



Power-to-X Production in Colombia

Study of Fraunhofer ISE within the framework of the Colombian-German Dialogue on re-industrialization via renewable hydrogen

Christoph Hank, Lucas Edenhofer, Friedrich Mandler, Marius Holst, Christopher Hebling
Kickoff Meeting, 27th September 2023
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Agenda



**The Fraunhofer Institute for Solar Energy Systems
ISE, Freiburg, Germany**

The PtX Supply Chain

The Study for PtX Production in Colombia

- **Overview and project goal, key results**
- **Work packages**

The Fraunhofer Institute for Solar Energy Systems ISE

Performing research for the energy transition for over forty years



The Institute in Numbers

Institute Directors:

Prof. Dr. Hans-Martin Henning

Prof. Dr. Andreas Bett

Employees: ca. 1,400

Budget 2021:

Operation €104.4 million

Investment €12.3 million

Total €116.7 million

Founded in 1981

The Fraunhofer Institute for Solar Energy Systems ISE

Performing research for the energy transition for over forty years



Photovoltaics

Energy Efficient Buildings

Solar Thermal Power Plants and Industrial Processes

Power Electronics, Grids und Intelligent Systems

Hydrogen Technologies and Electrical Energy Storage

Fuel Cell Systems

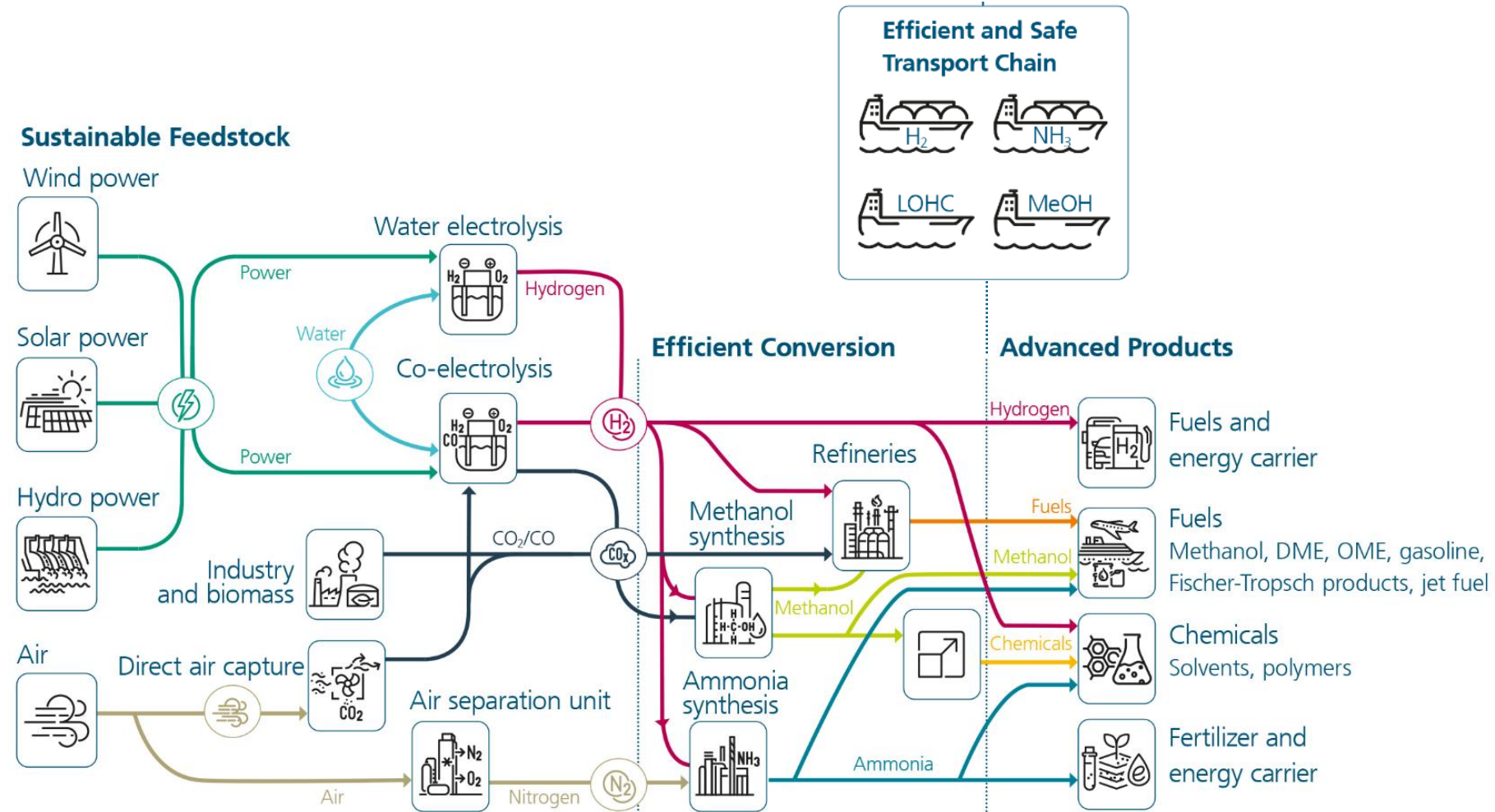
Sustainable Synthesis Products

Electrolysis and Power-to-Gas

Power-to-X Supply Chains at Fraunhofer ISE

Overview

- Production and Import of hydrogen and derivatives as a central element of a future sustainable energy system
- Focus of our ongoing analyses:
 - Liquid hydrogen (LH₂)
 - Ammonia (NH₃)
 - Methanol (MeOH)
 - efuels (e.g. DME, OME, aviation fuel)
 - Gaseous hydrogen (pipeline)



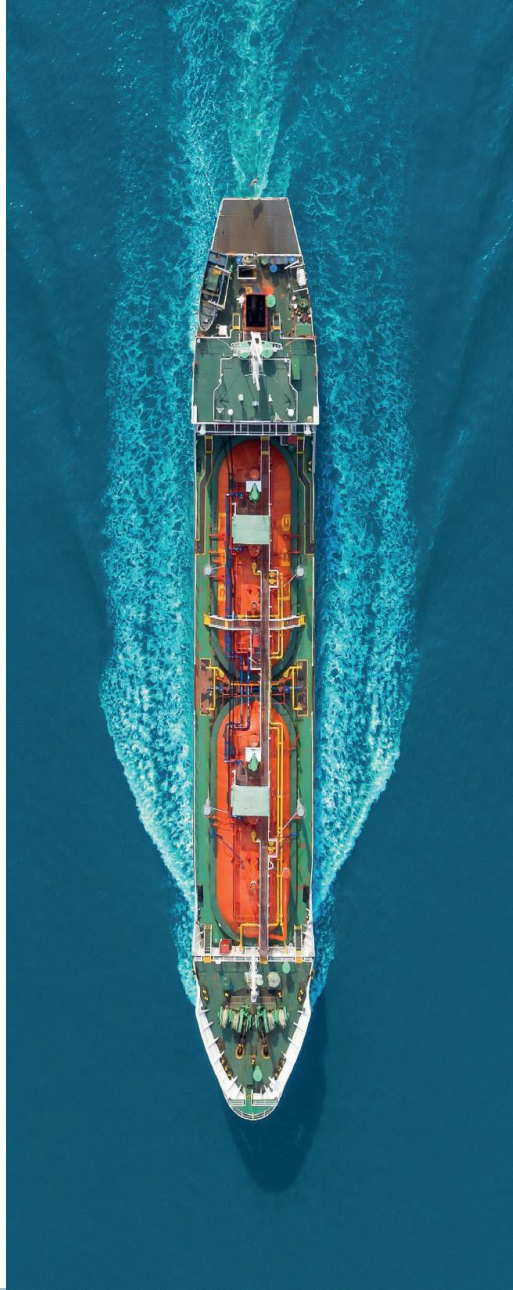
PtX Study for the Colombian-German Dialogue

Project goal

A **techno-economic assessment** of different production paths **for green hydrogen and its derivatives**, taking into account **the potential for renewable energies** as well as **local infrastructural conditions, synergies and the needs of local stakeholders**.

Key results

Local generation and (export) supply costs (incl. long distance transport) of liquid hydrogen, ammonia and methanol for selected sites, potential analysis for renewable electricity production (onshore wind and PV) power generation in Colombia, identification and mapping of relevant infrastructure.



Project Team and Work Packages

- **Project phase:** July 01, 2023 - March 31, 2024 (9 months)
- **Staff involved:**
 - Dr. Christoph Hank: Project management, synthesis pathways
 - Marius Holst: Simulation of PtX pathways, hydrogen production and conversion
 - Lucas Edenhofer: GIS Analysis of renewables potential analysis and overview of relevant infrastructures in Colombia
 - Prof. Dr. Christopher Hebling: Consulting for any hydrogen and power-to-X topics in Colombia, Germany and internationally
- **Work packages:**
 - WP1: RE potential analysis and overview of relevant infrastructures in Colombia
 - WP2: Technoeconomic simulations and optimizations for Power-to-X production and supply chains
 - WP3: Workshops and reporting



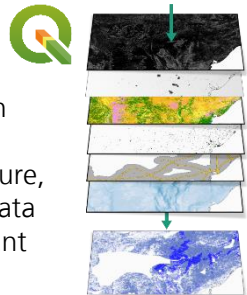
Techno-Economic Optimization of PtX Supply Chains at Fraunhofer ISE

General Methodology

Data Input

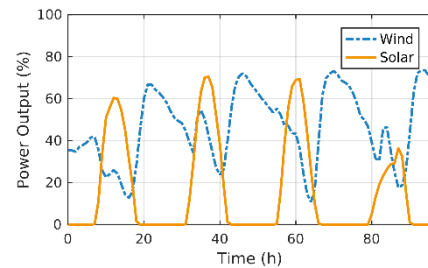
Location Parameters (capital costs, grid power costs)
 Export destination
 Location related boundaries (Desalination required, max. available land)
Internal Database for technical and economical parameters for system components (Efficiencies, Capex, Opex, etc.)

GIS analysis of countries to identify best suited regions taking land use, topology, population density, infrastructure, weather data into account



Preparing

Generation of **annual wind and solar** timeseries based on satellite data from the past 10 years (TMY) or user specific input timeseries



Automatic **Transport route analysis** based on real world shipping routes



System Optimization

Complete **PtX production and supply chains** (RE, electrolysis, H₂-liquefaction/ synthesis, transport,...)
 System optimization using **Genetic Algorithm (GA)** to solve complex problems
 Dynamic, **non-linear modelling** of PtX production plants
 Considering of **operation management** taking component behaviors into account, e.g., limited part load operation of synthesis (continuously running process)

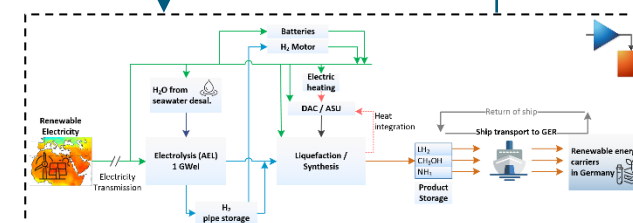
Strong simulation server for **parallel computing**

Optimization Algorithm
 (mutation and crossover functions)

Handover of parameters

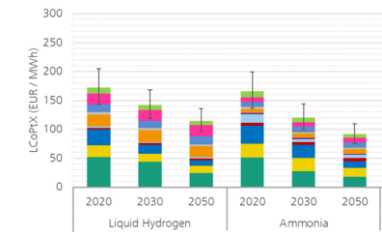


Results (EUR/kg)



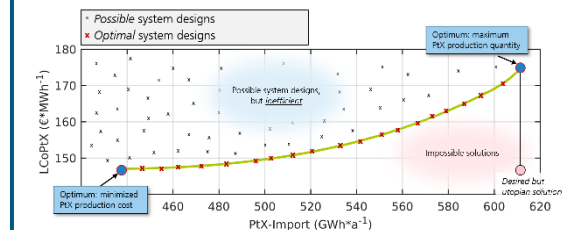
Result Output

Key performance indicators: levelized costs of product (EUR/MWh; EUR/kg), production quantity, total investment costs, overall system efficiency, full load hours, water consumption, energy flows, cost structure of product



Plant design in the cost optimum, e.g., optimized ratio of wind/ solar to electrolysis, intermediate hydrogen storage, etc.

Pareto front of multi objective optimization



Thank you for your kind attention

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Hydrogen and PtX Technologies

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PtX Colombia - Work Packages

WP 1: RE potential analysis and overview of relevant infrastructures in Colombia

WP goal

1. Classification of renewable energy potentials in Colombia and identification of two suitable locations
 - Suitable RE-related evaluation criteria will be selected, weighted, and matched with appropriate GIS data sets
 - Available solar and wind data sets will be compared and assessed based on their suitability
 - Site selection for renewable energy production (onshore wind and ground-mounted photovoltaics) is conducted via a weighted multi-criteria overlay analysis
 - Renewable energy site suitability maps are generated for focus-regions
2. Identification of two suitable locations and potentials for large-scale PtX production within or nearby pre-selected focus-regions
 - Suitable PtX-related evaluation criteria will be selected, weighted, and matched with appropriate GIS data sets
 - The results from the renewable energy section serve as an input for the Power-to-X section
 - Site selection for PtX production is conducted via a weighted multi-criteria overlay analysis
 - PtX site suitability maps is generated for the focus-regions

PtX Colombia - Work Packages

WP 1: RE potential analysis and overview of relevant infrastructures in Colombia

Onshore wind



Wind resource

- Wind speed
- Wind power density
- Seasonal variability



Technical and physical suitability

- Slope
- Elevation

Ground-mounted photovoltaics



Solar resource

- Solar irradiation
- Sunshine duration
- Seasonal variability
- Temperature
- Relative humidity



Technical and physical suitability

- Slope
- Aspect



Economic suitability

- Transmission lines
- Main roads



Land use and location

- Settlements and infrastructures
- Ecologically sensitive areas
- Natural hazards



Economic suitability

- Transmission lines
- Main roads



Land use and location

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- Ecologically sensitive areas
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PtX Colombia - Work Packages

WP 1: RE potential analysis and overview of relevant infrastructures in Colombia



Renewable energy

- Onshore wind potential
- Ground-mounted PV potential



Power grid

- Transmission lines
- Substations



Water

- Fresh water sources
- Coast proximity
- Desalination plants
- Wastewater treatment plants



Carbon source

- Biogenic point sources
- Industrial point sources
- Direct air capture



Industry

- Industrial areas
- Potential PtX offtakers
- Potential oxygen offtakers
- Waste heat sources



Storage

- Salt caverns for H₂
- Aquifers for H₂
- Depleted gas fields for H₂
- Geological storage for CO₂



Transport

- Ports
- Fuel bunkers
- Inland waterways
- Railways
- Pipelines

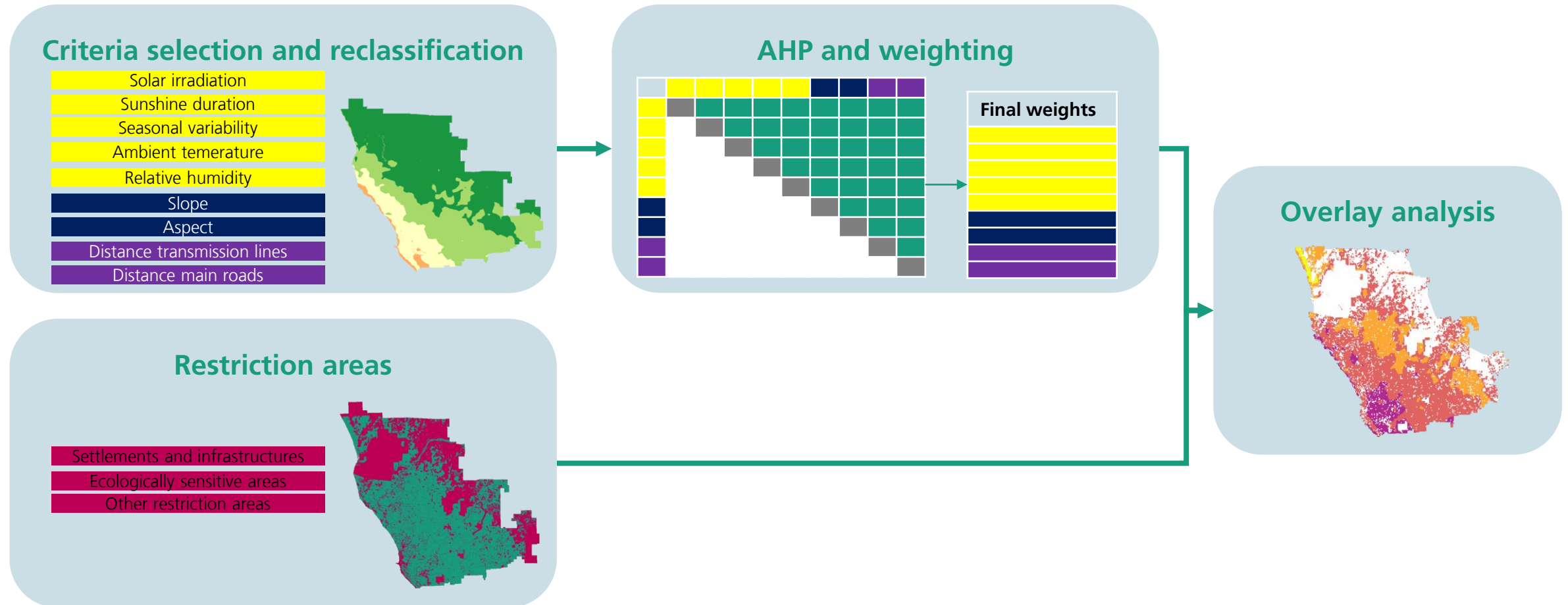


Land use

- Settlements and infrastructures
- Ecologically sensitive areas
- Topography
- Natural hazards

PtX Colombia - Work Packages

WP 1: RE potential analysis and overview of relevant infrastructures in Colombia

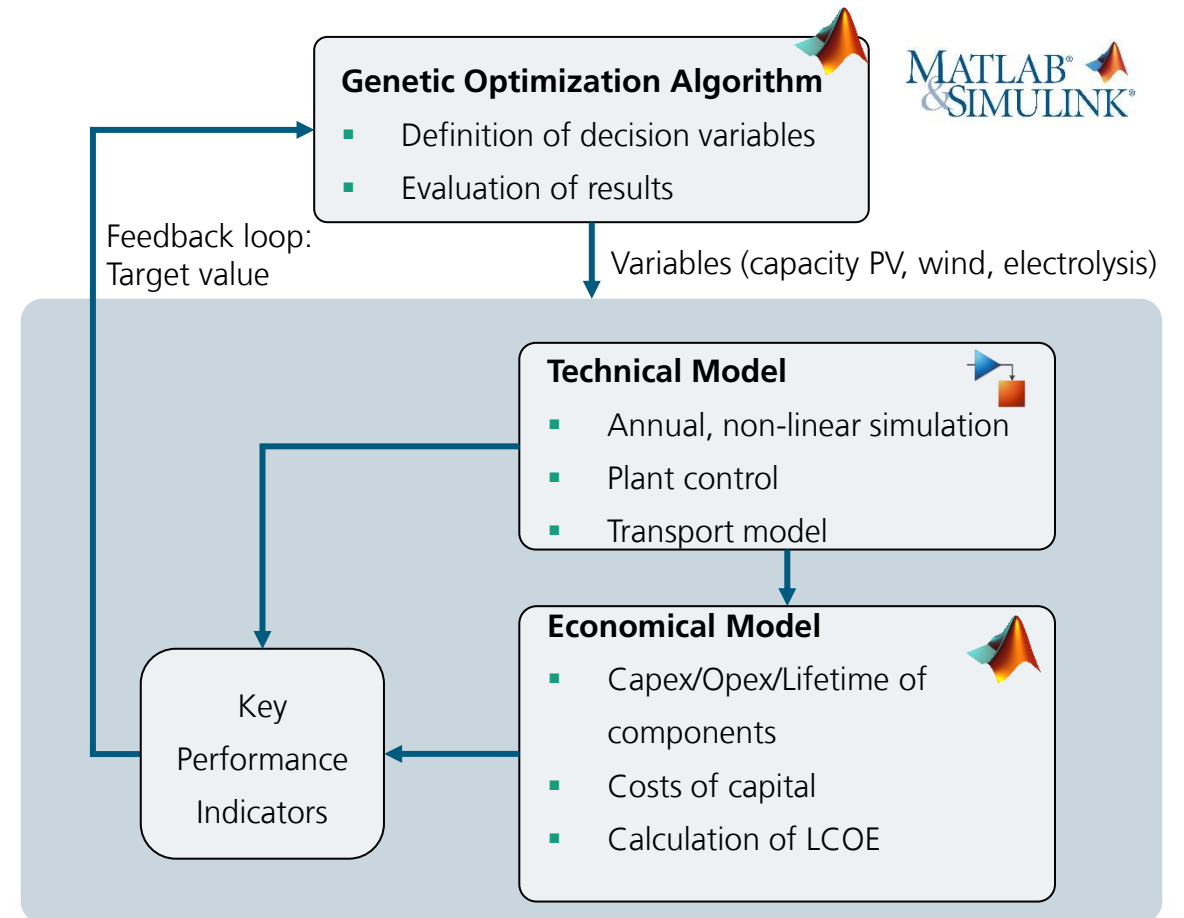


PtX Colombia - Work Packages

WP 2: Technoeconomic simulations and optimizations for Power-to-X production and supply chains

H₂ProSim – Model structure

- MATLAB
 - Upper level for calling simulation model and functions
 - Cost calculation with economic model (calculation of hydrogen costs)
 - Assessment of system parameters (e.g., efficiency, power curtailed power, full load hours, etc.)
 - Genetic Optimization Algorithm
- Simulink
 - Technical models of system components (e.g.: electrolysis, compression, Storage)
 - System control
 - Evaluation of simulation (annual simulation)



PtX Colombia - Work Packages

WP 2: Technoeconomic simulations and optimizations for Power-to-X production and supply chains

H₂ProSim – Cost model

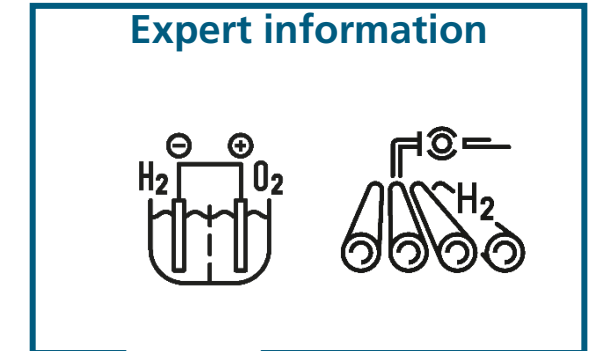
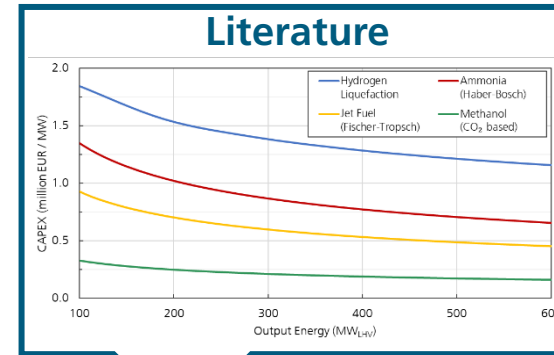
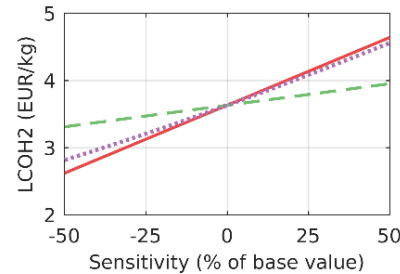
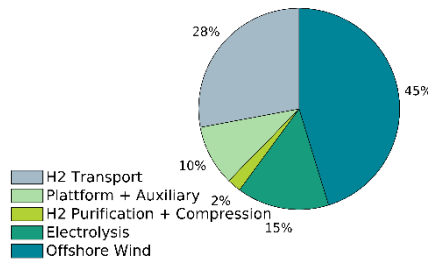
- Cost data from our database or customers specific data input
- Calculation of hydrogen production cost based on annuity methodology:
 - Capex, Opex and technical lifetime of individual component
 - Cost of capital (WACC)

$$LCOH_{2,i} = \frac{CAPEX_i * \frac{WACC(1 + WACC)^{n_i}}{(1 + WACC)^{n_i} - 1} + OPEX_i}{m_{H2}}$$

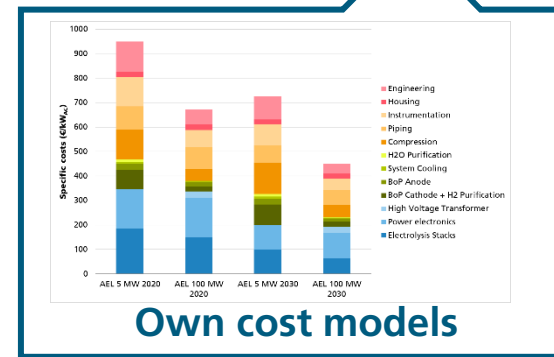
Project specific WACC:
Dept-equity-ratio; costs of dept/equity; tax rate; expected inflation rate

- Cost breakdown to identify main cost drivers
- Sensitivity analysis to identify effect of change in cost

Example of cost breakdown and sensitivity analysis



Cost database



PtX Colombia - Work Packages

WP 3: Workshops and reporting

WP goals

- Webinars:
Coordinated perspective on hydrogen in Colombia in consideration of harmonized needs of local stakeholders as input for the technoeconomic assessments conducted in this project
- Reporting:
Communication and documentation of project results

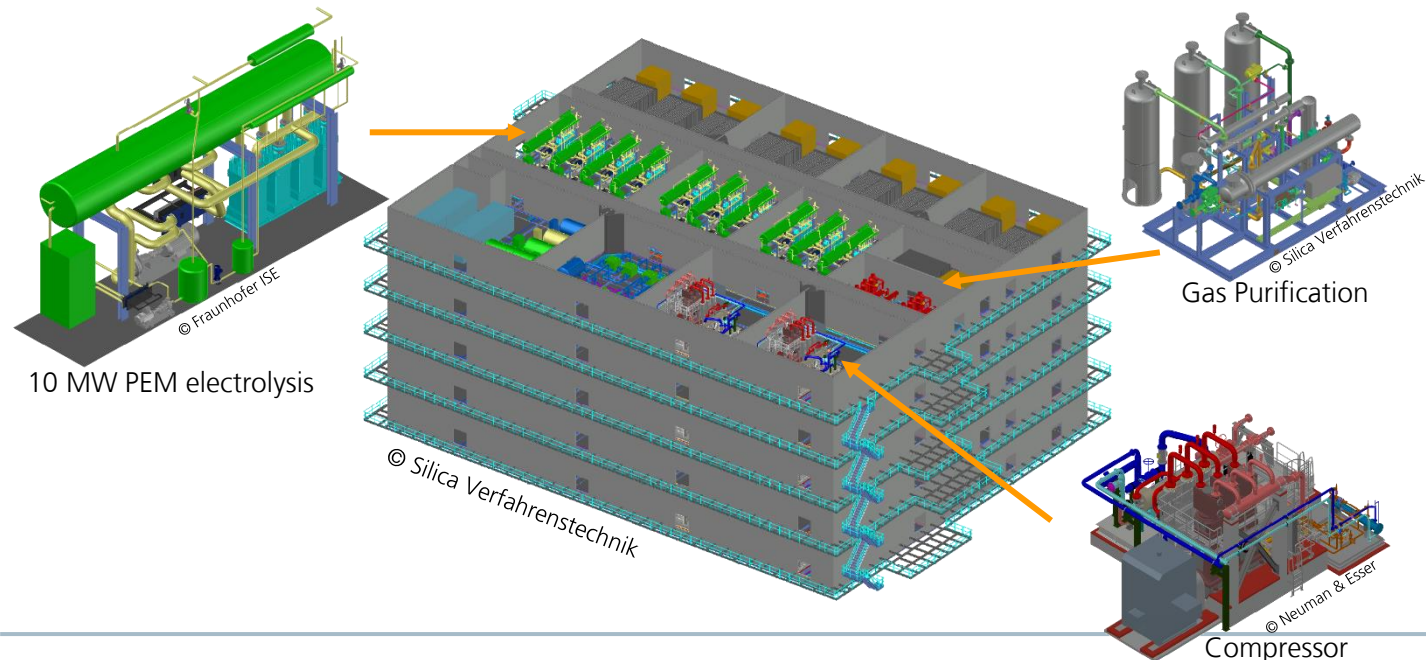
Scope, report and deliverables

- Participation in 3 Webinars + Final conference (COL)
- Project report (max. 25 p. excl. Appendix)
- A final presentation (*.pdf file)

Examples of our Work

OffsH2ore: Offshore hydrogen production with Offshore Wind Energy

- Basic design of an offshore platform with 500 MW electrolysis capacity
- Electrical system development and analysis of island grid stability
- Development of a 500 bar H2 transport ship
- Techno economic analysis of the concept and alternative transport pathways (e.g. pipeline transport)



Project Partners



Supported by:

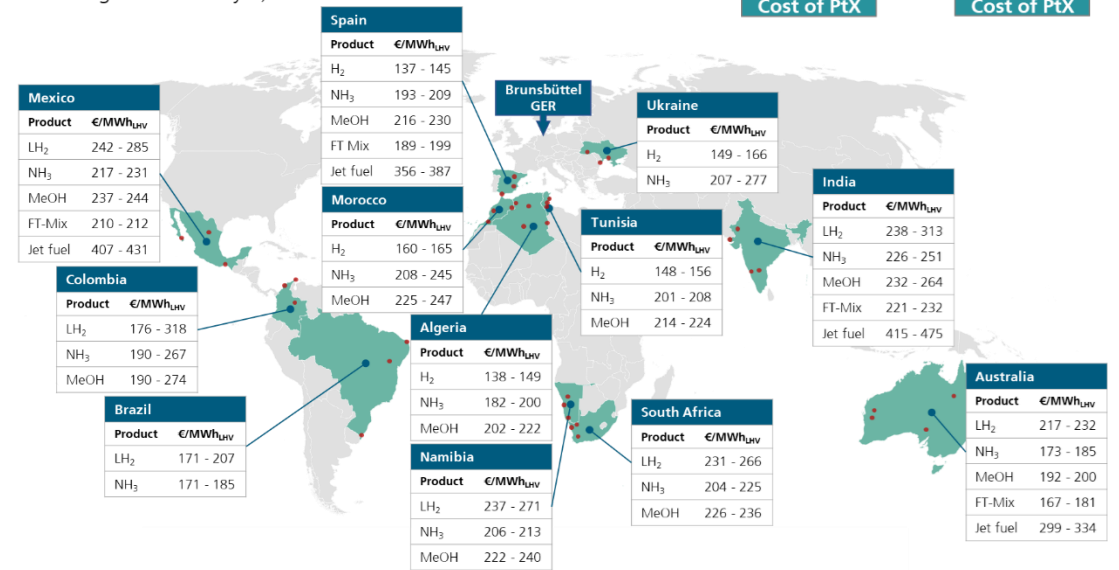
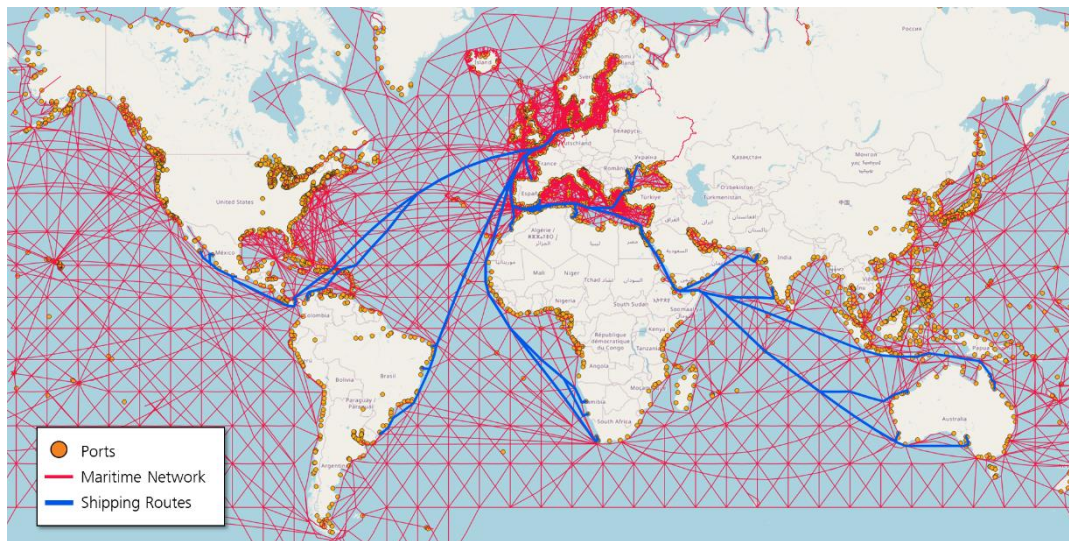
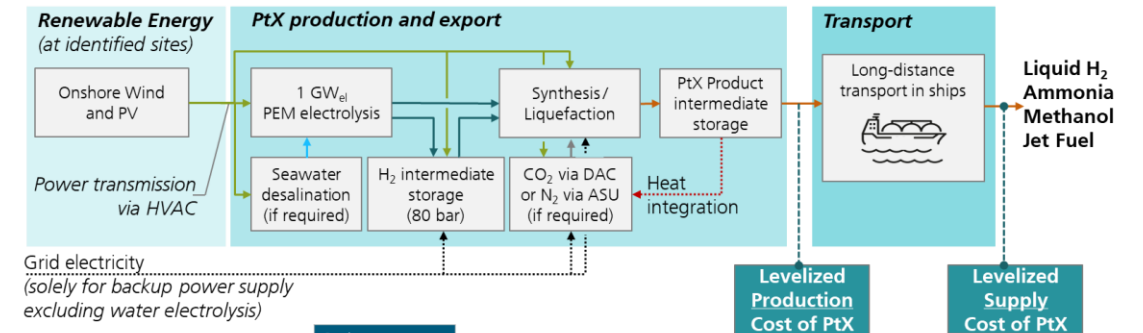


on the basis of a decision by the German Bundestag

Examples of our Work

H2Global: Site specific analysis of PtX import to Europe

- GIS analysis to identify suitable regions for RE installation for multiple countries
- Annual simulations of the PtX production plants using site specific RE production profiles (satellite based)
- Time resolved ship transport model



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DOI: 10.1039/C9SE00007A

Energy efficiency and economic assessment of imported energy carriers based on renewable electricity†

Christoph Hank,†* André Sternberg,† Nicolas Köppler,† Marius Holst,† Tom Smolinka,† Achim Schaad,† Christopher Hebling,† and Hans-Martin Henning,†

The production of energy carriers based on renewable electricity via the Power-to-X (PtX) approach holds the key for a holistic transformation of our global industries from fossil fuels towards renewable energy sources. To compete with cheap fossil PtX products, several energy-efficient processes and low-cost renewable electricity. Therefore, the import of PtX products from countries with high renewable energy potentials to countries with high energy demand presents a promising pathway. However, the question which set of PtX products qualifies as suitable for long distance transport has not yet been answered. In this context, this paper assesses the energy and cost efficiency of low PtX energy carriers (methane, methanol, ammonia, liquefied hydrogen and hydrogen bound in CO₂). Furthermore, we evaluate the influence of fluctuating renewables, availability of water and transport distance in a case study for large-scale PtX production in Morocco. Our results show that the evaluated PtX pathway efficiencies vary between 40–52% (base cases) and 44–58% (optimistic cases). None of the pathways assessed is significantly affected in its cost efficiency by a PtX transport over an intercity distance of 4000 km. However, for longer transport distances the cost difference between the assessed pathways increases. The production cost of the PtX energy carriers (120–158 €/MWh) depends on the availability of excess heat, energy density of the product and its required distribution efforts. In summary, this paper reveals that the long-distance transport and import of PtX products present an interesting option for the ongoing integration of renewable electricity into our energy system and industries. The technochemical and cost estimates in particular, as well as heavy goods transport, shipping and aviation, will be highly dependent on these imported synthetic energy sources.

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Introduction

The global carbon cycle is out of balance due to drastically increased fossil greenhouse gas (GHG) emissions to the atmosphere and thus exceeding the capacity of our biogeochemical cycles. The result is an anthropogenic greenhouse effect which is associated environmental problems† and extreme weather events – the latter having tripled since 1940. In order to reach the goal of keeping the global temperature rise below 1.5 °C, a radical decarbonisation of the global economy is necessary.†† The good news is that even the scenarios with highest energy demands for 2050 are well surpassed by the latest estimations

on the total renewable energy (RE) potential that could be harvested by utilisation of present technologies.† Characterised by an increase growth within the last two decades, modern RE (i.e. excluding nuclear and traditional biomass) accounted for 16.6% of total final energy consumption in 2017 (i.e. 4.4% compared by 2016),† but only 2% is yet covered by electricity generated with modern renewable technologies. Up to 80% of the total final energy consumption is still covered by fossil fuels. The integration of RE beyond direct electrification into the energy, mobility, industry and private sector via hydrogen (H₂) based renewable energy carriers is referred to as “Power-to-X” (PtX). When powered with renewable electricity PtX can enable highly decentralised primary energy generation. It represents a cornerstone for integrated energy systems and thus, a closing of the carbon cycle. However, shifting our sectors from fossil to RE based primary energy necessarily requires capacities of already installed RE capacities.††† For example, replacing fossil based processes in the chemical sector with PtX based ones, both would lead to a significant increase in the electricity demand. In this context, Köppler et al. (2019) established the fossil based precursors for the production of 50 large-volume

Study IndWEde – Brief Overview
Industrialisation of water electrolysis in Germany: Opportunities and challenges for sustainable hydrogen for transport, electricity and heat

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COST FORECAST FOR LOW TEMPERATURE ELECTROLYSIS – TECHNOLOGY DRIVEN BOTTOM-UP PROGNOSIS FOR PEM AND ALKALINE WATER ELECTROLYSIS SYSTEMS

A cost analysis study on behalf of Clean Air Task Force



Projekt Offshore-Wasserstoff - Endbericht

Offshore-Wasserstoffzeugung mittels Offshore-Windenergie als Insellösung

PNE Fraunhofer ISE SILICA KONGSTEIN Wystrachl



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Christoph Hank, Marius Holst, Connor Thelen, Christoph Kost, Sven Längle, Achim Schaad, Tom Smolinka

Site-specific, comparative analysis for suitable Power-to-X pathways and products in developing and emerging countries

H2Global Stiftung

Coming soon:

- Hydrogen production costs across Europe
- Hydrogen refueling stations for heavy duty vehicles
- Evaluation of clustering algorithms for hydrogen ecosystems