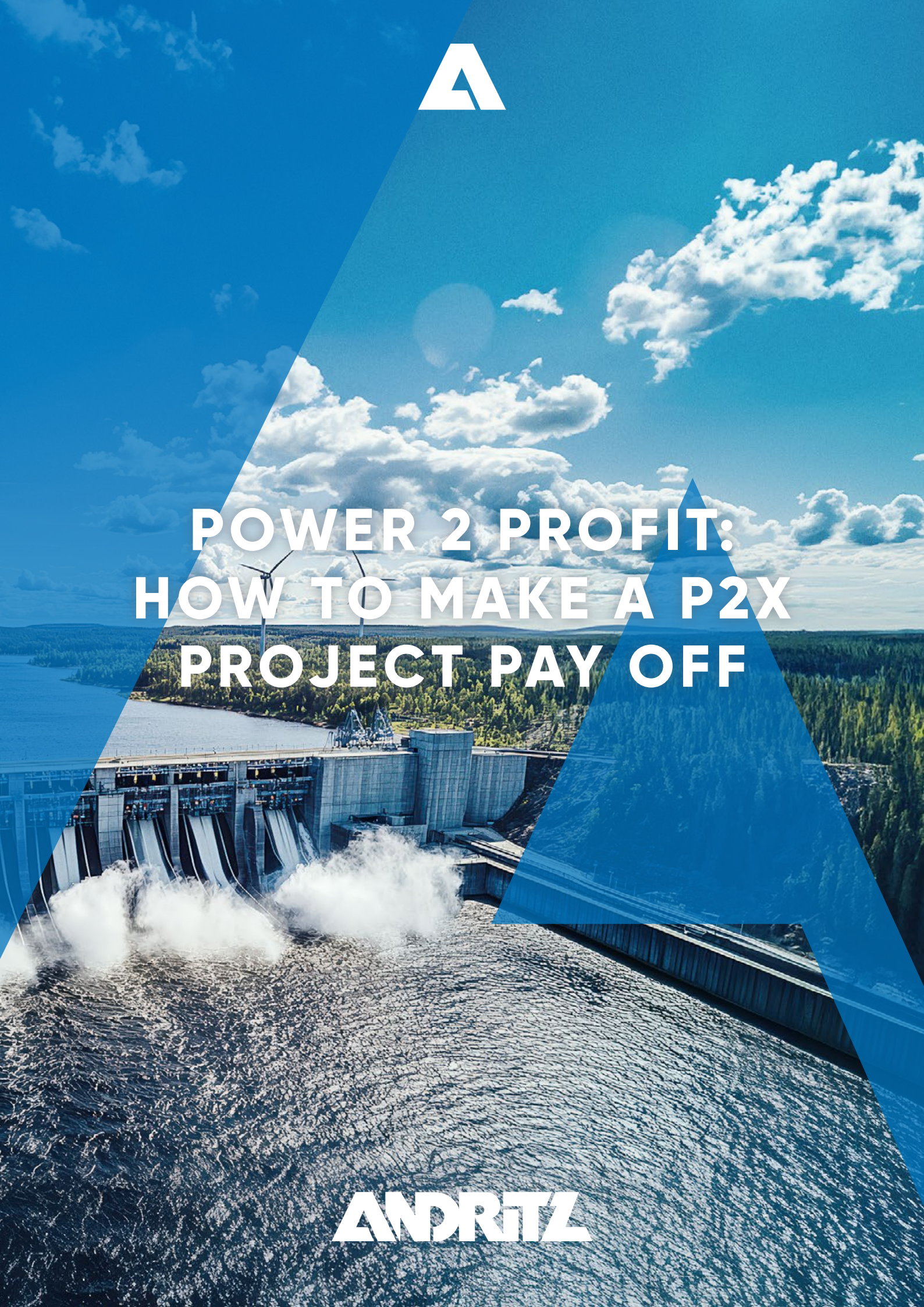


POWER 2 PROFIT: HOW TO MAKE A P2X PROJECT PAY OFF

ANDRITZ

Introduction

The world is in the process of a major green transition, with the aim to decarbonize human activity and slow the rate of climate change. We have made great strides in our ability to generate energy in a clean and renewable way and, according to the IEA, the installation of renewable energy capacity is accelerating. However, there were record-high energy-related CO_2 emissions in 2024, so there is clearly more to be done.

Power-to-X (P2X) energy infrastructure is an intermediary step between renewably generated electricity and the green-molecule market of the future, i.e. the green hydrogen and e-methanol that many industrial sectors will need as they decarbonize. P2X will play a major role in the process of replacing fossil fuels and for producing chemical building blocks, such as methanol and ammonia, and it represents a huge opportunity for developers and investors alike.

As with any industry infrastructure project, though, P2X project development comes with its complexities, all of which are compounded by the fact that the maturity of the market and the readiness of the technology are still at an early stage.

In an emerging market, like the one for green molecules, project developers in the transport or commodity industries have to wear multiple hats to analyze the ecosystem beyond their areas of expertise. This is a daunting task as it involves factors like financing, economies of scale, electricity cost, product end-use case, transport costs, regulations, funding and so on, all of which are critical to prevent stranded assets. A good metric for the economic viability of P2X projects is, therefore, the levelized cost of product (LCOP), which is the culmination of all of these factors. To that end, this eBook highlights and analyzes the topics that we feel have the biggest impact on the profitability of P2X projects.

ANDRITZ is a global engineering, technology and manufacturing company working with industries that are facing up to the challenge of decarbonization. For over 170 years, ANDRITZ has been delivering cutting-edge engineering, technologies, and entire industrial plants—along with operating and maintenance services, to our customers. Now, we're bringing that same expertise and commitment to our P2X customers.

Growing interest and support for P2X, without the pressure of immediate demand, means that the industry is in an excellent position to prepare thoroughly for the arrival of future fuels. In an ideal world, when that time comes, all the big lessons will have already been learned. The potential for substantial profits is undeniable and it's the time for first movers to come in and secure their share.

Contents

1 Knowing the End-Use Case

Naturally, the end-use case of your P2X product has a major impact on the cost structure and profitability of your P2X project.

Different industries have different needs, and vastly different expectations when it comes to product price. This is universally true, but it is more than just a platitude in the case of P2X. That's because the green molecule market is in its infancy, being driven primarily by policy and regulation. Some industries are required to cover the green premium - in others, it is voluntary.

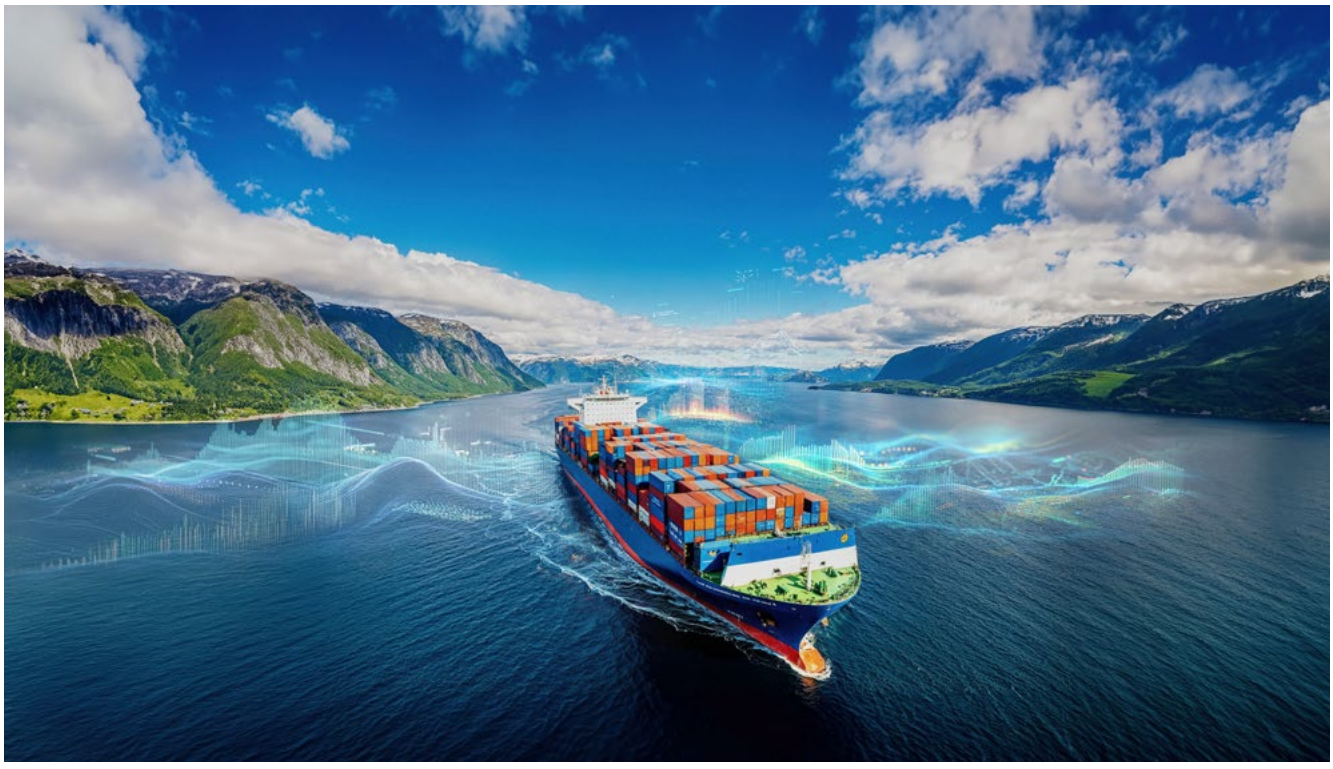
The shipping industry, for example, has a target of Net Zero by 2050 imposed by the IMO, and has therefore set a maximum price cap on alternative fuels, including RFNBOs. By its nature, such a target will be incredibly demanding, and will mean your project needs to be exceedingly well-designed to reduce the cost of your product sufficiently.

In contrast, a P2X molecule could also be used as a green feedstock for producing other fuels like kerosene or gasoline, and as a chemical feedstock for products like plastics, which will minimize scope 3 emissions for offtakers in what is otherwise a critically hard-to-abate sector.

The most important point is that there are often multiple end-use cases. If your project can meet the needs of several markets, you'll have a better chance at success. Project viability will be positively impacted if your P2X product can be used in several industries, such as e-methanol, which can be used as a fuel for Maritime, as a green building block in chemical processing, or as a feedstock for refineries.

SUCCESS FACTORS FOR STRONG END-USE CASES:

- **Use-case flexibility** – To improve offtake certainty
- **Sustainable market demand** – Driven by regulation certainty
- **Green premium** – From growing ESG pressure



2 Energy Price, Electricity Availability and Utilization Rates

Electricity is the single biggest cost factor in producing green hydrogen and derived products such as e-methanol. Naturally, if energy is expensive, the price is wildly variable, or the availability is intermittent, you will need to cover these costs by hiking up the price of your P2X product.

And price variability is common. In Germany in 2023, for example, the average exchange electricity price was €92.29/MWh, according to Fraunhofer. Such high average prices at the point of consumption make P2X market development very difficult.

A project's feasibility is entirely dependent on access to affordable and scalable renewable electricity at high load-factors. Lower utilization rates due to things like inconsistent renewable energy availability can significantly raise production costs. And sites with no direct electricity availability or grid connection will require dedicated financing efforts for this additional infrastructure, drastically increasing CapEx. The TNO's very helpful evaluation of the levelized cost of hydrogen based on proposed electrolyser projects in The Netherlands demonstrates this tangibly. But, by our calculations, the magic number for an electricity cost threshold is €40/MWh.

KEY CONSIDERATIONS ON ENERGY AVAILABILITY:

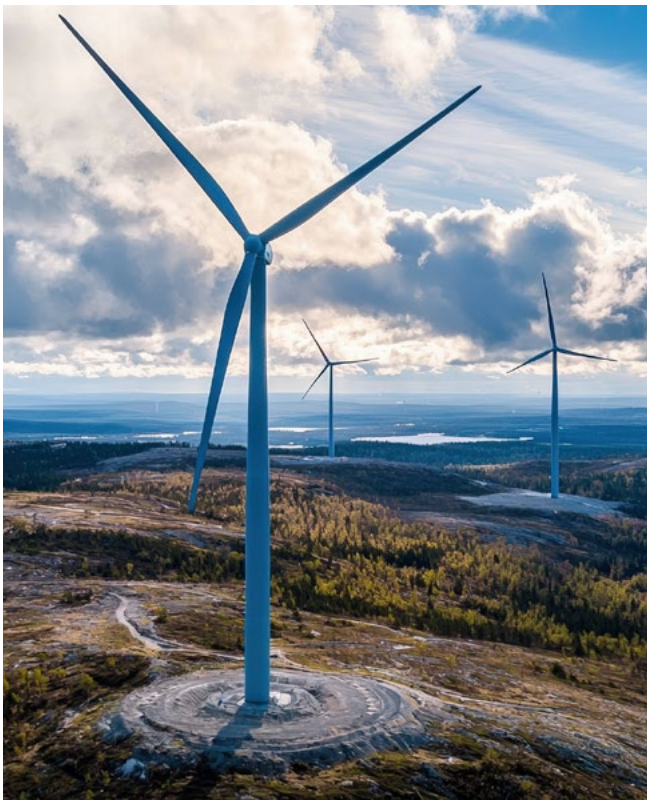
- **Low-cost energy regions vs. high-cost markets** – when comparing two sites in different regions, it may be that energy availability is better at the site in a higher-cost market
- **Have a target threshold** – our calculation is €40/MWh delivered at the battery limit of the plant
- **Utilization rates** – the more energy-efficient your project is, the lower the levelized cost of product

UTILIZATION RATE AND LEVELIZED COST OF PRODUCT (LCOP)

It's not just about price and availability. There is an inverse correlation between energy utilization rate and LCOP. In other words, the higher your utilization rate, the lower your LCOP, and vice versa.

$$LCOP = \frac{\text{Total lifetime cost}}{\text{Total lifetime production}} = \frac{\Sigma \text{CAPE X annualized} + \Sigma \text{OPEX annual} + \Sigma \text{Financing annual}}{\Sigma \text{ Production year}}$$

The formula for P2X Levelized Cost of Product (LCOP)



3 Project Location and Regulation

It can be inferred from the previous chapter that project location is necessarily very important to the viability of a P2X project. That is absolutely true, and not just due to electricity availability: regulation is also a critical factor, and so is the surrounding infrastructure.

The EU's Renewable Energy Directive III (RED III), for example, is directly relevant to P2X projects. It defines strict sustainability criteria for all new energy infrastructure. Different countries are at different levels of RED III implementation, making it essential to understand where the rules support — or hinder — investment decisions.

RED III KEY REGULATION POINTS:

- **"Additionality Rule" Post-2028:** New projects in fossil-heavy electricity grids must prove direct renewable integration
- **Renewable Fuels of Non-Biological Origin (RFNBO) Encouragement:** Incentives for truly renewable hydrogen and e-fuels
- **Each EU country must implement RED III:** Some will lead, others will be slower

One of the biggest risks in P2X investment is the possibility that the location you choose becomes unviable due to regulatory or economic changes. To derisk your investment, you need to target locations that have both good energy availability and strong political backing.

OPTIMAL SITES IN EUROPE:

- **Nordic countries (Norway, Sweden, Finland)** – Low-cost wind and hydropower
- **Iberian Peninsula (Spain, Portugal)** – High solar potential, growing wind sector

CHALLENGING SITES:

- **Central Europe / Bavaria (Germany)** – Areas that have high electricity costs or high carbon-intensity in the grid are challenging both from an economic and a sustainability point of view
- **High-demand industrial hubs** – May lack sufficient cheap renewables, increasing costs

Another key factor to consider when selecting your P2X site location is the existing infrastructure. Low-cost production means very little if transporting your product to market is exorbitantly expensive.

In Europe, for Green H2 production, the ideal scenario is that your site is connected to the European Backbone, the cross-Europe H2-dedicated pipeline network, which connects sites with ideal production conditions with areas of high demand, such as industry clusters. Transporting P2X product by truck-and-trailer is roughly 10 times more expensive.

KEY TAKEAWAYS ON PROJECT LOCATION:

- **RED III regulations impact project viability:** Some locations will require dedicated renewables, others benefit from existing clean grids
- **Pipeline infrastructure is a key competitive advantage:** Regions connected to future hydrogen backbones will have lower transport costs
- **Regulation will always be uncertain to a degree:** Track policy evolution to avoid stranded assets

GUEST VOICE

Product Price Decides Project Profitability – Prime Capital

Thomas Zirngibl, Director of Engineering at Prime Capital, talks on why Power-to-X is worth the investment, what it takes to have a viable project, and shares some lessons-learned from the company's project in Kristinestad, Finland.

Decarbonizing the world is expensive and consumers will ultimately bear the cost. So, why are we pursuing Power-to-X (P2X), when fossil fuels are so much cheaper?

The answer is that fossil fuels are only cheaper at a first glance. But if we don't address our emissions, increased indirect costs coming from natural disasters, food shortages, and mass human displacement will outweigh the savings, at the cost of future generations. The focus should therefore be on making low or zero-carbon options like P2X competitive to be able to fully de-fossilize in hard-to-abate sectors.

Prime Capital has established over 1 gigawatt of renewable power in the Nordics over the past few years. We saw an opportunity to put our green electricity to additional use through P2X, and so our Kristinestad project began. We thought, and still think, the investment was well worth it. But the process has taught us a few things worth sharing.

While investors, developers and regulators are all aware of the necessity of P2X, it is still challenging to get a project off the ground. Generally, permitting for infrastructure projects is not straightforward, and requires very careful and close stakeholder management in particular if certain reservations against the project are to be expected. With P2X, which is a new type of energy infrastructure, the risks are even greater. And greater risks come with higher cost of capital — which, overall, is not helping to reduce the green premium for a viable P2X plant. Careful planning is required.

The first step in your plan has to be the location of the project. A prime site will have favorable green electricity prices as well as other feedstock and infrastructure availability, a developer-friendly regulatory environment, and political stability and support. Sites that check every box are hard to come by, and many are already occupied by developers.

We were lucky with Kristinestad, where we already have over 200 megawatts of wind power to convert into e-methanol. Our main market for this product will be the shipping industry, and the site is located near a port, meaning our transport costs will be low. The site itself is an old coal plant, with grid infrastructure already in place, eliminating one of the major bottlenecks of any energy infrastructure project.

Your partnerships are also really important. A P2X project is made viable in the planning stages, so you need to consider everything up front. Combining existing technologies with smart engineering is key. The market is still in its infancy, so you need to select your partners carefully if you want to make your project as profitable as possible.

These things will dramatically reduce our costs, which in turn reduces the price of the end product – and the price of the product is what defines project profitability.

4 Financing and Funding

The very nature of P2X makes it challenging to finance. Investors and banks perceive P2X as higher risk than other energy infrastructure projects because the green-molecule market is still emerging.

Here is their line of thinking: no developer has much of a P2X track record; the projects are complex with interdependent technologies; and while policy mandates make market demand less speculative, the regulatory environment is always evolving. You should therefore expect banks and investors to treat P2X investment as venture capital, with risk mitigated by a higher cost of debt.

There are two main approaches to financing in general. Corporate financing, where large companies cross-finance projects through their existing business operations, is typically lower-risk and easier to approve for a financial institute. Project financing for Special Purpose Vehicles (SPV) without an existing business (project-specific funding) decouples projects from industrial players but comes with higher interest rates and extensive risk assessments.

To secure a bank loan to an SPV you need to be able to provide long-term revenue contracts in the form of off-taker agreements or RFNBO supply contracts, or other forms of securities like guarantees of a financially stable partner or of an Export Credit Agency (ECA).

To this point, an ECA coverage or a strong sponsor will help to decrease the loan interest rates. It's therefore fundamental to find "bankable" partners to implement a P2X project.

THE ROLE OF PUBLIC FUNDING

Public funding can cover at least a portion of P2X investment costs, and there are good arguments as to why it should.

Public support is the key to the scale-up of new and sustainable technologies. Wind and solar, for example, received a great deal of public support in their early days and, as a result, those are now the cheapest electricity sources. It should be possible to make that happen with green molecules too.

Equally important to policy makers is the fact that old, polluting industries are, naturally, shrinking and therefore losing jobs. New technologies like P2X, in contrast, create a huge range of jobs.

On top of this, many P2X projects would not be financially feasible without subsidies or grants. However, funding availability is regionally inconsistent, and where it does exist, you will find that it tends to come with lengthy application processes and strict eligibility criteria. For example, many grants exclude projects already in progress — so, make sure you apply before you sign project contracts.

There are typically both international funding options, like the European Hydrogen Bank, and national-level grants and subsidies. Germany, Finland, Spain, and Portugal, for example, provide direct and indirect support for hydrogen and e-fuels. Some programs even fund projects outside their borders; Germany funds P2X abroad, if the product is imported into Germany.

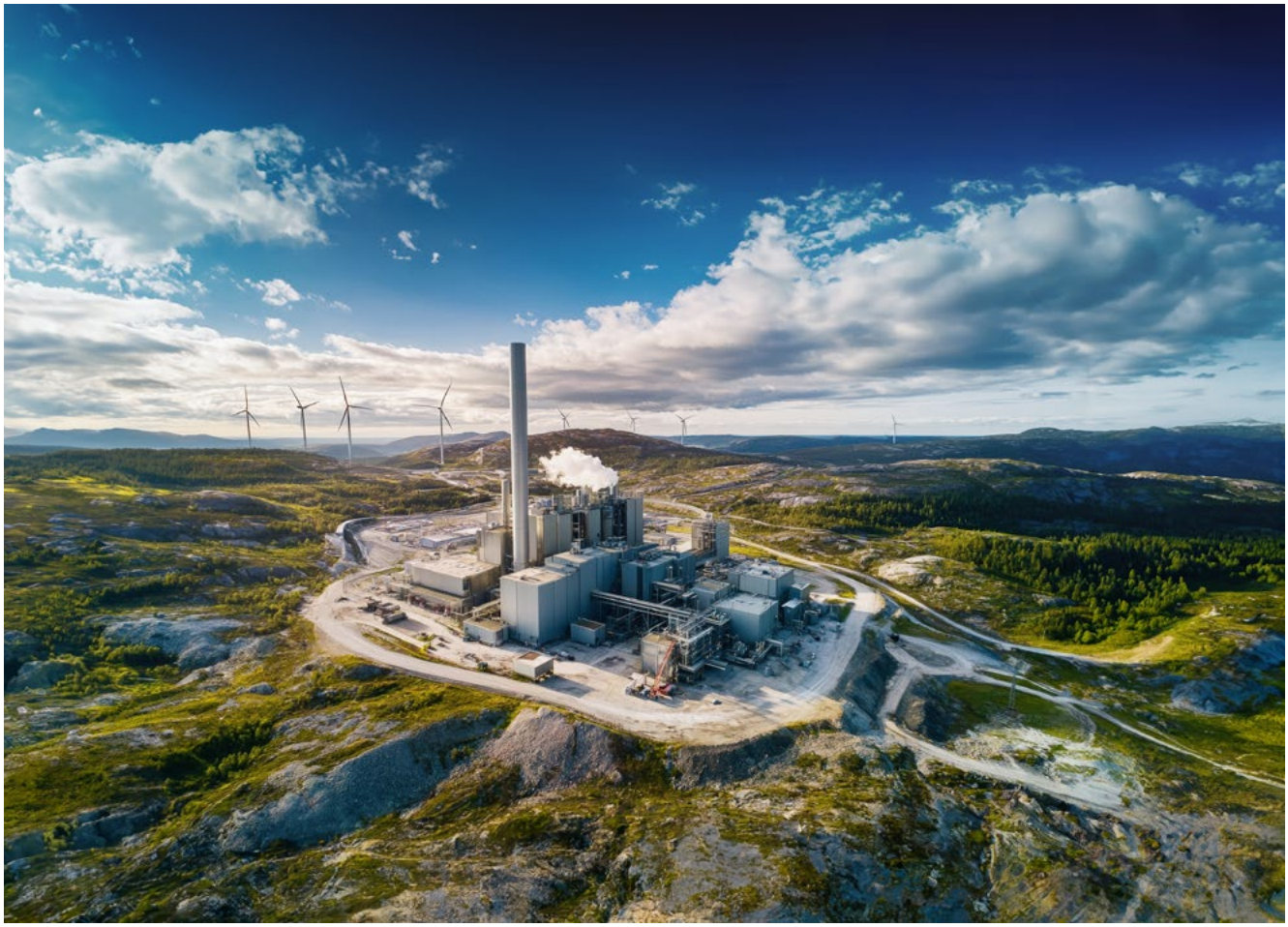
WHAT BANKS LOOK FOR IN P2X FINANCING APPLICATIONS:

- **Stable power supply contracts** (e.g., long-term PPAs at low-cost renewables)
- **Firm off-take agreements for hydrogen or e-fuels** – Ensures project revenue
- **Low electricity price (< 40 €/MWh)** – A major determinant of economic viability
- **Strong technology and EPC partners with a track record / proven expertise and a true EPC integrator which has a big enough balance sheet to stand behind the promise** – Reduces perceived project risk and CapEx as units can be smaller
- **Regulatory compliance** (RED III, RFNBO classification, emission reduction commitments)
- **A financially strong partner to secure the repayment of the loan**

WHAT INCREASES FINANCING COSTS?

- **Capex uncertainty:** Uncertain Capex including all costs owner/investor must bear regulation uncertainty: Uncertain policy environment delaying project approvals
- **Technology uncertainty:** Deployment of unproven technologies without commercial references or guarantees
- **Market uncertainty:** Lack of strong industrial buyers and spot price markets for the produced hydrogen/e-fuel
- **Operational uncertainty:** Uncertain life-time cost including operation and maintenance cost

In short: Uncertainty of any kind leads to higher financing and capital cost



5 Reducing OpEx through Smart Integration

P2X production requires various consumables such as heating, cooling, and plant air that may be integrated with the surrounding infrastructure. Likewise, the byproducts from the P2X process, such as oxygen, may be of value.

Smart integration means engineering P2X facilities in such a way that they reuse energy, reduce waste, and improve economic efficiency. In other words, optimal design of your P2X project will actively reduce operating costs and improve the economic viability of the plant.

The waste heat generated in one process plant may be of use in another. For example, the heat generated from electrolysis could be used for the desorption cycle in a Carbon Capture plant, or the in the gasification of LNG, if they are located close enough.

HEAT INTEGRATION AND WASTE HEAT RECOVERY

- Reusing electrolysis waste heat reduces external heating costs
- Carbon capture and methanol synthesis generate heat that can be recycled into industrial processes
- District heating applications can turn waste heat into revenue

OXYGEN UTILIZATION IN INDUSTRIAL PROCESSES

- Electrolysis produces oxygen as a byproduct: for industrial offtakers (pulp and paper, steel), this could reduce their chemical costs
- Integration with pulp mills using oxygen for bleaching or as Oxyfuel in the recovery boiler

HYDROGEN CASCADING BETWEEN PROCESSES

- Using hydrogen in multiple applications within the plant (e.g., direct fuel use, chemical feedstock, repowering in gas-turbines)
- Hydrogen pipeline connectivity reduces the need for expensive onsite storage

However, this additional design and engineering effort to reduce OpEx, does impact CapEx.

KEY SUCCESS FACTORS FOR REDUCING COST THROUGH SMART INTEGRATION

- **Aim for total gain:** Typically, CapEx will increase when implementing a design feature but the offset in OpEx must give a total gain.
- **Evaluate all possible design configurations:** Each configuration must be evaluated in terms of both CapEx and OpEx, which admittedly takes time and resources.
- **Expect challenges**: Smart integration is great in theory, but can often be more difficult due to things like layout and the distance that recovered heat has to be transported to be utilized.

Summary

PROFITABLE, NO-REGRET P2X INVESTMENT PLAYBOOK

Factor	No-Regret Decision	Potential Regret
Electricity Cost	**€30-40/MWh** (or lower) via long- term PPA, direct renewables supply	**€60+/MWh**, exposed to volatile grid pricing, fossil-heavy energy mix
Plant Utilisation Rate	**>80%+** utilisation → Maximises electrolyser efficiency and lowers OpEx	**<50%** → Low operational hours drives up cost per kg H_2
Regional Selection	Located in **low-cost renewable energy zones** (e.g., Nordics, Iberian Peninsula, MENA, Australia)	Located in **high-cost energy markets** or unstable policy regions
RED III Compliance (2028 Onwards)	**Meets EU sustainability rules** for hydrogen and e- fuels (**RFNBO-certified**) → Unlocks funding and long-term viability	**Fails to meet fuel origin criteria** → Ineligible for subsidies, regulatory risks
Integration with Industrial Plants	**Co-located with manufacturing, pulp mills, steel production** → Shared costs for heat, oxygen, CO_2	**Stand-alone hydrogen/e-fuel production** without industrial synergy
Funding and Grants	**Secured public funding** (EU Hydrogen Bank, national grants) **before contracts start**	No public funding secured → **100% reliance on private capital and loans** = Higher financing risk
Carbon Capture and CO_2 Supply	Located near **biogenic CO_2 sources** or emitters to simplify CCU	**No local CO_2 supply**, requires costly transport or DAC (Direct Air Capture)
Waste Heat Utilisation	Waste heat **recycled into industrial processes or district heating → Lower OpEx**	**Heat vented/lost**, increasing factory operating costs
Oxygen Byproduct Handling	**Integrated pipeline or industrial offtaker for oxygen reuse** (e.g., pulp bleaching)	**Vented oxygen disposal adds no value**, increasing inefficiencies
Hydrogen and e-Fuel Transport	**Connected to Hydrogen Backbone pipeline** → Minimise reliance on trucking and liquefaction	**Requires complex storage and cryogenic transport infrastructure**
Regulatory Influence on Investment	Operates in a **RED III-prepared country** with clear legal framework (e.g., **Finland, Spain, Portugal, France**)	Located in markets where **hydrogen laws are undecided** → High investment uncertainty
Additionality Rule (Post-2028)	In a country exempt from additionality (e.g., **Nordics, Austria**) OR co-developed with renewables	Grid-powered electrolysis in a fossil-heavy country → May **not qualify as green hydrogen**
Bankability and Investor Confidence	**Strong financial model, existing corporate financing or long-term offtaker agreements**	**SPV financing with no secured offtakers**, exposing project to market volatility
CapEx and OpEx Optimisation via Smart Integration	Designed for **cost-efficient energy and mass flow utilisation** (heat loops, minimal losses)	**Poor system integration** results in higher OpEx and excessive infrastructure costs

IN SHORT, THE IDEAL P2X INVESTMENT COMBINES:

- Cheap, low-carbon electricity (≤€40/MWh)
- Regulatory compliance (RED III, RFNBO, ETS eligibility)
- Smart integration of heat, oxygen, and fuel transport networks
- Strategic location – aligned with a hydrogen pipeline infrastructure, such as Europe's Hydrogen Backbone
- Long-term financial stability – mix of public and private financing

Success in the P2X market is not just about generating hydrogen for the sake of it – it's about generating hydrogen profitably and avoiding emissions and, ultimately, replacing fossil fuels. Even in the absence of widespread adoption today, there is an opportunity to leverage regulatory interest to establish a P2X market that will be ready to capitalise on the inevitable influx of demand for future's carbon neutral and renewable fuels and chemicals. Investors who prioritise cheap energy, regulatory foresight, and smart system integration will achieve long-term financial stability in this evolving industry.

We enable the green transition

ANDRITZ P2X SOLUTIONS

ANDRITZ responds to the urgent need for decarbonization and green transition. We provide integrated P2X solutions for the production of green hydrogen, e-methanol and e-ammonia – ranging from consulting to EPC projects with full performance guarantees. Our long-term service agreements are based on our proprietary digital solution.

EXPLORE OUR P2X SOLUTIONS

GLOBAL
p2x@andritz.com

JOIN US ON SOCIAL MEDIA