GREEN HYDROGEN EDGING CLOSER AS REPLACEMENT FOR FOSSIL FUELS IN 2030

ABN·AMRO

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- A large share of Dutch industry has heat intensive production processes requiring temperatures up to 850°C. These contribute to 31% of greenhouse gas (CO2) emissions – the highest amongst the key contributors in the Netherlands.

- The EU and Dutch government decided to be lenient to many industries in the near term in terms of introducing a carbon tax, given the risk of carbon leakage and the economic impact of the Coronavirus. Nevertheless, from 2025 onwards, various forms of carbon tax will really start to kick-in and impose a hefty levy on the heat intensive industry of as much as EUR 80 per tonne CO2 by 2030.

- Industrial heating processes can be altered to accommodate a clean fuel, such as green hydrogen. Green hydrogen is made by running renewable electricity and water through electrolysers and has no CO2 footprint. The fuel is currently uncompetitive and even with a steep rise in carbon taxes would need to come in at roughly EUR 1.78 per kg in 2030 to start contemplating a switch from fossil fuels.

- Electrolyser technology is developing and the various efforts to improve the technology are bound to ensure that costs come down and/or efficiency improves. There are many ways to Rome, and as an for example we look at a frontier technology allowing for high electrolyser efficiency. Should this technology be commercialized at industrial scale, we can as a scenario see green hydrogen production being manufactured at a price of EUR 2.19 per kg in 2030, narrowing the existing price/efficiency gap between green hydrogen and fossil fuels considerably.

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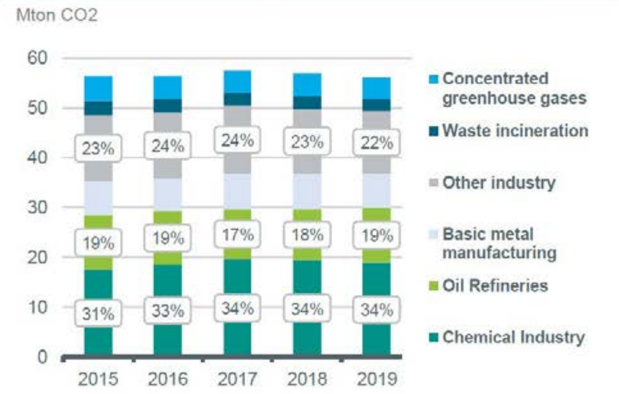
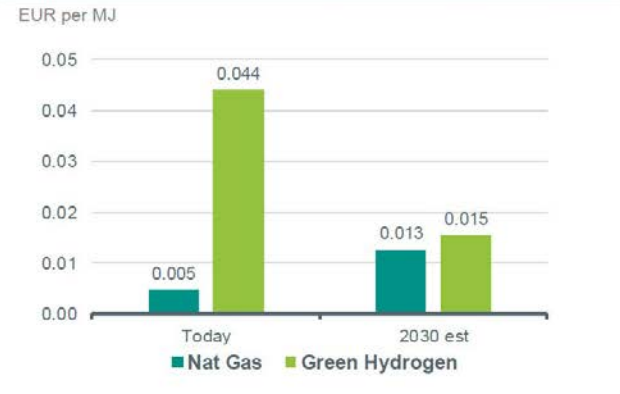
Dutch industrials – CO2 emission per subsector



Source: CBS, ABN AMRO Group Economics

Green hydrogen nearly a competitive fuel by 2030



Source: ABN AMRO Group Economics

First steps taken to investigate the potential of renewable hydrogen in the Netherlands

First steps taken to investigate the potential of hydrogen in the Netherlands
Energy demand in Northern Europe is largely driven by industrials. For instance, 31% of Dutch CO2 emissions are contributed by the industrial sector. Large parts of the industrial production processes work on a reaction basis, which require intensive heat levels only achievable by burning fossil fuels. For example, the steam cracking process used by the likes of Shell Chemicals, Sabic and Dow requires temperatures of 850 °C in the furnace, while the production of ammonia by companies such as OCI and Yara requires a temperature of up to 600°C. The existing low natural gas price levels and limited alternatives currently available to replace natural gas for heating in the reaction processes imply that the chances of an imminent improvement in the carbon footprint are low.

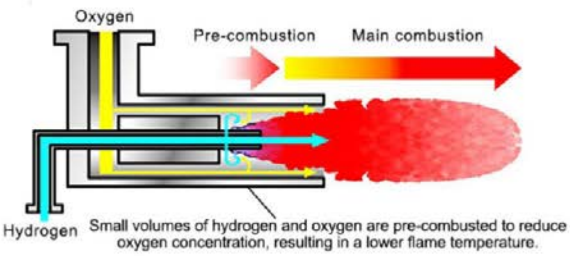
But in the longer run that could change. The advent of renewable hydrogen and the upscaled commercial availability of renewable hydrogen could be the game changer. Certainly, renewable hydrogen could be used as fuel to replace natural gas in the burner as it has roughly the same energy capacity in the burner (Wobbe index value for low/high calorific natural gas = 44/51 MJ/m3 vs hydrogen = 45MJ/m3). Just like natural gas, it could be tapped from a pipeline and Dutch gas transmission company Gasunie is looking into building a national hydrogen backbone to facilitate this. Project NorthH2 (explained later) is intended to become an industrial-sized producer of renewable hydrogen and could at a 10GW installation capacity eventually be able to produce 842mn kg of renewable hydrogen and replace over a third of fossil fuels used by Dutch industry for thermal purposes. Toyota has recently developed technology to burn hydrogen while also lowering the undesired emission of nitrogen oxide (NOx), typically responsible for smog.

Some of the frontrunners have already started to work on pilot projects involving renewable hydrogen such as Nouryon, a spin-off of Akzo Chemicals. The early pilot projects are small in scale and require subsidies due to still expensive technology and the relatively low cost for carbon emissions still making fossil fuels attractive. In this paper we look at whether Dutch industrials could switch to using renewable green hydrogen in their reaction process by the turn of the decade, as the Dutch

Hydrogen backbone - transport role taken up by Gasunie

Source: Gasunie, ABN AMRO Group Economics

Toyota's hydrogen burner prevents undesired side-effects



Source: Toyota, ABN AMRO Group Economics carbon price quadruples and cost of green hydrogen technology comes down. We provide some basic economics behind the cost of clean hydrogen and how its future price could spur fuel switching. Assumptions behind the cost of carbon emissions, wind powered electricity and the cost of electrolysers are imperative in the analysis and we shall also reflect on these.

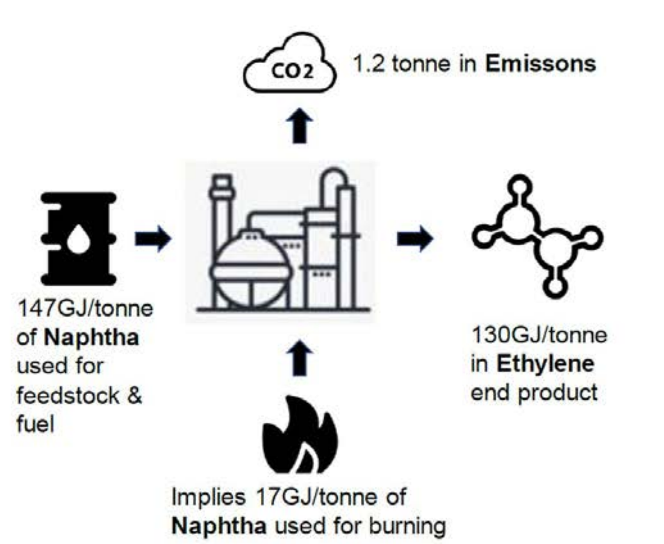
INDUSTRIAL PROCESSES REQUIRE HIGH ENERGY USAGE TO CREATE HEAT

Before we dig into the detail, we would like to illustrate why a demand for a cleaner fuel is needed by looking at examples of industrial companies heat processes and accompanied CO_2 output. The foundation of a chemical company's business model is that it uses established techniques to convert an existing compound into a new compound by using reaction processes. Take for example the commonly used organic chemicals ethylene & propylene, which are building blocks for plastics (polymers), non-woven products (such as textiles) and alcohol for example. These building blocks are often made through a process called steam cracking. In this process the energy demand lies in the production of high pressure water steam (which is added to the hydrocarbon) and the burning of this mixture of hydrocarbons and steam. Modern crackers have the ability to re-cycle heat and hydrogen, which is then used for reproducing steam. Nevertheless, net fuel demands are still there and the chart below shows potential 10mn tonnes of annual CO_2 emissions in the Netherlands attached to this process. Switching to a clean fuel for the reaction would clearly provide environmental benefits.

A second large chemical industry in the Netherlands is the manufacturing of mineral fertilizer. There are two-fold savings in CO_2 emissions to be made here by switching to renewable hydrogen. The conventional way of producing ammonia (NH_3) is through the Haber-Bosch process which has two stages of high energy demand. Firstly, natural gas (methane) is run with steamed water through a reformer and heated to temperatures of 600°C to separate the natural gas molecules into hydrogen and CO_2. In the second stage,the hydrogen and nitrogen are passed through a reactor and heated to 450°C. The entire process is known to produce 2.9kg of CO_2 per kg of NH_3 (twice the emission of ethylene) and with Dutch capacity for ammonia close to 2.6mn tonne per annum the potential CO_2 output in Dutch ammonia production is close to 7.5mn tonnes per annum (or nearly 4% of Dutch CO_2 emissions).

A recent example that CO_2 free hydrogen fuel can achieve heat levels typically realized with fossil fuels has been provided by Norway-based Ovako. Steel company Ovako replaced LPG with hydrogen in the furnace of its hot rolling mill. Hot rolling requires temperatures of roughly 900°C to mould the steel, a temperature level that is representative of other high temperature production processes that are currently powered by burning fossil fuels such as natural gas.

Energy and emission flow in Naphtha powered steam cracker to make 1 tonne of ethylene



- Modern crackers have 17GJ of net fuel requirement to produce 1 tonne (1000 kg) of ethylene through a steam cracker.
- 17GJ worth of burning naphtha would equate to a 1.2kg CO_2 emission per kg worth of ethane according to standard fuel and CO_2 emission factors.
- According to Eurostat the Netherlands produced nearly 5.5mn tonnes of ethylene and propylene in the first 8 months of 2020.
- This would accordingly equate to nearly **10mn tonnes of CO_2 emissions per annum** (or over 5% of Dutch CO_2 emissions).

Source: Energy use in steam cracking and alternative processes, Utrecht University (2004), ABN AMRO Group Economics, GJ = giga-joule

CARBON TAX STARTS TO KICK-IN FROM MID-20'S; EFFECTS FOR FOSSIL FUEL POWERED INSTALLATIONS COULD BE SIGNIFICANT

The price for carbon emissions, or carbon tax, is a key driver in the competitiveness of renewable energy sources. Dutch industrial companies are already subject to the EU emission trading system (EU ETS – European tax) and will also face a national carbon levy ("CO2 Heffing") soon. We first start with the outlook for the European tax, which is governed by the EU ETS and its tradeable product the EU Allowance (EUA). The market price for EUA in the phase 4 period running from 2021 till 2030 (the top line in the left hand chart below) is set to be influenced by supply interventions from the European Commission (EC). Besides a 2.2% linear reduction of allowances in circulation per annum, the EC also performs ad-hoc interventions whenever there are too many or too few allowances in circulation (a system called the Market Stability Reserve; MSR). As such the price for EUA could rise to EUR 52 per tonne by 2030 as suggested by Bloomberg New Energy Finance (BNEF), which expects an increase in the linear reduction factor to 4.3% from 2026 onwards.

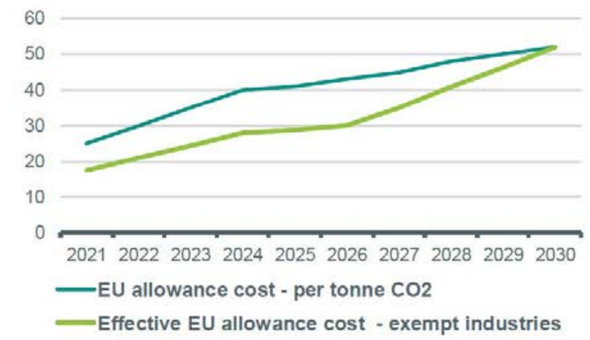
During the phase 4 EUA period, various large industrial sectors have been earmarked as having a risk of carbon leakage. To alleviate the burden, the companies involved would receive free allowances to cover 30% of their emissions. This 30% exemption will stay in place through 2026, after which this is phased out to zero free allowance through 2030. On the back of these exemptions one can calculate the effective (real) EUA price the exempt industries will have to pay, which is reflected by the bottom line in the left hand chart, which shows the convergence to the market price for EUA in 2030. The right-hand chart shows that prices for CO2 emission could be even higher due to plans by the Dutch government to apply a top-up levy, which we explain next.

The Dutch government judges that EUA system could be insufficient to achieve its own desired CO2 reductions by industrial companies from 54.2mn tonnes today to 39.9mn tonnes by 2030. Hence the Dutch authorities are about to implement a top-up CO2 levy for industrial companies in the Netherlands, called 'CO2-heffing'. This system also works with free allowances (dispensations) and due to the Coronavirus all companies will receive a full allowance to cover all emissions in 2020. From 2021 however there will be a 3% annual reduction in free allowances for 9 years to achieve the desired 14.3mn reduction in industry driven CO2. Dutch government thinktank Planbureau voor de Leefomgeving (PBL) has established all-in-price scenarios for the total carbon tax (i.e. including the EU allowance) to achieve the desired reduction, taking into consideration that free allowances of a minimum 70% will be granted (starting with 97% free allowances in 2021). We use the first of these scenario's, which are the mildest and assume that imminent technology such as CCS (explained later) will be able to take a decent bite out of industrial CO2 emissions. Finally, heavy users of natural gas in the Netherlands will be confronted with higher energy taxes per M3 from 0.9€c/0.5€c currently to 2.5€c. Only the most efficient operators will be exempt from this supplement.

PWC Advisory did an impact assessment of the total carbon tax on various Dutch high emission plants and revealed that for example a particular petrochemical in the Netherlands could see its emission-related

Trajectory of EU allowances cost through 2030

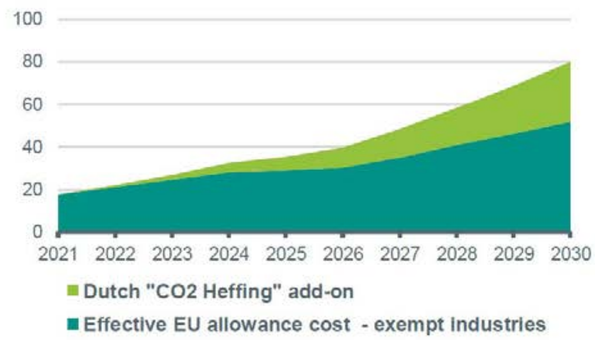
Forecast price per metric tonne (T) of CO2 emission



Source: European Commission (EC), ABN AMRO Group Economics

Trajectory of the all-in carbon tax for industrials through 2030

Forecast price per metric tonne (T) of CO2 emission



Source: PBL, EC, ABN AMRO Group Economics costs rise by 155% from the current levels and that these measures would add 10% to the total cost base. The obvious question on the more penalizing Dutch top-up levy is whether Netherlands based industrial producers would do better by moving their operations to other European countries, perhaps even closer to end-demand, such as Germany, to avoid both the CO2 top-up levy and transport costs. Indeed, Germany for example foresees the EUA mechanism to be sufficient in pricing carbon by its industrial companies. However, that assessment is likely made on the back of existing installations in Germany. Were Germany to be faced with an influx of new burner installations due to a high carbon price in the Netherlands, that relaxed position might quickly change. Furthermore, setting up shop in low cost countries outside of Europe with no carbon tax regime would face difficulties as well since the export of end-products to Europe would fall under the EC proposed carbon border adjustment mechanism and be taxed at the border to reflect the carbon usage in the production process.

Eventually it seems that final consumers will end up paying the bill for the Dutch and European climate ambitions in the industrial space. In the meanwhile a carbon tax level as high as EUR 80 per tonne of CO2 in 2030 will certainly have triggered many CEO's and CFO's to evaluate cleaner alternatives, despite their existing richness. One of these alternatives would be green hydrogen and in the next paragraph we show that adjusting the burner installation to accommodate the use of green hydrogen in the burning process seems like a reasonable investment outlay.

CARBON TAX PUSHES NATURAL GAS PRICE FROM EUR 0.19 PER M3 TO EUR 0.50 PER M3

Based on the above, the all-in price for natural gas as paid for by wholesale clients such as Dutch industrials is set to rise considerably. We take the current natural gas price for Dutch wholesale users (up to 28mn M3 consumed per annum) and extrapolate for the 2030 assumptions for the rise in European natural gas prices as established by the Worldbank. Natural gas prices are set to rise in the long run as demand from emerging markets this decade will be strong since populations grow and the fuel is a much cleaner alternative to coal for them to curb their CO2 footprints. Wood Mckenzie expects global demand for LNG to rise by over 50% this decade.

Wholesale price Dutch natural gas - forecast

Source: CBS, Worldbank, ABN AMRO Group Economics

After accounting for the various carbon and other levies mentioned in the previous paragraph, the all-in rate for 1M3 natural gas is set to rise from EUR 0.19 today to EUR 0.50 in 2030. The table below also shows the natural gas price levels per MJ and accordingly this allows us to calculate the maximum price level for renewable hydrogen as users would only consider a switch from fossil fuels to renewable hydrogen when the price per unit of thermal energy is similar.

	Now	2030
Natural gas wholesale price	0.128	0.27
Natural gas transport price	0.02	0.02
CO2 emissions (burning 1M3 releases 2.2kg CO2)	0.04	0.18
Wholesale energy tax	n/a	0.03
All-in natural gas cost	0.19	0.50
All-in natural gas cost per MJ (1M3 gas contains 39.8 MJ energy)	0.0047	0.0126
Max equivalence price of hydrogen kg (1kg hydrogen contains 142MJ energy)	0.67	1.78

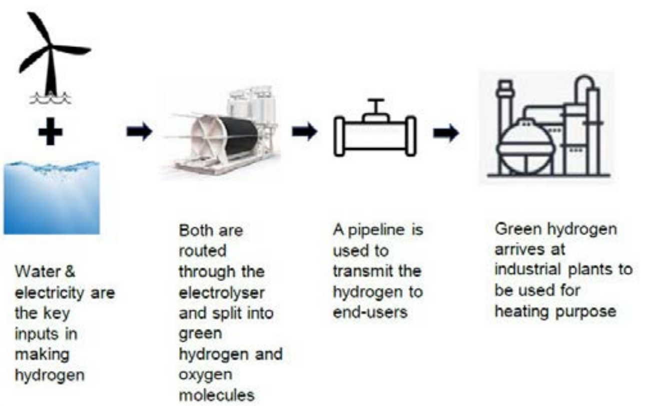
source: ABN AMRO Group Economics

Next we shall review whether the cleaner alternative fuel being green hydrogen can achieve a price level close to EUR 1.78 per kg. There are significant technological developments in progress which are intended to lower the cost of producing green hydrogen.

GREEN HYDROGEN USES THE ABUNDANCE OF WIND AND WATER IN EUROPE

Producing green hydrogen is carried out by running renewable electricity and water through an electrolyser, which splits the water molecules into oxygen and hydrogen. The process is also referred to as 'Power-to-Gas' and hydrogen produced this way is called 'green' hydrogen. Specifically, renewable electricity is used in this process and with the advent of many windfarms and solar panels in the electricity mix the excess from these renewable sources is intended to create green hydrogen.

Green hydrogen: the power-to-gas production chain



Source: ABN AMRO Group Economics

The upside to green hydrogen is obviously that the process from 'cradle to grave' does not result in CO2 emissions, while wind-power and water as inputs are physically in abundance in Northern Europe specifically. The EU commission's offshore renewable energy strategy is looking for an increase in off-shore renewable wind capacity from 12GW installed today to 300GW in 2050. The 2050 target was recently upsized by 60GW, specifically to be used in the production of green hydrogen. 60GW would be able to generate roughly 5bn kg of green hydrogen per annum should commensurate peak electrolyser capacity be available as well.

The limitations currently are the high costs involved, mainly related to the cost of renewable electricity and the still infant electrolyser technology. Therefore it would be challenging to switch to green hydrogen today. But let's fast forward 10 years from now and see how the cost picture could evolve. Below we show that the most important cost components, mainly the cost for renewable electricity and the equipment used in the electrolysis, should develop favourably in the next 10 years to lower the cost close to the EUR 1.78 per kg defined earlier.

RENEWABLE OFF-SHORE WIND POWER COST TO COME IN AT EUR 44 PER MWH (ALL-IN)

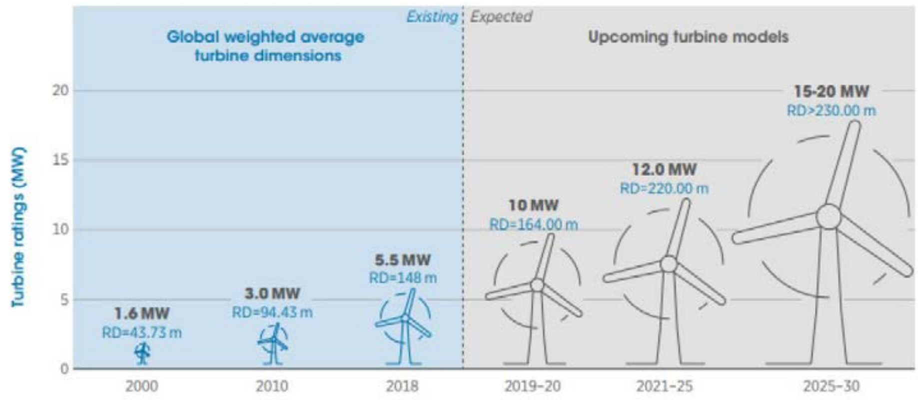
Our assessment of green hydrogen's economic feasibility will focus on 2030, since we expect costs related to renewable energy and green hydrogen technology to come down considerably by then from existing levels. We will look at an industrial scale type power-to-gas installations and take the earlier mentioned by NortH2 project as a template. NortH2 is still in feasibility study and the consortium including Shell, Gasunie and Groningen Seaports are probably still undertaking a lot of research & due diligence on this mega-sized project. However, it is reportedly one of the largest green hydrogen projects being considered, having a plan to produce at 4GW scale in 2030 and 10GW scale in 2040. The large envisaged size and its intended use for the industrial sector is the main reason why we took NortH2 as a benchmark in our analysis.

NortH$_2$

- North Sea wind powers 4GW (2030) and eventually 10GW (2040) of collective turbines
- Resulting in green hydrogen production levels = 337mn kg in 2030 and 842mn kg in 2040
- Hydrogen intended for industrial purposes (fuel and feedstock)
- Gasunie's existing natural gas transmission pipelines carry fuel to its destination
- Storage of excess hydrogen in existing salt caverns

The idea behind an industrial scale electrolyser is to have the windfarm entirely dedicated to the production of green hydrogen, as the large scale would allow for substantial cost reductions in the production of green hydrogen. NorthH2 is targeting a 4GW capacity in 2030, which in power terms would come close to 4 nuclear plants or 6 coal-fired power plants.

Off-shore wind should see vast improvement in efficiency and costs



Source: GE, MHI Vestas, IRENA, ABN AMRO Group Economics, RD = radius

Renewable electricity is a key part of green hydrogen production as it powers the electrolyser to convert water into hydrogen. The abundance of wind, a reduction of turbine costs and advance in floating off-shore wind technology would keep the costs for renewable electricity low. Off-shore windfarms are deemed the most efficient solution for industrial sized power-to-gas installations as they capture the higher windspeeds at sea. The load factor for off-shore wind is roughly 50%, while for solar in Spain this is 20%. Due to expected technological developments in turbine design and the size of the blades, the capacity of a typical turbine is set to nearly double through 2030 as the radius in the blades is set to rise from 150 metres today to over 230 metres in 2030.

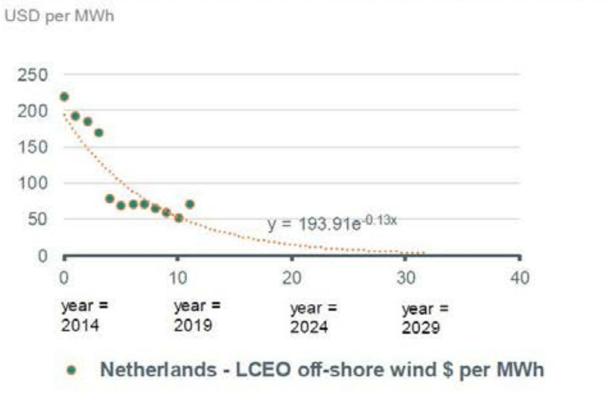
Experts accordingly see the levelized cost of energy (LCOE – represents all the lifetime costs divided by lifetime power production of a wind turbine) to drop to as low as EUR 30 per MWh in 2030. This does not seem overly optimistic given that the investment decision on windfarm Hollandse Kust 3 & 4 was taken based on an assumption of EUR 43 per MWh in 2019, while the LCOE per MWh for Dutch off-shore wind energy today has declined by roughly 75% from 2014 levels. A simple cost trend analysis reveals that the EUR 30MWh is indeed achievable, while experts also see the investment cost dropping by 18% from the levels seen today.

Furthermore, infrastructure funds seeking stable returns will be happy to assume the wind park investment in the power-to- gas value chain as they will be reimbursed the EUR 30 per MWh for 20 years and are no longer subject to the price volatility in the wholesale electricity market or the trouble of renewing medium term PPA's. Hence, for our analysis the EUR 30 per MWh for renewable wind powered electricity is entirely a variable cost. We also need to take grid connection fees into consideration and assume EUR 14 MWh for off-shore connection fees, like the one recently calculated by Dutch Ministry of Economic Affairs Dutch for grid operator Tennet on its latest off-shore connections. Total costs related to electricity therefore add up to EUR 44MWh.

ELECTROLYSER EFFICIENCY SET TO RISE SIGNIFICANTLY

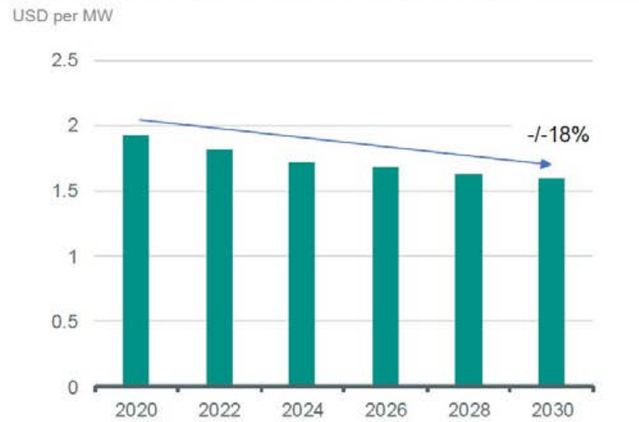
The next significant cost items is the electrolyser, which is used to derive hydrogen by splitting the water molecule. In laymen terms, electricity is passed through water where the separation of water into hydrogen and oxygen takes place at the two electrodes – cathode filters hydrogen and the anode filters oxygen. The drawback with electrolysers today is the lack

Cost trend analysis shows that EUR 30MWh is achievable



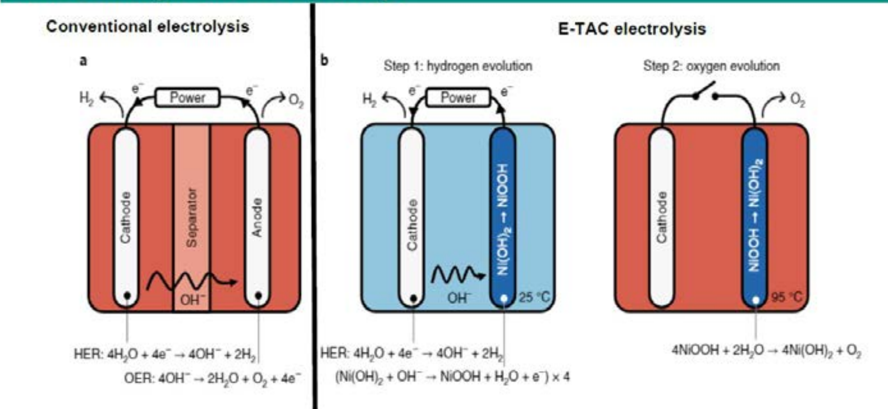
Source: Bloomberg NEF, ABN AMRO Group Economics

Off-shore wind capex set to decline by 18% by 2030



Source: Bloomberg NEF, ABN AMRO Group Economics of efficiency. For every unit of electricity used in the electrolysis process, only an equivalent of 66.5% of energy is ultimately stored in the hydrogen format. However, new technologies (which have yet to be commercialized) are looking promising and one of these technologies is E-TAC which is short for Electrochemical – Thermally Active Chemical. As the name flags, the electrolysis process under E-TAC consists of two phases. The first electrochemical step is not different from conventional alkaline electrolysis where the cathode reaction delivers the desired hydrogen. However, under the second phase in E-TAC, oxygen is produced through a chemical reaction of a charged anode and water, hence eliminating the need for electricity. Hence, E-TAC is able to achieve an efficiency of 98.7%. Furthermore, under E-TAC the process does not need to take place in one chamber, which makes the membrane used in conventional electrolysis redundant and could therefore drive cost efficiency for materials as well. The inventors published their findings in peer reviewed scientific journal 'Nature Energy'.

E-TAC electrolysis occurs in two steps



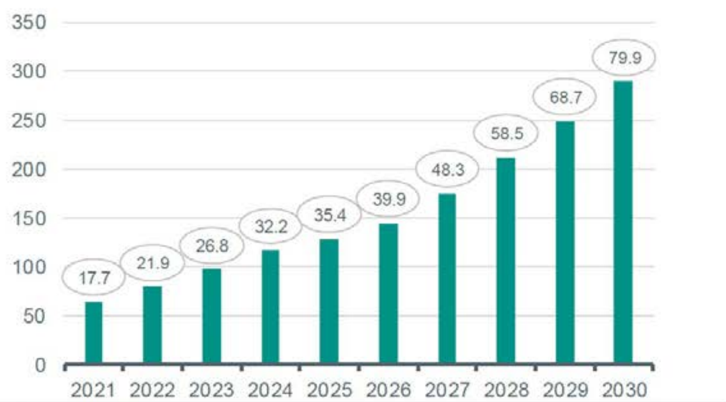
Source: Nature Energy, Technion, ABN AMRO Group Economics

Now switching back to cost expectations for electrolysers. As detailed expectations regarding cost reduction for materials under E-TAC have not been given (the inventors expect E-TAC cost to be 50% of traditional electrolysis), we stick to the cost expectations for standard alkaline solutions, yet jack-up the efficiency to E-TAC suggested levels of 98.7%. The cost for the stacks/ancillary equipment for alkaline electrolysers is set to drop from EUR 500/980 per KWe currently to EUR 333/400 per KWe in 2030 as per average Bloomberg New Energy Finance (BNEF) and IEA expectations. As you would want to capture the generated electricity from the windfarm as much as possible, we install a 4GW capacity electrolyse which allows for 456mn kg of hydrogen production annually. Finally we pencil in 2% annual opex on the electrolyser capex.

CARBON PROCEEDS TO BE APPLIED TO REDUCE GREEN HYDROGEN COST

Remember the carbon tax we mentioned earlier? The EC and the Netherlands have committed to spend the proceeds from the carbon tax on renewable energy projects. Based on the 456mn kg green hydrogen production potential and our trajectory for carbon, we can calculate how much proceeds the authorities will generate from the carbon tax under energy equivalence. Remember that the trajectory for carbon tax (and therefore the potential proceeds) was based on a scenario where there would be some quick relief in carbon emission coming from example CCS (as explained later). Hence we already consider other technologies becoming available, yet the final and largest abatement will only come from a switch to renewable hydrogen as a burning fuel. We are indifferent as to whether the EUR 1.6bn

Authorities collect EUR 1.6bn this decade by taxing fossil fuel heat production of same energy content as NorthH2's hydrogen production



Source: ABN AMRO Group Economics, labels represent the carbon tax trajectory as shown earlier

Assumptions:

A: annual hydrogen production 4GW power to gas (kg) = 456.1mn kg

B: annual thermal energy of A = 64.7PJ

C: annual CO2 emissions related to thermal energy in B, in case natural gas being used (tonne) = 3.6mn tonne based on 0.056kg per MJ cumulatively raised will be spent to subsidize R&D in the next years or as a grant to alleviate capex for the power-to-gas installation in 2030. Fact remains that cost for green hydrogen are set to come down even more than currently expected by the market because of technological development. As such we deduct these proceeds from the initial investment. This also provides relief in the calculation of the return on capital as upfront costs come down. For the return requirements we calculate a simple annuity on the total EUR 1.4bn capex outlay and deduct the initial investment to exclude for amortization part of the annuity. For the annuity we assume a 5.2% IRR, reflecting Dutch market premiums and the unlevered beta of ESG frontiers Iberdrola and Orsted.

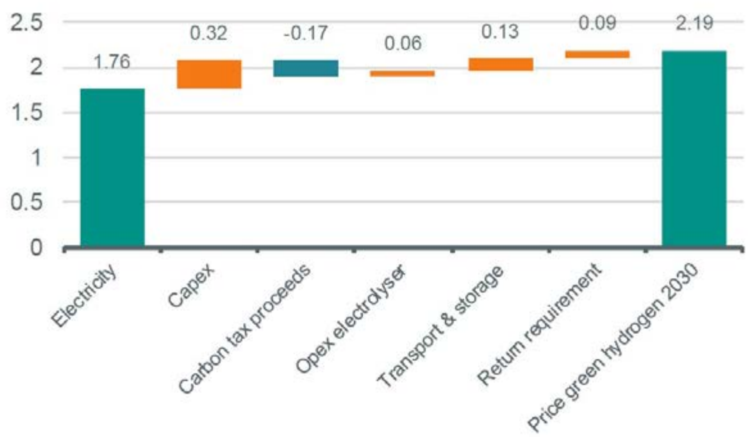
GREEN HYDROGEN TO COME IN AT EUR 2.20 PER KG IN 2030

With the major cost (and rebate) components covered, we can now finally make an estimate of the price for green hydrogen in 2030. We show the price per kg based on lifetime cost build-up approach and also solve for the price under an NPV approach as we now have the various cost components and return requirements to do so.

	Unit price	Value (EUR bn, unless stated otherwise)
Lifetime	20 years	n.a.
Load factor windfarm	52%	n.a.
Electrolyser efficiency	98.70%	n.a.
4GW dedicated wind electricity running at 52% load factor for 20 yr at EUR 44 MWh	EUR 44 MWh	16
4GW stacks capex - stacks should be able to run for 90k hours	EUR 333 KW	1.3
4GW other electrolyser equipment	EUR 400 KW	1.6
Carbon tax proceeds commensurately used to lower capex cost of project	n.a.	-1.6
Opex electolyser (20yr)	2% capex	0.6
Transport - allowed return & depreciation on EUR 2bn pipeline adjustment	EUR 0.12 per kg	1.1
Storage - EUR 0.55 per M3 hydrogen at 200 bar and 1 month supply	EUR 0.0027 per kg	negligible
Return requirement - cumulative annuity based on 5.2% unlevered IRR (reflecting risk renewable utilities) on net capex investment, 20yr timeframe -/- initial investment value	n.a.	0.9
A: Sum of all cost and return components for 20 years	**EUR**	**19.9**
B: Cumulative production in 20 years	**kg bn**	**9.1**
C: Price per kg = A/B	**EUR**	**2.19**

source: ABN AMRO Group Economics

Green hydrogen's price based on lifetime cost build up approach



Source: ABN AMRO Group Economics

We also solved for an average price per kg for green hydrogen through a net present value (NPV) calculation, which is displayed in the table below. Besides the assumptions used in the previous lifetime cost build-up calculation, we also account for straight line depreciation (applied on net investment - after deducting the carbon tax proceeds from electrolyser capex) and a 25% corporate tax rate. This iteration returned a EUR 2.22 required price per kg for green hydrogen in order for the NPV of the NorthH2 4GW project to be zero.

EUR price per kg of green hydrogen	2.22
Production per annum (mn kg)	456.1
Unlevered IRR	5.20%

	CF0	CF1	CF2	CF3	CF4	CF5	CF6	CF7	CF8	CF9	CF10	CF11	CF12	CF13	CF14	CF15	CF16	CF17	CF18	CF19	CF20
Electrolyser Investment (net)	-1,375																				
Annual production times price		1,013	1,013	1,013	1,013	1,013	1,013	1,013	1,013	1,013	1,013	1,013	1,013	1,013	1,013	1,013	1,013	1,013	1,013	1,013	1,013
Cash costs		-885	-885	-885	-885	-885	-885	-885	-885	-885	-885	-885	-885	-885	-885	-885	-885	-885	-885	-885	-885
Tax		-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15
Annual cashflow	-1,375	113	113	113	113	113	113	113	113	113	113	113	113	113	113	113	113	113	113	113	113
Discount factor	1.00	0.95	0.90	0.86	0.82	0.78	0.74	0.70	0.67	0.63	0.60	0.57	0.54	0.52	0.49	0.47	0.44	0.42	0.40	0.38	0.36
NPV: Σ CF0 - CF20 = EUR 0	-1,375	107	102	97	92	87	83	79	75	71	68	65	61	58	55	53	50	48	45	43	41

Source: ABN AMRO Group Economics, all Cashflow (CF) amounts in EUR mn's

Like we showed on the right-hand chart of the first page, green hydrogen is set to make great strides at the start of the next decade, however the future price levels seem likely to remain above fossil fuel alternatives. Remember, green hydrogen needs to come in at EUR 1.78 per kg to start becoming competitive with natural gas. However, there are some levers which might still tip the balance in favour of green hydrogen. Firstly, a recent report by Bloomberg New Energy Finance showed that the cost of stacks in alkaline electrolysers could drop to $115 (EUR 100) per KW in 2030 under an optimistic scenario. This would shave off an additional EUR 0.15 per kg, while the difference in EUR per MJ to natural gas would then be 0.1c instead of 0.2c. Secondly, the Netherlands has tiered gas pricing system and green hydrogen would be at cost equivalence to natural gas for lower intensity users which consumer up to 100TJ per annum. Thirdly, in case imminent technology such as CCS (explained below) would for some reason not be able to reduce CO2 emissions in the near term sufficiently (because of higher than expected economic activity for example), then the price for carbon tax could rise to EUR 120 per tonne i.s.o. the EUR 80 per tonne assumed and thereby boost equivalence pricing between natural gas and green hydrogen from EUR 1.78 to EUR 2.07, which sits much closer to the above calculated price level of green hydrogen produced by NorthH2. Finally, scope 3 downstream emissions will become part of the EU taxonomy. Dutch industrials who use of fossil fuels in their thermal process will struggle to sell their goods to clients, as these clients will have to verify that the purchased goods were manufactured in a sustainable fashion (i.e. without burning fossil fuels). This is bound to create fragmentation in capital risk premiums, i.e. higher capital cost for fossil fuel burning and lower capital cost for hydrogen fuel burning. All in all, it seems that there are decent upsize risks which could ultimately drive equivalence between fossil fuels and green hydrogen in 2030. A lot can happen in 10 years from now!

FURTHER ALTERNATIVES FOR DUTCH INDUSTRIALS TO REDUCE CARBON FOOTPRINT

There is still a long way to go before green hydrogen becomes commercially viable. In the meantime, industrial and power companies are not resting on their laurels. One of the most imminent technologies geared towards reducing industrial CO2 is carbon-capture-and-storage (CCS). Under this technology the CO2 would not be emitted in the atmosphere, but is captured and stored underground in depleted North Sea gas fields. Indeed, two high profile projects are being contemplated in the Netherlands, which intend to connect industrial users to a main pipeline, Porthos and Athos. The industrial plants wanting to connect to Porthos/Athos would have to capture the CO2 themselves and direct it to the main pipeline. In terms of ease of use, the location of Porthos in Rotterdam port works perfectly for the chemical plants and refineries in the Rotterdam industrial area. Indeed, Shell, ExxonMobil and Air Products and Air Liquide, all of which have operations in the Rotterdam Botlek area, are set to request subsidies estimated at reportedly EUR1.5bn on their carbon capture investments.

On the main pipeline, the EC is set to provide a EUR 102mn subsidy to the Porthos project, which is a sizeable contribution to the overall EUR 400mn /500mn envisaged investment. CCS would also allow the production of blue hydrogen, which is hydrogen still being made by using natural gas as feedstock and burning fuel. However, there would be virtually no CO2 emissions in the production of blue hydrogen as CCS would capture and store the ensuing CO2 emission.