storage + Offtake Port Facilities
Scenario 3		HV Line Power Transmission		Ammonia Secondary Storage + Offtake Port Facilities



CASE STUDY 1 – ILF OPTIMIZATION STUDY PROVIDED A VALUABLE ANALYSIS THAT GUIDED THE CONCEPT SELECTION AND ENGINEERING DEVELOPMENT, BRIDGING THE TECHNICAL AND COMMERCIAL FEASIBILITY

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» Analysis – interesting findings

Legend: CAPEX / OPEX

Power/BESS
Hydrogen
Ammonia
Water
Other

Category Contribution:
1. Power
2. Hydrogen
3. Ammonia
4. Water
5. Other

Main project groups LCOA contributors:

1. Electrolysis
2. Solar PV
3. Ammonia ASU

CASE STUDY 2 – DUQM PORT GREEN AMMONIA - OPTIMIZATION OF GW SCALE GREEN HYDROGEN AND AMMONIA PROJECT IN FEL-1

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Project Information

Cost and Market Driven Approach

FEL 1 - Appraise	FEL 2 - Select	FEL 3 - Define
» **FEL 1**	» FEL 2 study	» FEL 3 (FEED)

Client	Confidential
Time Frame	2024 – Ongoing
Project Info	Multi GW facility in DUQM development area. 1+ Million Tons of Green Ammonia per Year & Local Hydrogen Offtake
Service	Feasibility Study and Pre-FEED scoping RFI process **PLEXOS techno commercial system modelling and optimization including phasing**

Added value:

- Accurate cost and production modeling for optimal concept
- Efficient engineering effort
- Higher confidence for next project phase gate

CASE STUDY 2 – ILF CONDUCTED AN OPTIMIZATION STUDY FOR A GREEN HYDROGEN AND AMMONIA PROJECT IN OMAN, DETERMINING THE OPTIMAL PLANT CONFIGURATION, SIZING, AND PHASED PROJECT IMPLEMENTATION.

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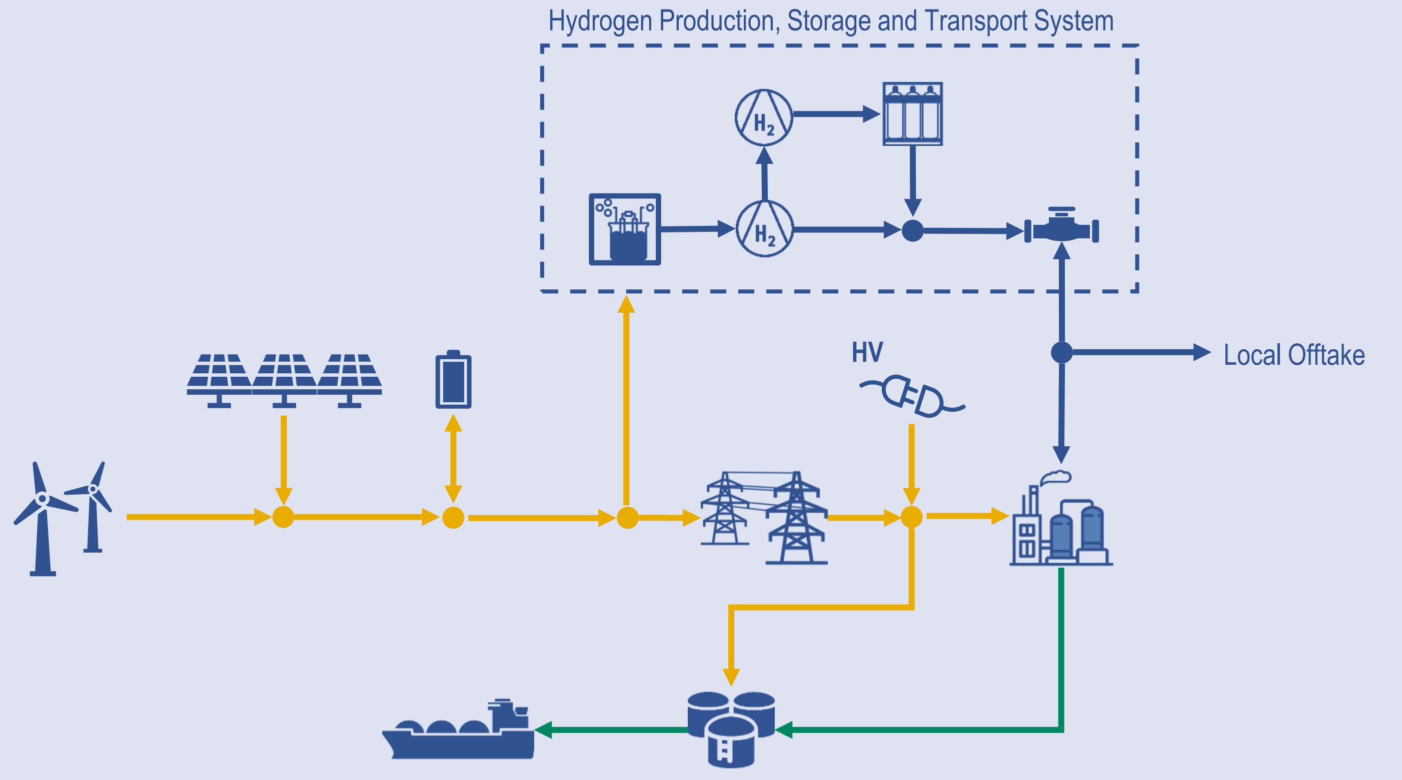
A brief insight into the project for a production of 1+ millions tons of Ammonia per year

Optimization Technical Objectives

- Business case framing/proofing - Minimization of LCOH and LCOA
- Optimal Production Target Selection
- System architecture selection – Island vs. grid connection, Line pack, BESS, H2 Storage
- Compliance with "green product regulations" for target off-take markets (e.g., RFNBO)
- Definition of sizing for the engineering development

Project Basic Design



CASE STUDY 2 – ILF OPTIMIZATION STUDY PROVIDED A VALUABLE ANALYSIS THAT GUIDED THE CONCEPT SELECTION AND ENGINEERING DEVELOPMENT, BRIDGING THE TECHNICAL AND COMMERCIAL FEASIBILITY

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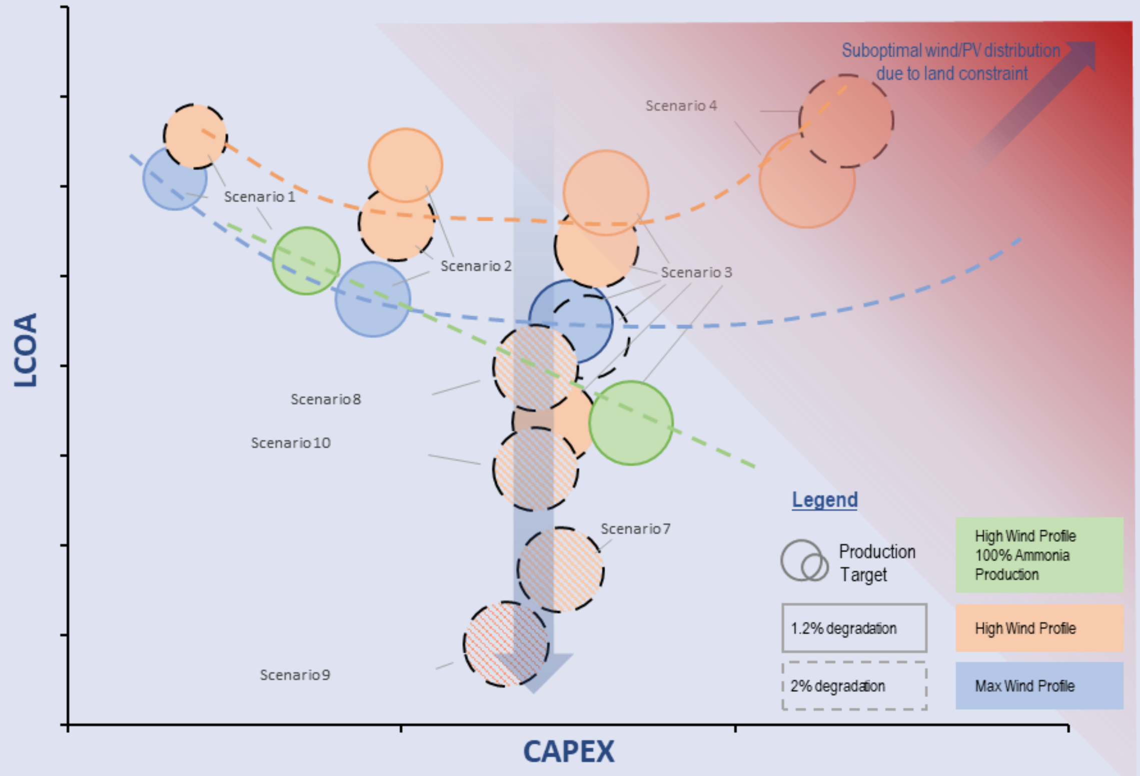
Analysis – interesting finding



Some key findings:

- The Project highlighted the importance of applying an interdisciplinary approach → In combination with energy yield assessment and Request For Information (RFI) process
- The PV and wind layout that minimizes the LCOA does not correspond to the LCOE optimal design
- Production maximization does not correspond to LCOA minimization
- Having access to common transport infrastructures can improve the business case (e.g. HVL, Line pack and grid connection), however, the main LCOA driver remain the CAPEX

CASE STUDY 3 – EVERWIND FUELS – CONCEPT VALIDATION STUDY THROUGH MODELLING AND OPTIMIZATION PRIOR TO FEL-3

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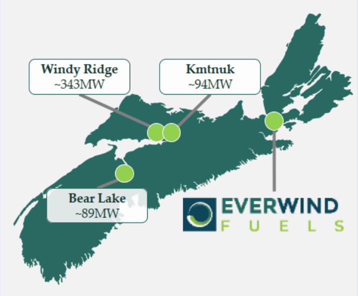
Project Information

Schedule Driven Approach

FEL 1 - Appraise	FEL 2 - Select	FEL 3 - Define
» FEL 1	» FEL 2 study	» FEL 3 (FEED)

Client, Time Frame, Project Info

2023 – ongoing



EverWind Nova Scotia Phase 1

240,000 Tonnes Annual Green Ammonia Production

650MW Onshore Wind Capacity

280MW Electrolyzer Capacity

150MW & 100MWh Solar & Battery Capacity

Service

- Owner's Engineer, Design Review of FEL-2 and FEL-3
- Project Management Consultant (PMC)
- System Modelling with PLEXOS

Added value:

- » Validation and partial improvement of an already defined concept
- » Modelling and simulation to demonstrate the techno-commercial feasibility to support FID (Final Investment Decision)
- » Confidence boost for investors, off-takers, and stakeholders

CASE STUDY 3 – THE ENERGY SYSTEM MODELLING AND OPTIMIZATION STUDY HAD THE OBJECTIVE OF DEMONSTRATING THE TECHNO-ECONOMIC FEASIBILITY OF A FEL 2 CONCEPT

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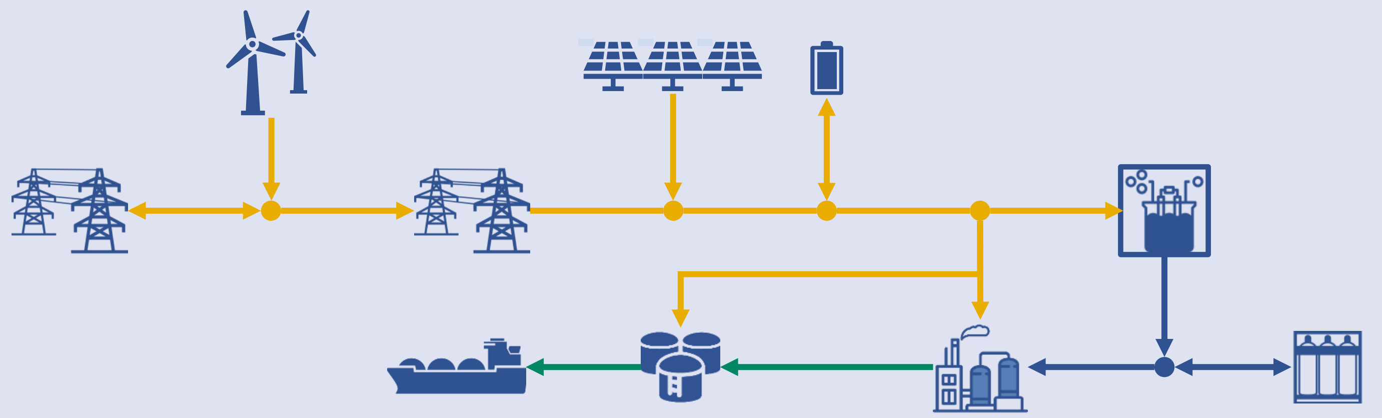
A brief insight into the project for a production of 240 000 tons of Ammonia in Atlantic Canada

Optimization Technical Objectives

- Detailed LCOA calculation
- Power supply concept and capacity sizing
- Energy storage Vs. gas storage
- Plant operations optimized to minimize LCOA
- Comparison of different electrolysis technologies and vendors
- Assess feasibility of green ammonia plant operations coupled with fluctuating power supply

Project Basic Design



The main goal of the optimization was the ***validation of the FEL-2 concept,*** *evaluating performance and further optimizing the renewable power supply concept*

CASE STUDY 3 – ILF PROVIDED A STUDY TO SIZE THE POWER SUPPLY AND STORAGE CONCEPT TO MEET THE TECHNICAL CONSTRAINTS WHILE MINIMIZING THE LEVELIZED COST OF AMMONIA.

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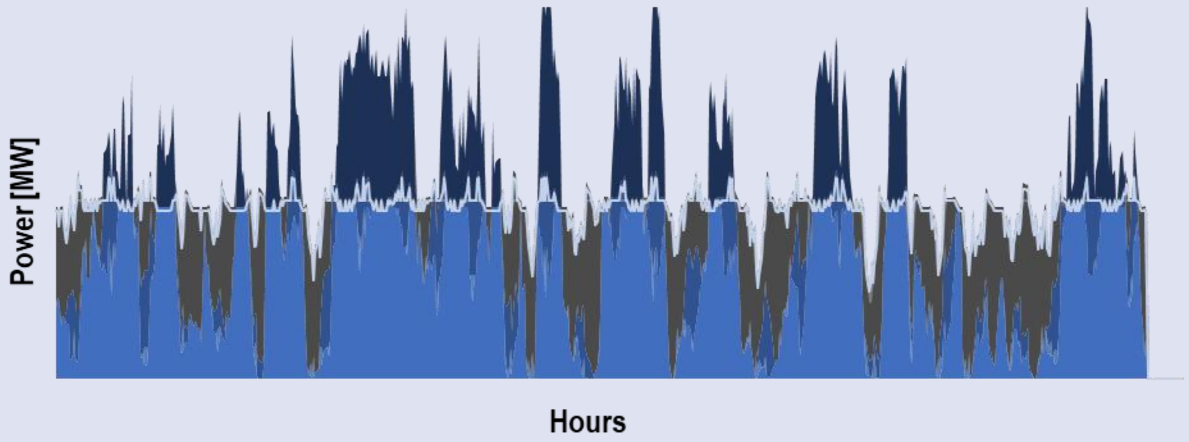
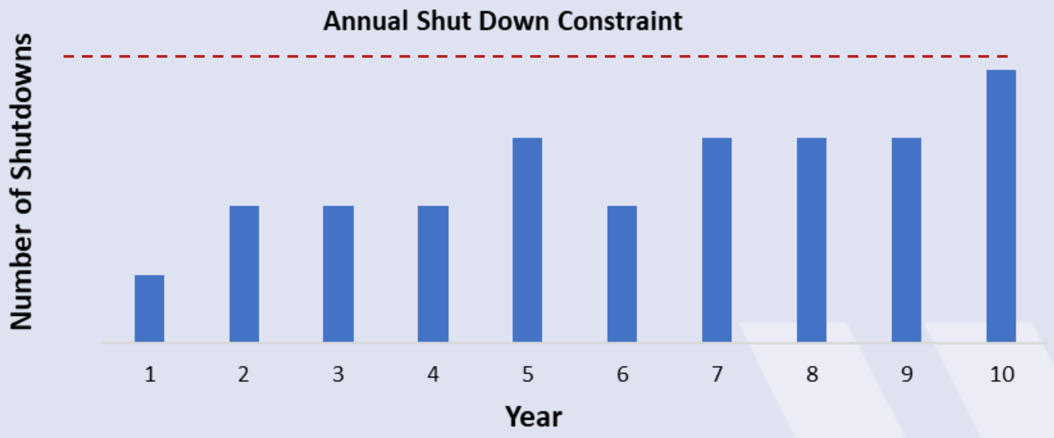
Post Sizing Analysis

Commodity Flow Analysis



Analysis on the techno-commercial implications of a different mix of wind, PV, and grid power and storage options.

Resilience Testing



Testing the optimized facility capacities against plant shutdowns and ramping constraints initiated by intermittent renewables

UTILIZING INDUSTRY-LEADING MODELLING AND OPTIMIZATION METHODOLOGIES IS A PREREQUISITE FOR THE SUCCESSFUL DEVELOPMENT OF A PTX PROJECT

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Why is it necessary?

- The **engineering development** requires a quantitative methodology to determine the optimal concept selection
- **Project developers** need to optimize resources and want to maximize the project value
- **Investors** require the confidence in the feasibility of the business case
- **Off-takers** require the confidence that the project will deliver

What PtX Modelling & Optimization offers:

- **Selection of the optimal** system configuration and sizing
- **Maximization of the project** value and reduction of project **development risk**
- **Validation of a business idea** demonstrating that all key techno-economic challenges have been addressed in due time

Thank you for your time and engagement.

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