USAEE 2020 CASE COMPETITION

HYDROGEN INVESTMENT PORTFOLIO AND IMPACT OF CLIMATE POLICIES

Urbana Consultants

Richard Lombardo, Aaliya Husain, Paul Papillo, Mukesh Loganathan, Chris Hu

Table of Contents

Executive Summary

Due to the promising hydrogen markets in Europe, Aeirgas Corporation has hired Urbana Consultants to offer hydrogen investment portfolios to expand into France, Italy, Spain, and Portugal. After reviewing a myriad of relevant research on the growing hydrogen feedstock demand market and using H2A models to estimate the costs, we have developed investment recommendations for these four countries dependent on their national climate policy and available infrastructure. In the near term, we encourage Aeirgas corporation to invest in SMR plants with CCS at 90% carbon capture efficiency in France and Italy, a small SMR plant without CCS in Spain, and an alkaline electrolysis plant powered by solar PV in Portugal.

The demand for industrial hydrogen feedstock has tripled since 1975, and we see little reason for this growth to dramatically slow down. Using IEA and FCH data, we created three models to estimate the demand for industrial hydrogen feedstock until 2040. These models each feature a unique characteristic of the factors that have contributed to the growth of the hydrogen feedstock market, and so looking at them together truly shows a complete picture of this market. Thus, we project that by 2040, the industrial hydrogen feedstock market will be sized at 110 - 145 TWh in France, 70 - 100 TWh in Italy, 45 - 65 TWh in Spain, and 8.6 - 11.0 TWh in Portugal.

Using H2A central production analysis software, we have been able to calculate the LCOE of three different forms of hydrogen production. Namely, we did models for an SMR plant without CCS, an SMR plant with CCS, and a plant utilizing alkaline electrolyser technology that is powered by solar PV. As expected, we saw the lowest cost but the highest quantity of CO2 emissions from the grey hydrogen plant that used SMR without CCS. Interestingly, we saw large scale benefits in SMR plants with CCS at 90% carbon capture efficiency, and mega-sized plants were able to effectively compete with grey hydrogen on a cost basis. Moreover, while green hydrogen faced high costs of production using current technology, we discovered that a substantial portion of the green hydrogen LCOE will be reduced by improvements in technology to reduce the price of solar PV electricity. Thus, it is reasonable to conclude that green hydrogen will likely be the largest beneficiary of future improvements in technology, and these headwinds seem likely to mitigate a large portion of the risk involved in an investment in such technology.

Given the above cost and demand metrics, we were then able to synthesize this with relevant national climate policies and system-level factors to make our investment portfolio decisions. Countries with greater levels of accommodative hydrogen infrastructure lowered the risk of investing in green hydrogen production for the long-term, which was one of the motivating factors behind our recommendation to invest in an alkaline electrolysis plant powered by solar PV in Portugal.

Lastly, we analyzed the climate impact of our investment portfolio recommendations in our target countries. We determined that the investment portfolio of Portugal would be the most environmentally beneficial by emitting zero carbon emissions throughout its entire lifespan since it took advantage of the surplus in green energy sources available within the country itself. The country that would have the biggest impact on the environment initially is France since it would be pursuing a large SMR plant with CCS for the first 20 years. This has the largest impact due to the sheer volume in which CO_2 would be released during those 20 years and the models predict that this volume would be closer to around 40 million kg of CO_2. Though the environment will be impacted by this input of CO_2 it would be mitigated by the large Carbon tax that the government has placed since the revenue obtained from the Carbon tax would go towards clean energy initiatives. Furthermore, since all our models have an eventual final usage of green hydrogen plants the long term impact on the environment is an overwhelmingly positive and financial incentive.

1. Introduction

In a consulting project for the Aeirgas Corporation, Urbana Consultants have assembled an investment recommendation to assist Aeirgas in expanding into Europe while following the European Union's net-zero greenhouse gas emission policy by 2050. The goal of this partnership is to better understand the future potential that green and blue hydrogen systems have to grow between 2020 and 2050 and to investigate investment opportunities in target countries of France, Italy, Spain, and Portugal. To achieve this, Urbana Consultants have chosen to focus on what we anticipate the future demand for hydrogen is as well as future cost projections of each type of plant and by region to make a developed recommendation to Aeirgas.

Hydrogen has a relatively new and exciting role to play in the future of a carbon-free energy system. One exciting way for this is hydrogen energy through fuel cells as when burned it gives off heat and water vapor without carbon emissions [1]. It has become apparent that to meet the European Union's net-zero carbon emission goals, changes must be made as soon as financially reasonable. Due to the eventual environmental requirements from the EU, we must look into new methods for hydrogen production and use.

The implementation of hydrogen has always been focused on its costs compared to other energy sources and the increasing social perspectives on CO2 emissions. The International Energy Agency has advocated for expanding the role of cleaner blue and green hydrogen, despite the cost concerns. Part of this is due to their expectations of the price of producing green hydrogen to drastically decrease soon, which emphasizes the need for investments today. It is predicted that there would be a reduction of 70% of costs in the next decade in the production process of clean green hydrogen [14]. Also, transitioning towards this cleaner source of energy is more streamlined than other low carbon sources; blue hydrogen facilitates a transition from high-carbon to low-carbon through a mix of both, while high carbon infrastructure such as the existing pipelines can be modified or upgraded to accommodate low carbon networks.

This report expands upon the cost aspects of the investment portfolio in grey, blue, and green hydrogen, and demand projections through future outlook in our target countries. Additionally, this report looks at the anticipated future demand for hydrogen by industry, largely focusing on refining and ammonia production. Finally, we chose to look at predicted environmental policy from the French, Italian, Spanish, and Portuguese governments in addition to EU policy to help get a better picture of a timeframe and the importance of each method of production for future success. In doing so, we can propose ideal investment portfolios to Aeirgas, backed up by analyses of investment attitudes, regulation projections, and the ability to incorporate existing infrastructure into low carbon development.

2. Hydrogen Feedstock Demand and Impact of Climate Policies

2.1. Hydrogen Feedstock Demand Models

As of now, virtually all hydrogen produced is used as feedstock for industries such as ammonia production, oil refining, methanal production, and steel production [3]. These industries have bolstered the demand for hydrogen in previous decades, leading to a threefold increase in demand for industrial hydrogen feedstock compared to 1975. The combination of the high growth expectations of these industries shortly along with the increasing potential to produce cost-efficient clean hydrogen has led to our optimistic growth projections of the demand for industrial hydrogen feedstock up to 2040.

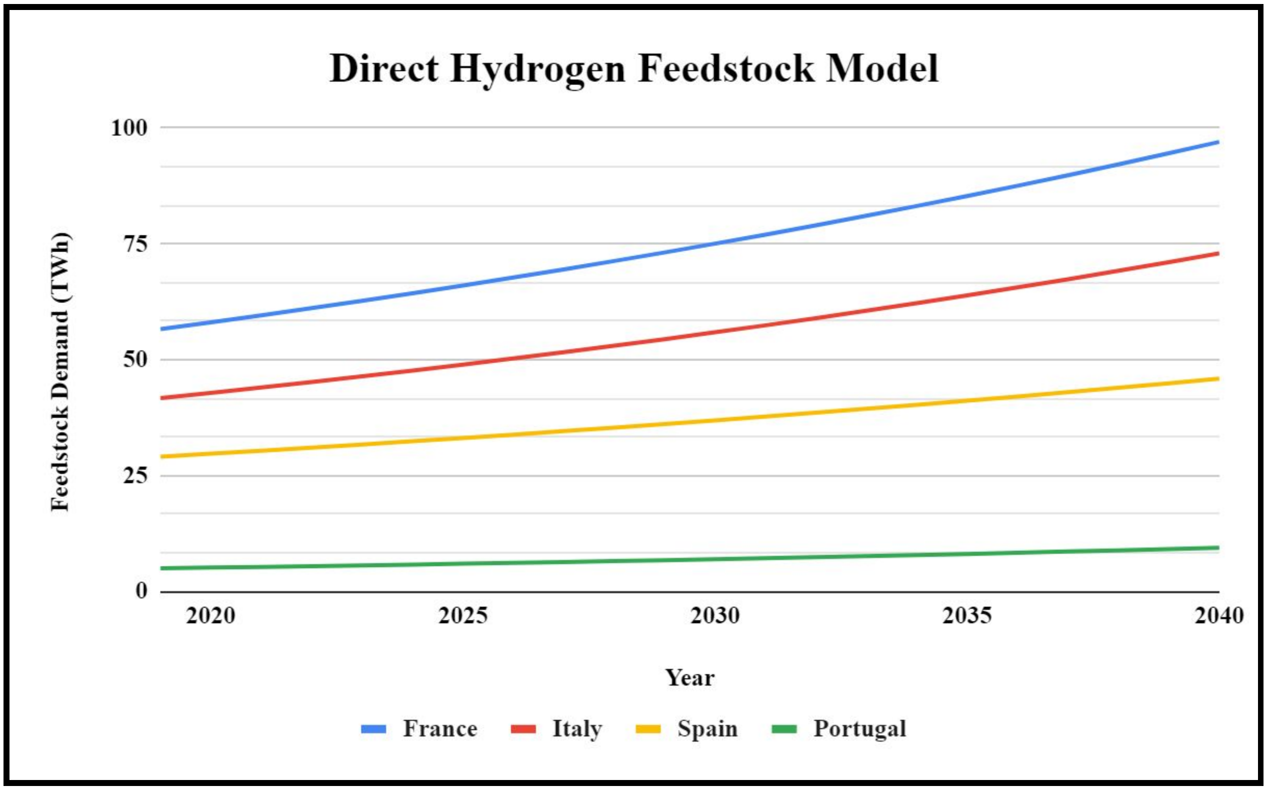
2.1.1 Methodology

To capture the complex nature of hydrogen feedstock demand projections, we have used IEA [4] and Fuel Cells and Hydrogen (FCH) [5] data to create three separate models for demand. For our direct feedstock model, we calculated the current value of the industrial hydrogen feedstock market in the four target countries and projected the industry growth rate in each country based on the country's GDP growth rate, level of accommodative infrastructure and regulations, and global hydrogen feedstock growth projections. For our industry breakdown model, we used IEA data on relevant industries such as oil refining and ammonia production to project the growth of these industries and then use this information to estimate the demand for industrial hydrogen feedstock. Lastly, for our total hydrogen production model, we used projections for how much hydrogen production is expected to increase over the coming decades and combined that with the proportion of hydrogen we expect to be used for industrial feedstock applications.

2.1.2. Direct Feedstock Model

In the direct feedstock model, we calculated the size of the current industrial hydrogen feedstock market in our four target countries and then projected a future growth rate. This growth rate was calculated through a combination of analyst projections [6], national GDP growth rates [6], and level of supportive infrastructure to support hydrogen transportation and production. For our four target countries, we projected baseline industry growth rates of 2.6% for France, 2.7% for Italy, 2.2% for Spain, and 3.1% for Portugal. After sensitizing our inputs, we projected 2040 industrial feedstock hydrogen demand as 90.07 - 99.29 TWh for France, 67.68 - 74.60 TWh for Italy, 42.76 - 47.16 TWh for Spain, and 8.68 - 9.57 TWh for Portugal. Our base case graphs for the four target countries are depicted in figure 1 below.

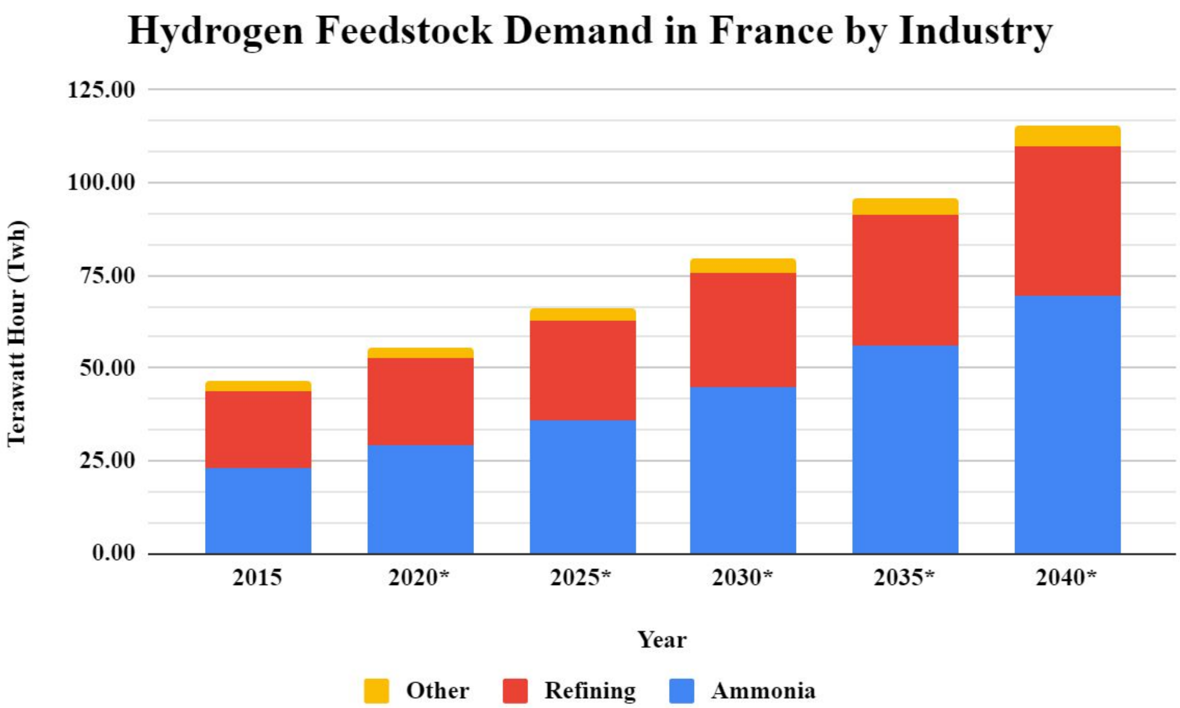
Fig. 1: Baseline Values for the Direct Feedstock Model for all Target Countries



2.1.3. Industry Breakdown Model

For the industry breakdown model, we analyzed how the global demand for hydrogen feedstock has increased over time in industries such as oil refining and ammonia production. For simplicity's sake, we split feedstock hydrogen into three categories: feedstock for refining, feedstock for ammonia production, and feedstock for other industries. Note that the largest component of the other category is feedstock from steel production. Given these categories, we used IEA data [15] to estimate the CAGR of the relevant industries from 1975 to 2015. Then, we used the historical CAGR values combined with market growth projections for the industries [18]. This led to us assuming growth rates of 4.5%, 2.7%, and 3.2% for refining, ammonia, and other, respectively. Sensitizing these growth rates, we predicted 2040 industrial hydrogen feedstock demand of 97.80 - 122.52 TWh in France, 72.11 - 90.34 TWh in Italy, 50.12 - 62.79 TWh in Spain, and 8.69 - 10.89 TWh in Portugal. A graphical representation of the model for France is displayed in figure 2.

Fig. 2: Baseline Values for the Industry Breakdown Model for France



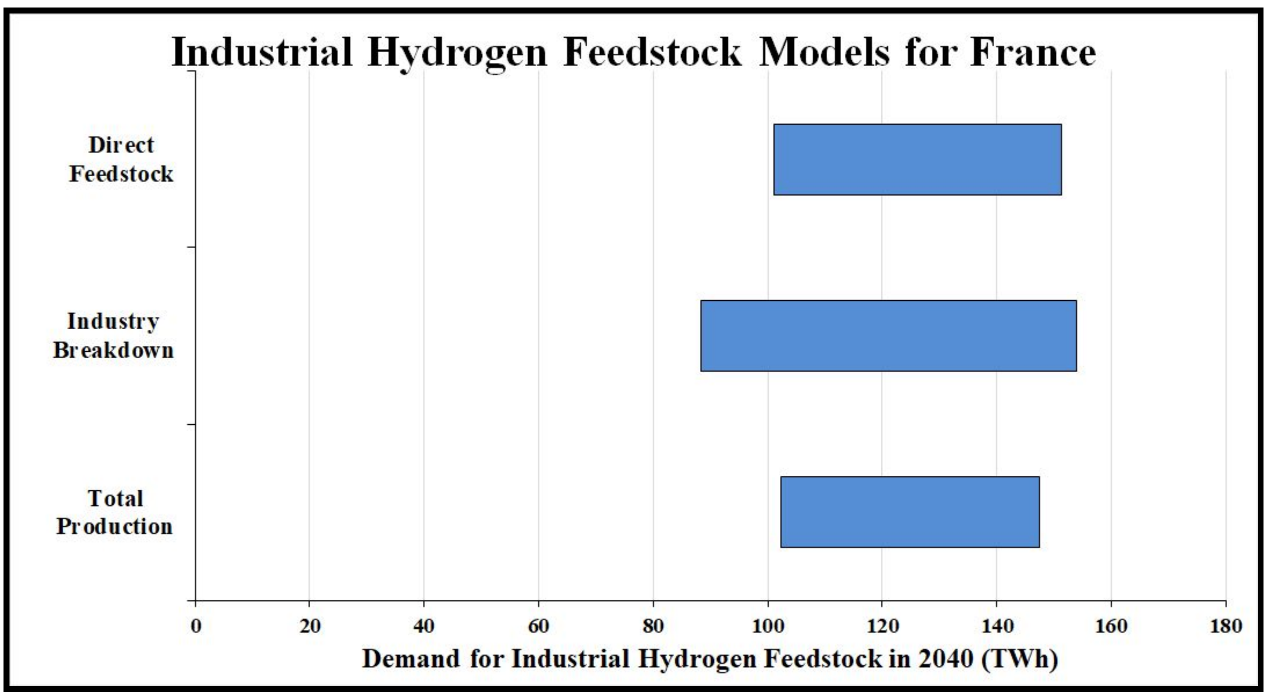
2.1.4. Total Hydrogen Production Model

Broadly, for the total hydrogen production model, we projected the total production of hydrogen in future years up to 2040 and then calculated what percentage of this demand we expect to be used as an industrial feedstock. To project the total production of hydrogen, we looked at the historical CAGR of 3.5% of hydrogen production from 1975 to 2015 as well as market analyst projections for total production. This led to us projecting a benchmark CAGR of 3.0% from the present to 2040, leading to global hydrogen production of 201.75 million tons of hydrogen produced in 2040. We then used a linear regression model to estimate the percentage of total hydrogen that will be used as industrial feedstock, based on data from the FCH [10]. Note that currently, virtually all hydrogen is used as feedstock, but by 2050 this is expected to decline to 28.1 - 50.1% of total hydrogen production. Thus, our model accounts for this as hydrogen begins to be used as an energy source and for residential heating. This, combined with our expectation for the proportion of feedstock used in our respective target countries to total feedstock offered us a reasonably accurate estimate of industrial hydrogen feedstock demand in 2040. This led to our projections of 2040 demand as 102.43 - 147.54 TWh in France, 75.48 - 108.73 TWh in Italy, 52.58 - 75.75 TWh in Spain, and 8.97 - 12.91 TWh in Portugal.

2.1.5. Analysis & Discussion of Results

The three models that we have created all highlight different aspects of the increasing demand for hydrogen feedstock. The direct feedstock model takes the most direct route by projecting growth for the specified good but may lack the necessary complexity of the other models to show the future production of hydrogen. The industry breakdown model has the highest spread of market demand valuations of the three models, as the model inherently highlights the complicated nature of projecting these different industries. While the baseline estimates for the industry breakdown model are lower than other models, we believe this is due to the possibility of new industries that will begin demanding for hydrogen feedstock that would be exceedingly difficult to project now. Lastly, the total production model shows how global hydrogen production will increase in the coming years, but also how lower percentages of that hydrogen will go to feedstock. Thus, this model is interesting to analyze with our investment recommendations as it projects two complex metrics. Overall, each model has been used for our benchmark hydrogen demand feedstock projections to form an accurate estimate of the growth of this feedstock. The combination of these models for France is shown in figure X, forecasting the demand for hydrogen feedstock in the country in 2040.

Fig. 3: Hydrogen Feedstock Models for France



From the three models, we are reasonably confident in the following projections for industrial hydrogen feedstock demand in our four target countries.

France: 110 - 145 TWh by 2040
Italy: 70 - 100 TWh by 2040
Spain: 45 - 65 TWh by 2040
Portugal: 8.6 - 11.0 TWh by 2040

2.2. Climate Policies and Impact on Demand Projections

2.2.1. Climate Policies of the EU

The European Union is paving the path for climate neutrality by 2050. First introduced in 2019, the Green Deal establishes policy initiatives that aim to help reach this ambitious goal. This Deal addresses three key targets for 2050: no net emissions of greenhouse gases; economic growth is decoupled from resource use, and no person nor place is left behind [3]. To accomplish this, milestone goals have been set for 2030, which include at least 40% cutes in greenhouse gas emissions (from 1990 levels), 32% share for renewable energy, and 32.5% improvement in energy efficiency [2]. With a holistic approach for climate regulation, all member countries of the EU are also a part of the EU Emissions Trading System (EU ETS), which is a market created to trade a capped amount of greenhouse gas emissions allowances. Unfortunately, our target countries have struggled to implement effective carbon taxation methods. Either the taxing levels are too high/low, they have too many exemptions, or they have inadequate implementation procedures. Although Spain, Italy, France, and Portugal all have the same end goal, their approach to reach climate neutrality differs.

2.2.2. Climate Policies by Country

The Spanish Government drafted a new bill for parliamentary approval outlining a template to reduce greenhouse gas emissions to net-zero by 2050, parallel to the Paris Accord on climate change. To achieve the mid-century goal, "Spain would need first to reduce its 1990 carbon emissions by 23% by the end of the current decade. The country would also need to be more efficient to reduce energy consumption by 35% from current levels and switch to renewable sources to generate all of its electricity by mid-century." [20] Spanish citizens have the right to receive a return on operation for high-efficiency multigenerational facilities that use renewable fuels/natural gas. This will help Spain improve energy efficiency and reduce emissions in large scale production venues. There is an increasing level of urgency to establish an operation that will be sustainable and financially viable. The Draft Bill for the Sustainable Economy Law is a modern model for the Spanish economy. It is constructed around three central themes:

“improvements to the economic environment, the promotion of competitiveness and the development of sectors working in the fight against climate change.” [3]. The law will better research and development processes by cutting tax percentages for innovative projects.

Italy has had a long history of being pro-renewables and has excelled in “integrating large volumes of variable renewable generation.” From the 2013 National Energy Strategy, optimistic goals were set to reduce energy costs, scale alongside environmental targets, and foster sustainable economic growth. As of 2019, Italy has adopted the “climate decree” as a means of compliance with the EU directive 2008/50/EC, which focuses on “improving air quality, reducing waste, and improving soil quality.” The Italian government is granting 500€ to individuals who choose to do away with inefficient vehicles and use that money to purchase public or electric transport. Each added measure is going to help the nation reach the EU’s goals in the suggested timeframe. Italy’s current obstacle is figuring out a way to increase development in the gas sector.

Since the establishment of the Energy and Climate Change Law 2019, France has laid out clear standards for reaching carbon neutrality. There is a focus set on the simultaneous growth of renewable energy as well as electric vehicles. France has even announced that they plan to eliminate the use of single-use plastics (plastic plates, cups, and cotton swabs) by 2020. By 2025, all single-use plastics will be removed from personal consumption. This is all in hopes of achieving a “circular economy”, where 100% of plastic is recycled. The increasing importance of green earth is not only a priority for bureaucratic agencies but also the people. There is a national carbon tax that brings in around five billion euros of revenue which is allocated to renewable energy research and implementation. Unfortunately, the tax did not have as great of an impact as the leaders had expected. In the first year of its implementation, there was no real effect on curbing emissions. To ensure a better outcome, President Macron planned to further increase the carbon tax by 2022. This was met with a great adversary and the advent of the yellow vests movement. Supporters of this movement believed this increased tax is socially unjust. Since then, the tax has been set at €44.60. The French carbon tax has other issues as well. There are too many methods for loopholes and ways to become exempt from the tax.

Portugal has set ambitious targets for carbon neutrality. By 2030, the nation hopes to implement 80% renewable electricity by 2030 and 100% neutrality by 2050. This will only happen through detailed policy measures. A high priority will be set on market reforms to encourage the financial benefit of solar and wind resources, as well as the capacity to support natural gas. Circa 2009, under the National Energy Efficiency Action Plan, the Program for Electric Mobility in Portugal set “national targets of reducing energy dependence and combating climate change.” This Program encourages the use of electric vehicles, a massive decrease in fossil fuel consumption, and increases in electric charging stations. The 2008 version of the plan also incentivized energy-efficient companies, building, schools, etc.

2.2.3. Assessment of the Impact of Climate Policies

The demand elasticities for carbon-intensive goods such as energy are highly sensitive to time and geography. Most countries within the EU have struggled to quantify the effectiveness of the carbon tax relative to the production of hydrogen energy. To implement carbon tax policies that encourage companies to switch to hydrogen, the policies must be socially accepted and presented as a way of bettering the economy--not just the environment [19]. There is no evidence that a European carbon tax can succeed in significantly curbing CO_2 emissions. Other policy measures, as well as a societal understanding, must be met. As we are seeing today, the EU is assessing whether or not they should implement a carbon border tax, which would globalize the importance of respecting climate goals [23]. As world leaders begin prioritizing a decrease in carbon emissions, only then will companies seek out hydrogen energy.

3. Levelized Cost Analysis of Hydrogen

Levelized cost is a crucial energy measurement that is frequently used to compare different forms of energy [16]. This measurement uses the discounted costs of producing a form of energy divided by the discounted quantity of hydrogen produced, yielding a fair comparison metric for different forms of hydrogen production. A simplified equation for LCOE is shown below.

$$\frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

In the above equation, *I* is investment expenditures, *M* is annual O&M costs, *F* is annual fuel costs, *E* is annual electricity generation, *r* is the discount rate, and *n* is the length of the life of the system. It is important to note that for our LCOE calculations, we will be following the IEA convention to only include “plant-level” costs and no system-level factors nor the distribution of the produced hydrogen. However, as these factors are relevant for an informed investment decision, we have included these system-level factors in section 4 with our recommendations.

3.1. Methodology

To calculate LCOE, we used the H2A hydrogen central production model from NREL. Initially, we made some minor reforms to allow the reference year to be 2019 and to update some of the relevant input costs from the model's creation. We used this model, combined with the relevant case studies, research, and recommendations by Aeirgas executives, to calculate the LCOE of different hydrogen technologies. These technologies include a grey hydrogen SMR system with a design capacity of approximately 40,000 kg of hydrogen per day, a blue SMR system with CCS that has 40,000 kg/day design capacity and 90% carbon capture efficiency, and a green alkaline electrolysis system that uses 18 stacks to have the same design capacity as the others.

3.1.1. Model Description

The H2A models are used to compare different hydrogen technologies as well as discover the sensitivity of LCOE to different inputs [4]. Given information on relevant inputs such as capital costs, feedstocks, and financial parameters, the model calculates the levelized cost of producing hydrogen and sensitizes for different levels of uncertainty. Thus, this crucial model has proven to be a powerful tool for making informed investment decisions at Aeirgas.

3.1.2. Model Assumptions and Parameters

For our LCOE calculations, we generally assumed standard financial parameters as defined by the H2A software. A complete list of these exists in the appendix, but some include 40% equity financing, a 3.7% interest rate on debt, an inflation rate of 1.9%. Along with these, we used adjusted case study data for several inputs [7] as well as research articles that offered cost analysis for hydrogen production plants [5].

For comparability purposes, we had the baseline output capacity of our three cost models be approximately 40,000 kg of hydrogen production per day. However, grey and blue plants see very large benefits from scale, so we assumed a scaling factor exponent of 0.6 for any analysis of the impact of scaling.

3.2. Results

Table 1: Summary of results from H2A. Note that the 90% intervals are determined by a Monte Carlo simulation of the relevant sensitivities by Microsoft Excel

Model	90% Probability LCOE Range	Total GHG (CO2 eq)	Largest LCOE Contribution
Grey	\$1.46 - \$1.53 / kg h2	11.305 kg / kg h2	Feedstock (64.8%)
Blue	\$3.24 - \$3.47 / kg h2	3.001 kg / kg h2	Capital Cost (46.9%)
Green	\$4.59 - \$5.20 / kg h2	0	Feedstock (87.8%),

3.2.1. Technology Comparison

The different sources of hydrogen productions vary most directly in the source of energy used to split hydrogen from its initial components. The small modular reactor uses steam reformation techniques to separate methane efficiently by combining the exothermic chemical reaction to power the endothermic chemical reaction [12]. Given this, we saw a 72.1% production process energy efficiency for blue and grey hydrogen.

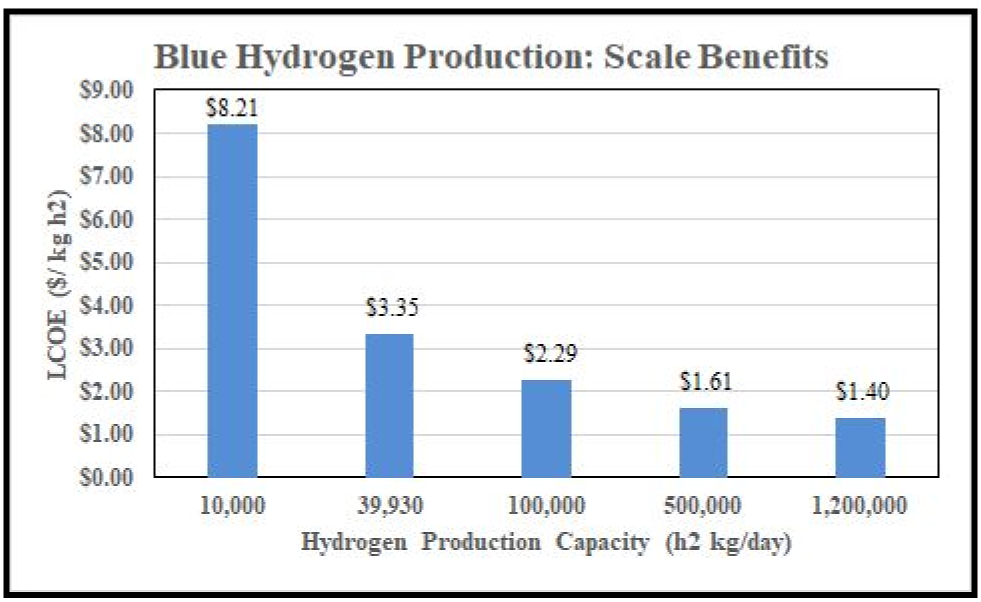
The CCS system in the blue hydrogen model manifests itself in two ways in our LCOE model compared to the grey hydrogen model: increased capital cost for the plant to capture carbon and increased variable operating expenses for this unit to operate. Thus, we saw higher LCOE for blue hydrogen relative to grey hydrogen by a considerable amount. However, there are two important caveats to this LCOE metric that allow us to still believe that blue hydrogen has great potential. Firstly, an SMR plant with CCS at 90% carbon capture efficiency produces 3.001 kg of CO2 equivalent per kilogram hydrogen produced, compared to 11.305 kg CO2 equivalent for an SMR plant without CCS. Thus, it is far more climate-friendly and avoids more risk of climate regulation and carbon taxes that may adversely impact the grey hydrogen investment. Given the climate policy discussions that we brought up earlier, we feel that grey hydrogen in these European nations includes much more risk than blue hydrogen as a result of uncertainty over future EU climate policies. Secondly, the SMR plant with CCS has 46.9% of its LCOE contributed by its capital cost -- its most significant contribution, and a clear indicator that it will benefit from scale.

Uniquely, alkaline electrolysis plants can function by deriving all of its energy sources from renewable energy sources that are not harmful to the earth. Currently, the most cost-efficient renewable energy sources available in the market are solar panels and wind power. The energy that runs through green hydrogen plants has zero CO2 impact, meaning that it bears almost no impact from future climate policy changes in our target countries. Moreover, as renewable technology continues to accelerate at a rapid rate and hydrogen energy shows to be an increasingly promising source of future energy, our investment will benefit from powerful tailwinds as a result of this improved technology. The same cannot as easily be said of plants that produce grey hydrogen.

3.2.2. Impact of Scaling

In both grey and blue hydrogen, there is a significant improvement in the cost-efficiency of the technology at scale. As shown in figure 4, as plants increase in their production capacity, they realize strong scale benefits in the form of lower LCOE. For a mega-sized SMR plant with 90% carbon capture efficiency, the LCOE is $1.40 per kg hydrogen, a vast improvement over our baseline blue hydrogen LCOE of $3.35. In the case of a grey hydrogen SMR plant, there is only a 19.9% drop in LCOE from our base case to the mega-sized plant. This is not surprising, as SMR plants with CCS have larger capital costs than SMR plants without CCS, and these larger capital costs lead to increased cost-benefit from scale.

Figure 4: Scale Benefits of Blue Hydrogen Production



3.3.3. Impact of Future Technological Developments

While we did calculate considerably higher LCOEs for alkaline electrolysis than other forms of energy, it is important to note that this calculation makes fairly modest projections of future developments in renewable electricity. Utility-scale solar facilities have historically outperformed their goals and market expectations, and further development in this technology will have a massive impact on the LCOE of green hydrogen. Given that a stunning 87.7% of the solar-powered alkaline electrolysis LCOE is contributed to its cost if solar meets a 0.03 price goal by 2030 the LCOE will be at $2.14 which is very significant. Though it will be less efficient than the SMR at that scale the plus side is that there will be zero emissions at that state and the corresponding cost reduction associated with not having to pay a carbon tax

4. Hydrogen Investment Portfolio, System-Level, and Sitting Factors, and Climate Impact

Given our projections for the hydrogen feedstock demand market and our LCOE cost analysis of the different forms of hydrogen production, we recommend that Aeirgas invests in the following hydrogen investment portfolios. A concise summary of the specific costs and summary is listed below in Table 2.

France: Invest in a **large SMR plant with CCS now**, and invest in several **alkaline electrolysis plants powered by solar PV within 20 years**
Italy: Invest in a **moderate-sized SMR plant with CCS now**, and invest in several **alkaline electrolysis plants powered by solar PV within 20 years**
Spain: Invest in a **small SMR plant without CCS now**, and invest in **either blue or green hydrogen plants** dependent on several factors within 20 years
Portugal: Invest in a **moderate-sized alkaline electrolysis plant power by solar PV now**, and **expand on this investment with other green hydrogen plants in the next 20 years**

Table 2: Summary of Investment Portfolios and Relevant Data for the Portfolios

Country	Current Investment Plan	Future Investment Plan	Output of Current Plan (kg h2/day)	Emissions of Current Plan (kg CO2 equiv. / day)	LCOE ($/kg h2)	Perceived Risk
France	Large SMR plant with CCS	Alkaline electrolysis plants powered by solar PV	1,000,000	2,700,900	$ 1.45	Low
Italy	Moderate-sized SMR plant with CCS	Alkaline electrolysis plants powered by solar PV	400,000	1,080,360	$ 1.67	Low
Spain	Small SMR plant without CCS	Dependent on external factors	39,930	406,268	$ 1.50	Moderate
Portugal	Moderate-sized alkaline electrolysis plant power by solar PV	Expand on intial investment with more green plants	70,000	0	$ 4.79	Moderate

4.1 Hydrogen Investment in France

French gas network operators have previously put forward suggestions on transitioning towards hydrogen using existing pipelines, without much progress [17]. However, France is one of the forefront countries endorsing a transition to clean green hydrogen. Developments made in hydrogen infrastructure primarily focus on transportation, with multiple hydrogen refueling stations situated across France for hydrogen-powered vehicles [11]. Looking at a study submitted to the International Journal of Hydrogen Energy, it was found that trucks are more economical compared to developing new or upgrading existing pipelines, especially with low demand and/or in the short-term [1]. Also, the reluctance of both the government and the public in investing in such developments may be concerning to penetrating this market, especially since Aeirgas is not in the hydrogen fuel cell industry.

We propose that France approach its need for hydrogen energy with the introduction of a blue hydrogen plant that is used in the short term to develop initial infrastructure for the country and continue increasing overall hydrogen usage. Aeirgas needs to begin with this blue plant and begin as soon as the financial resources are ready. The risk of the investment is significantly lower than any other country analyzed with the lowest cost per kilogram of 1.45 $/kg h2 making it a very financially sound investment. France has a high carbon tax at around €44.6, which is detrimental since the output of carbon dioxide in the large SMR plant is high but this cost is offset by the creation of a green hydrogen plant in 20 years. France is one of the most active countries in Europe about climate policy. This means that hydrogen has the potential to become a much larger industry within the nation. While the French government strongly supports the development of green hydrogen we think Aeirgas should wait longer before developing green plants. Because of the extreme costs associated with green hydrogen production compared to blue hydrogen production, it is a wiser choice to build blue plants in the short term while more research into green hydrogen production can take place as well as likely decreases in the high costs related to green hydrogen. Taking a slower approach to hydrogen production by starting with blue plants opposed to green gives Aeirgas the ability to quickly gain market share as well as more experience in hydrogen production allowing for a better transition to green hydrogen compared to the competition when the time to change due to European and French policy comes into effect.

4.2. Hydrogen Investment in Italy

The potential for hydrogen piggybacking in existing natural gas pipelines is greatest in Italy. Snam is an Italian public company in the energy infrastructure industry. In just this company alone, there are over 41,000 km of pipelines in the gas transmission network, with 70% of them capable of transporting both natural gas and hydrogen. The incorporation of hydrogen into Italy's gas network was the result of the development of the NovaLT, a hybrid hydrogen turbine that can be implemented into existing gas pipelines. This publicly developed technology is part of an effort following the European Union's Hydrogen Strategy and also a good representation of the country's attitude towards climate regulation and goals. It is very plausible to assume the full incorporation of this technology in all Italian pipelines for the transport of hydrogen into all the appropriate industries, including those of Aeirgas. The NovaLT directly bypasses most of the physical infrastructure changes, such as a material upgrade, needed when fully converting a natural gas pipeline to a pure hydrogen network [9].

We feel that the best course of action for Aeirgas in Italy is to begin the production of Blue hydrogen production plants over the next several years to transition from blue to green around 2050. Italy has a relatively low cost for $/kg h2 of 1.62$ but has an output of over 1 million kg of CO2 which would cause additional carbon taxes to cut into revenue. Our reasons for this are largely based on Italy's pre-existing infrastructure with over 41,000 km of pipeline able to transport the gas. In addition to Italy's infrastructure, the country is also very open to increased regulation and is committed to trying to reach the European Union's goal of zero net carbon emissions by 2050, benefiting the climate through incorporation. Due to the high costs of Green hydrogen, we feel that Aeirgas should devote resources to Blue hydrogen plants in the short term. This allows for larger plants that have a longer expected working lifetime. This time that Blue plants are active allows for further infrastructure development in Italy as well as for costs in Green hydrogen to decrease further. We hope that by Aeirgas getting in on Blue hydrogen plants now, they will be able to take over a lot of market shares as well as be better positioned financially and by experience to make the eventual jump to Green hydrogen.

Italy does not have a specific carbon tax as of yet. However, with the consensus that carbon taxes are to be implemented and/or increased over the next few years, a carbon tax would affect the short-term production costs of blue hydrogen to some extent, depending on the price elasticity of hydrogen, which is unpredictable.

4.3. Hydrogen Investment in Spain

Despite the regulations set that favor the cleaner hydrogen feedstock, there is very little willingness to invest. Amidst the pragmatism by some companies in Spain, citing cost issues, there are some factors to take note of when considering Spain's market potential [21]. Spain's gas provider Enagás has begun diving into the transitioning concerns that involve existing gas pipelines, with small scale tests and injections underway in light of a partnership. However, it is unlikely to say if this attitude will continue. Following a recent net-zero carbon goal, it is estimated that there will be a rough 200 billion euro investment throughout a net couple of decades for low carbon infrastructure [29].

Penetrating the market in Spain would benefit most from a small-scale development of grey hydrogen plants. The cost is relatively low, at \$1.50/kg of h2 due to the cheapness of grey hydrogen, but it should be noted that there is a moderate level of risk due to the uncertainty of hydrogen feedstock transmission and demand in Spain. In the future, there is potential for further expansion of Aeirgas' market share as well as improvements in carbon responsibility through transitions towards blue hydrogen, should there be financial feasibility. It should be noted that while there is a favorable attitude towards hydrogen, it is to the extent that the costs justify a social carbon responsibility. Thus, while grey hydrogen may not be very clean, it is a great way to establish oneself in the market and transition into cleaner hydrogen once more transmission infrastructure is set up and/or further attitude or regulatory changes occur. Unlike the other countries analyzed, Spain is not optimal for proliferation.

There are very few short-term benefits to the climate with this portfolio. However, with the anticipation of increased demand for hydrogen both worldwide and in Spain, stakeholders can see this as establishing the foundations for blue and green hydrogen production a couple of decades down the line. Thus, the low output compared to the high emissions can be seen as a long-term investment. Spain has been criticized for having one of the worst carbon tax policies, at a €15/ CO_2-ton while only taxing fluorinated gases [2]. Thus, these taxes would not influence an investment decision in grey hydrogen much, unless future changes to it drastically affect the cost, which may be very likely.

4.4. Hydrogen Investment in Portugal

Introducing hydrogen transmission networks into Portugal using existing infrastructure has much greater potential with almost all current gas pipelines already made of polyethylene [30]. Portugal's grid mix comprises of hydro (13.4 TWh), wind (12.5 TWh), coal (11.1 TWh), natural gas (10.1 TWh), biomass (2.8 TWh), solar (0.8 TWh) and geothermal (0.2 TWh), with a total of, as well as the ever-growing social responsibility for greener sources,5.7 TWh [26]. There is a great abundance of renewable energy, which furthermore emphasizes the capabilities of developing sustainable green hydrogen in Portugal when factoring in the cost. In addition, this is in line with the national climate goals (EN-H2) set by the government in early 2020 that signified a 7 billion euro investment for a reduction of natural gas imports [28].

While it may seem ambitious, the analysis of costs, as well as the ever-growing social responsibility for greener sources, suggests that green hydrogen models are most ideal in both the short-term and long term. While the cost seems relatively high, at $4.79/kg of h2, a realistic comparison of costs compared to using grey or blue hydrogen may not be in line with the overarching cost analysis done above. Pursuing green hydrogen plants for the continuous future is an ideal mix of being an economically and environmentally efficient method available. There already remains an abundance of green sources of renewable energy, as seen in the grid mix, thus incorporating grey hydrogen loses meaning. The large investment budget would help offset the larger cost of creating a green hydrogen plant initially but is economically feasible. Portugal follows the rest of the EU with its carbon tax policy of Euro 7 placed on every tonne of carbon dioxide emitted. The investment portfolio of starting and only pursuing green hydrogen plants is in the best interest of the investors because the savings from zero carbon emissions and positive impact on the environment would be noticeably increased in comparison to the blue and grey hydrogen models.

5. References

[1] Andre et al, “Time development of new hydrogen transmission pipeline networks for France,” International Journal of Hydrogen Energy, Elsevier, 2014, 39 (20), pp.10323-10337. ff10.1016/j.ijhydene.2014.04.190ff.
https://halshs.archives-ouvertes.fr/halshs-02396799/document

[2] Asen, Elke. “Where Is Carbon Taxed in Europe?” Tax Foundation, January 2, 2020. https://taxfoundation.org/carbon-taxes-in-europe-2019.
The European Green Deal Explained in 3 Minutes. YouTube, 2020.
https://www.youtube.com/watch?v=zf74KGVOhm4.

[3] “A European Green Deal.” European Commission - European Commission, July 8, 2020.
https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en.

[4] “DOE H2A Production Analysis,” Energy.gov, https://www.hydrogen.energy.gov/h2a_production.html

[5]Edwin A. Harvego, James E. O’Brien, and Michael G. McKellar. 2012. “System Evaluations and Life-Cycle Cost Analyses for High-Temperature Electrolysis Hydrogen Production Facilities”. United States. DOI:10.2172/1047199. http://www.osti.gov/scitech/servlets/purl/1047199.

[6] “GDP Growth (Annual %).” Data. Accessed July 28, 2020. https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG.

[7] “H2A: Hydrogen Analysis Production Models,” NREL, https://www.nrel.gov/hydrogen/h2a-production-case-studies.html

[8] “Hydrogen Benefits and Considerations.” Alternative Fuels Data Center: Hydrogen Benefits and Considerations. Accessed July 28, 2020.

[9] “Hydrogen Pipelines.” Energy.gov. Accessed July 28, 2020. https://www.energy.gov/eere/fuelcells/hydrogen-pipelines.

[10] https://afdc.energy.gov/fuels/hydrogen_benefits.html.
“Hydrogen Roadmap Europe.” Europa, 2019. https://www.fch.europa.eu/sites/default/files/Hydrogen%20Roadmap%20Europe_Report.pdf.

[11] Kilgore, Erin. “France's Hydrogen Infrastructure to Expand with 33 Hydrogen Refueling Stations.” Hydrogen Fuel News, December 14, 2018. https://www.hydrogenfuelnews.com/frances-hydrogen-infrastructure-to-expand-with-33-hydrogen-refueling-stations/8536544/.

[12] “Hydrogen Production: Natural Gas Reforming.” Energy.gov. Accessed July 27, 2020. https://www.energy.gov/eere/fuelcells/hydrogen-production-natural-gas-reforming.

[13] Iea. “Sustainable Economy Law – Policies.” IEA. Accessed July 28, 2020. https://www.iea.org/policies/1452-sustainable-economy-law?country=Spain.

[14] Iea. “The Clean Hydrogen Future Has Already Begun – Analysis.” IEA. Accessed July 28, 2020. https://www.iea.org/commentaries/the-clean-hydrogen-future-has-already-begun.

[15] Iea. “The Future of Hydrogen – Analysis.” IEA. Accessed July 28, 2020. https://www.iea.org/reports/the-future-of-hydrogen.

[16] “Levelized Cost of Energy (LCOE).” US Department of Energy, n.d. https://www.energy.gov/sites/prod/files/2015/08/f25/LCOE.pdf .

[17] Morgan, Sam. “French Gas Networks Could Mix in Green Hydrogen in Future, Say Operators.” www.euractiv.com. EURACTIV.com, November 15, 2019. https://www.euractiv.com/section/energy/news/french-gas-networks-could-mix-in-green-hydrogen-in-future-say-operators/.

[18] “Oil Refining Market: Growth, Trends and Forecasts (2020-2025).” Home. Accessed July 28, 2020. https://www.mordorintelligence.com/industry-reports/oil-refining-market.

[19] Rocamora, Alexis. “THE RISE OF CARBON TAXATION IN FRANCE.” iges, May 2017. https://www.iges.or.jp/en/publication_documents/pub/workingpaper/en/5983/The_Rise_of_Carbon_Taxation_in_France_Rocamora_May_2017.pdf.

[20] “Spain Drafts Law Eyeing Climate Neutrality by Mid-Century.” AP NEWS. Associated Press, May 19, 2020. https://apnews.com/74f4a11e36f69fc81a6aad5e34ed9009.

[21] Rack, Yannic. “Spain's Naturgy Pours Cold Water on Hydrogen Hype.” Spain's Naturgy pours cold water on hydrogen hype | S&P Global Market Intelligence, July 22, 2020. https://www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/spain-s-naturgy-pours-cold-water-on-hydrogen-hype-59534851.

[22] Vialle, C., Adoue, Belaud, J,. *et al.* A circular economy and industrial ecology toolbox for developing an eco-industrial park: perspectives from French policy. *Clean Techn Environ Policy* 21, 967–985 (2019). https://doi.org/10.1007/s10098-019-01677-1

[23] Zachmann, Georg, and Ben McWilliams. “A European Carbon Border Tax: Much Pain, Little Gain.” core, March 2020. https://core.ac.uk/download/pdf/288435929.pdf .

[24] ———. “Climate Decree – Policies.” IEA. Accessed July 28, 2020. https://www.iea.org/policies/8786-climate-decree?topic=Climate+Change.

[25] ———. “Hydrogen - Fuels & Technologies.” IEA, June 27, 2019. https://www.iea.org/fuels-and-technologies/hydrogen.

[26] ———. “International Legal Business Solutions - Global Legal Insights.” GLI - Global Legal InsightsInternational legal business solutions. Global Legal Group. Accessed July 27, 2020. https://www.globallegalinsights.com/practice-areas/energy-laws-and-regulations/portugal.

[27] ———. “National Energy Efficiency Action Plan: Portugal Efficiency 2015 – Policies.” IEA. Accessed July 28, 2020. https://www.iea.org/policies/472-national-energy-efficiency-action-plan-portugal-efficiency-2015?country=Portugal.

[28] ———. “Portuguese Government Approves Hydrogen Strategy, €7B Investments,” FuelCellsWorks, May 25, 2020, https://fuelcellsworks.com/news/portuguese-government-approves-hydrogen-strategy-e7b-investments/.

[29] ———. “Spain unveils climate law to cut emissions to net zero by 2050,” Climate Home News, May 18, 2020, https://www.climatechangenews.com/2020/05/18/spain-unveils-climate-law-cut-emissions-net-zero-2050/

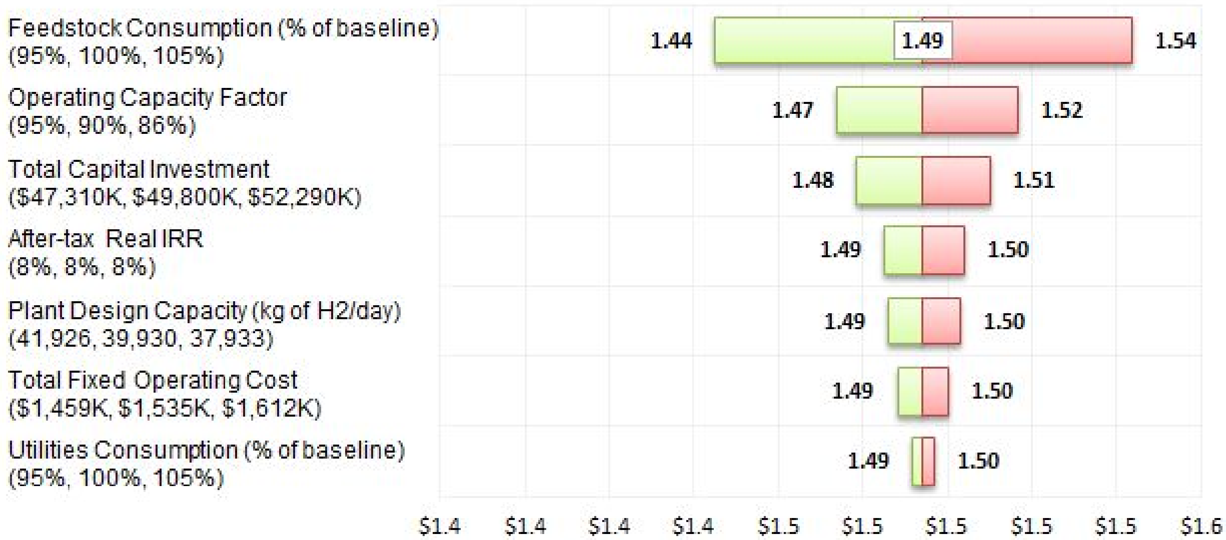
[30] ———. “The Role of Portuguese Gas Infrastructure in the Decarbonisation Process,” AFRY, February, 2020, https://afry.com/sites/default/files/2020-03/the_role_of_portuguese_gas_infrastructure_in_the_decarbonisation_process.pdf

6. Appendix

Operating and financing assumptions and parameters for blue hydrogen baseline case

List of Assumptions and Parameters for Blue Hydrogen Baseline Case					
Operating Capacity Factor (%)	90.0%	Interest rate on debt, if applicable (%)	0.037	Site Preparation ($) (may change to construction costs)	2657800.799
Plant Design Capacity (kg of H2/day)	39930	% of Fixed Operating Costs During Start-up (%)	0.75	Engineering & design ($)	13289004
Assumed start-up year	2020	% of Revenues During Start-up (%)	0.5	Project contingency ($)	19933505.99
Length of Construction Period (years)	3	% of Variable Operating Costs During Start-up (%)	0.75	Up-Front Permitting Costs ($) (legal and contractors fees included here)	19933505.99
% of Capital Spent in 1st Year of Construction	0.08	Decommissioning costs (% of depreciable capital investment)	0.1	Cost of land ($/acre)	50000
% of Capital Spent in 2nd Year of Construction	0.6	Salvage value (% of total capital investment)	0.1	Land required (acres)	2
% of Capital Spent in 3rd Year of Construction	0.32	Inflation rate (%)	0.019	Total plant staff (number of FTEs employed by plant)	3
Start-up Time (years)	1	After-tax Real IRR (%)	0.08	Burdened labor cost, including overhead ($/man-hr)	50
Plant life (years)	40	Total Tax Rate (%)	0.33	G&A rate (% of labor cost)	0.2
Depreciation Schedule Length (years)	20	WORKING CAPITAL (% of yearly change in operating costs)	0.15	Property tax and insurance rate (% of total capital investment per year)	0.02
Depreciation Type	MACRS	Industrial Natural Gas Usage (mmBtu/kg H2)	0.1558	Material costs for maintenance and repairs ($/year)	106802
% Equity Financing	0.4	Industrial Electricty Usage (kWh / kg h2	0.6	Other variable operating costs (e.g. environmental surcharges) ($/year)	487196

Grey hydrogen model case



Blue hydrogen model base case

Green hydrogen model base case

Feedstock Consumption (% of baseline)
(90%, 100%, 110%)
4.46
4.90
5.34
Total Capital Investment
($32,462K, $38,190K, $43,919K)
4.86
4.94
Total Fixed Operating Cost
($3,083K, $3,245K, $3,407K)
4.88
4.91
Plant Design Capacity (kg of H2/day)
(40,770, 38,828, 36,887)
4.89
4.91
After-tax Real IRR
(8%, 8%, 8%)
4.89
4.91
Utilities Consumption (% of baseline)
(95%, 100%, 105%)
4.90
4.90
Operating Capacity Factor
(88%, 84%, 80%)
4.90
4.90
$4.0
$4.2
$4.4
$4.6
$4.8
$5.0
$5.2
$5.4
$5.6