HyDelta

WP8 – Admixing

D8.3 – Pilots for introducing hydrogen blending quota

Status: final

Dit project is medegefinancierd door TKI Nieuw Gas | Topsector Energie uit de PPS-toeslag onder referentienummer TKI2020-HyDelta.

Document summary

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Document history

Version	Date	Author	Affiliation	Summary of main changes
1	18-10-2021	Jorge Bonetto Catrinus Jepma Rob van Zoelen	NEC	First version
2	5-11-2021	Jorge Bonetto Catrinus Jepma Rob van Zoelen	NEC	Editorial changes and conclusion included
3	26-11-2021	Jorge Bonetto Catrinus Jepma Rob van Zoelen	NEC	Feedback EAG included
4	17-12-2021	Jorge Bonetto Catrinus Jepma Rob van Zoelen	NEC	Feedback SG and ST included

Dissemination level

Dissemination Level		
PU	Public	X
R1	Restricted to • Partners including Expert Assessment Group • Other project participants including Sounding Board • External entity specified by the consortium (please specify)	
R2	Restricted to • Partners including Expert Assessment Group • Other project participants including Sounding Board	
R3	Restricted to • Partners including Expert Assessment Group	

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Executive summary

In this report three administrative mandatory blending schemes are discussed from the perspective how such schemes could be initiated, if the political decision to that end would be made, without distorting the market or creating other undue impacts. The presumption is that any mandatory blending scheme cannot be introduced just overnight, but rather that such introduction would need to be preceded by pilots or experiments in order to test how the scheme will work out if actually implemented in practice.

The various blending scheme pilots have been compiled on the basis of various criteria. A first criterion for specifying a pilot case was to check if existing technical installations and infrastructure would allow for a relatively swift and easy introduction of a first blending testing scheme. If a pilot would require significant additional investment, this would slow down the introduction of the pilot too much. Also local acceptance was considered as an important precondition. A second criterion for the pilot was if a scheme could be introduced that would be reliable and controllable enough for being accepted even as an experiment. This criterion not only relates to the actual physical blending but also to the reliability of the related blending certificate trading. A third criterion in specifying the pilots was that in actual practice the quota could be met by sufficient volumes of supply of clean hydrogen. If already in a pilot stage one would have problems with filling a quota, this would destroy the pilot and undermine the credibility of a further roll-out. The fourth criterion was that the pilot was compatible with the existing rules and regulations with respect to safety, grid integrity, etc. To the extent feasible it will need to be checked if special regulatory regimes for pilots and experiments could apply.

Based on the above criteria and on extensive expert review, three blending scheme pilots have been discussed in this report. First, an industrial blending scheme pilot is discussed in which some dedicated industrial sectors will introduce a combination of physical and virtual blending of clean hydrogen as energy carrier and feedstock. This pilot is proposed to be virtual and applied to some preselected industrial clusters. Second, a generic mandatory blending scheme pilot is discussed in which the energy suppliers to the grid will either physically or with the help of certificates have to demonstrate that they blend an x percent clean hydrogen to the gas entering the grid. This pilot will be restricted to some specific preselected regions. Thirdly, a pilot has been worked out in which the existing national fuel blending obligation under RED will be amended such that clean hydrogen is part of the existing quota. Again, this scheme can be filled in by the committed parties (i.e. fuel suppliers) either physically, or with the help of certificates. An advantage of this scheme is that it benefits from the already existing quota, and therefore can be introduced probably relatively quickly. This pilot was specified for a limited number of fuel stations.

The three blending pilot proposals are schematically outlined in Table 1. The table illustrates: which market parties are covered by the quota scheme, which parties face quota commitments, what the quota base is, and which energy carriers are (possibly) accepted within the quota.

Table 1 – Overview main characteristics of quota proposals

Proposal:	1: Industrial	2: Gases	3: Fuels
Market sectors	(Specific) industrial applications (e.g. ammonia, methanol, refineries)	Gas suppliers	Fuel suppliers for transport applications
Obligated Target parties	End-user: Industries consuming hydrogen	Suppliers: Gas suppliers	Suppliers: Fuel suppliers that deliver more than

			500.000 litres, kg or Nm^3 of fuel annually
Base of quota	% of total H_2 (kg) used in processes	% of total gas delivered	% of their total taxed fuels (GJ) supplied
Accepted quota energy carriers	• Renewable H_2 • (Low-carbon H_2)	• Renewable H_2 • (Biomethane) • (Synthetic methane)	• Current accepted renewable fuels • Renewable H_2

It is important to note that different blending schemes as discussed in this report can exist in isolation but also in combination. All the three blending schemes discussed can go together, but obviously this would require a correct alignment in order to prevent either double counting or greenwashing, or that specific parties are overcharged.

The timing of the various pilots discussed above obviously strongly depends on the expected overall development of the hydrogen value chain. Pilots towards mandatory blending in themselves already need time. In discussions with various stakeholders it was often expressed that even to prepare for a serious pilot may easily cost a few years. Next, pilots themselves will often reveal issues in actual practice that need to be resolved and may give rise to new regulatory measures etc., processes that again can easily take a few years. In other words, the process of preparing and introducing pilots should not be taken lightly timewise. At the same time pilots may have a considerable political signalling function to the extent that authorised pilots will readily be perceived by stakeholders as a precursor of a deep and lasting policy commitment towards introducing mandatory blending schemes at a much fuller scale, and may therefore already set in motion other processes driving investment in the hydrogen value chain.

As far as the timing of the introduction of the various quota scheme pilots discussed is concerned, it looks like the pilot related to fuel blending scheme can be introduced the earliest, because it is just a component of an already existing mandatory blending scheme under RED. A next candidate could well be the introduction of a pilot in the industrial uptake of clean hydrogen. This is not only because the recent proposal (see also the main text on more details) by the European Commission to introduce such a mandatory target by 2030, but also because the proposed pilot in the Netherlands is suggested to be virtual, i.e. on paper only, because real-life testing is considered too complex. The third proposed pilot, namely a more generic introduction of a clean hydrogen quota for gas entering the public gas grid, is probably the most complex one because even in a pilot all relevant appliances need to be ready for the new gas mix, and all safety preconditions need to be fulfilled. This is why this pilot needs to be based on physical blending under real life conditions, but also why this pilot is expected to be the last of the three to be introduced. Obviously, timing of the various pilots, if accepted, is a matter of further political decision making. As was mentioned before, ultimately all discussed blending schemes can coexist.

A possible timing scheme, keeping the above and further technological and regulatory issues in mind, is represented in the figure below.

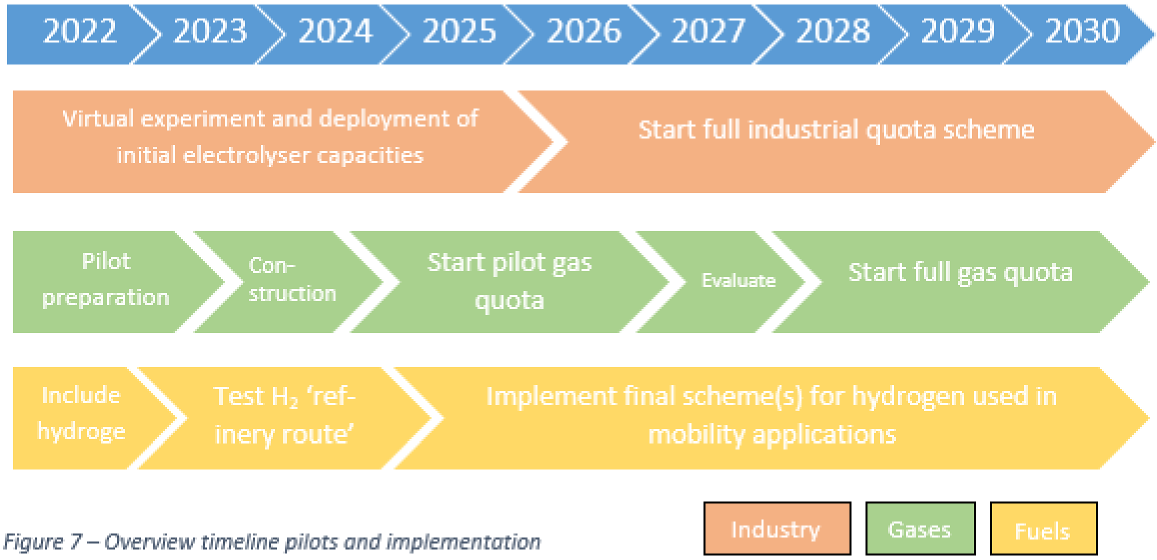


Figure 7 – Overview timeline pilots and implementation

Samenvatting

In dit rapport worden drie administratieve bijmengverplichtingregelingen beschreven vanuit het perspectief hoe deze geïntroduceerd zouden kunnen worden – mocht hier een politieke beslissing voor gemaakt worden – zonder dat dit leidt tot grote marktverstoringen of andere ongewenste effecten. De vooronderstelling die hierbij is gemaakt is dat bijmengverplichtingen niet van de een op de andere dag tot stand komen, maar dat de introductie hiervan gepaard gaat met een voorbereidende pilots of experimenten om te testen hoe een dergelijke regeling uit zal pakken in de praktijk.

De beschreven pilots voor mogelijke bijmengverplichtingen zijn tot stand gekomen op basis van verschillende criteria. Het eerste criterium was een check van de kansen en belemmeringen die bestaande installaties en infrastructuur met zich mee zouden brengen om een bijmengverplichting te introduceren. Wanneer een pilot grote additionele investeringen zou vereisen, zou dit een pilot erg vertragen. Daarnaast is ook de acceptatie van stakeholders meegenomen in de overwegingen. Een tweede criterium was of een experiment dermate betrouwbaar en controleerbaar zou zijn om geaccepteerd te kunnen worden als experiment. Dit heeft niet alleen betrekking op fysieke bijmenging maar ook op de betrouwbaarheid van administratieve handel in certificaten. Een derde criterium voor het specificeren van de pilots was dat er voldoende schone waterstofvolumes beschikbaar moeten kunnen worden gemaakt om aan het quotum te voldoen. Als er in de pilotfase al problemen zijn om te voldoen aan het quotum, zou dit weinig vertrouwen geven om regeling na een pilot verder uit te rollen. Het vierde criterium was om de pilots zo veel mogelijk in lijn te laten zijn met bestaande regelgeving omtrent veiligheid, netintegriteit, etc. Waar mogelijk zou uitgezocht moeten worden of speciale regelingen voor pilots en experimenten toe te passen is.

De hierboven beschreven criteria en uitgebreide consultatie van experts hebben geleid tot drie richtingen hoe regelingen voor een bijmengverplichting eruit zouden kunnen zien. Ten eerste is een industriële bijmengverplichting pilot beschreven waarbinnen vooraf bepaalde industriële sectoren verplicht zouden worden schone waterstof bij te mengen in grijze stromen gebruikt voor zowel energie als grondstof, wat zowel met certificaten als fysiek kan. Hiervoor is een virtuele pilot voorgesteld welke zal worden toegepast op een aantal vooraf geselecteerde industriële clusters. Ten tweede wordt een meer generieke bijmengverplichting besproken waarin energieleveranciers verplicht worden om een x percentage schone waterstof te leveren aan hun klanten. Deze pilot zal in begrenst zijn aan een vooraf gespecificeerde regio. Ten derde is een pilot uitgewerkt waarbij de huidige nationale bijmengverplichting voor vervoer zal worden uitgebreid met schone waterstof als onderdeel van het bestaande instrument. Ook hier kunnen de verplichte partijen (i.e. brandstof leveranciers) kiezen of ze aan het quotum willen voldoen door fysieke leveringen of slechts met certificaten. Een voordeel is dat in dit geval voortgeborduurd kan worden op de huidige regeling, waardoor implementatie mogelijk een stuk sneller mogelijk is. De beschreven pilot is gespecificeerd voor een beperkt aantal tankstations.

De drie voorstellen voor bijmenging zijn schematisch gerepresenteerd in Table 1. De tabel illustreert: op welke marktsectoren elk quotum zich richt, op welke partijen de verplichting rust, wat de grondslag van elk quotum is, en welke energiedragers (mogelijk) geaccepteerd worden in het quotum.

Tabel 2 – Overzicht van de hoofdaspecten binnen elk quotum voorstel

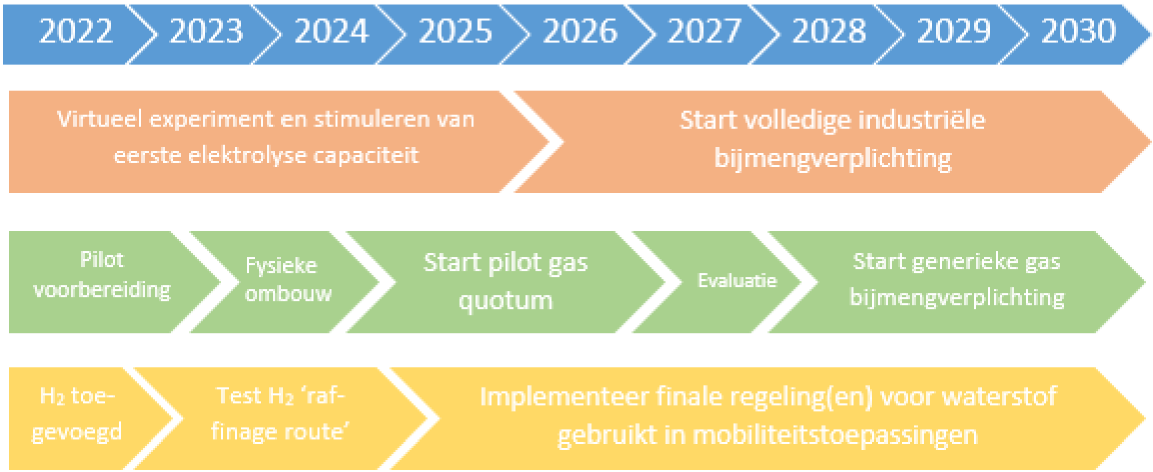
Voorstel:	**1: Industrie**	**2: Gassen**	**3: Brandstof**
Marktsectoren	(Specifieke) Industriële toepassingen (e.g. ammoniak, methanol, raffinage)	Gasleveranciers	Brandstofleveranciers voor transporttoepassingen

Partijen op wie de verplichting berust	Eindgebruikers: Industrieën die waterstof gebruiken	Leveranciers: Gasleveranciers	Leveranciers: Brandstofleveranciers die meer dan 500.000 liter, kg of Nm^3 brandstof jaarlijks leveren
Grondslag van de verplichting	% van de totale hoeveelheid H_2 (kg) gebruikt in processen	% van het totaal geleverde gas	% van het totaal geleverde brandstoffen (GJ) waar belasting voor is betaald
Geaccepteerde energiedragers om aan het qoutum te voldoen	• Hernieuwbare H_2 • (CO_2 neutrale H_2)	• Hernieuwbare H_2 • (Bio-methaan) • (Synthetische methaan)	• Huidig geaccepteerde brandstoffen • Hernieuwbare H_2

Het is belangrijk om te noemen dat verschillende bijmengverplichtingen die in dit rapport worden beschreven zowel afzonderlijk als naast elkaar geïmplementeerd kunnen worden. Alle drie voorgestelde verplichtingen kunnen samengaan, echter zullen ze dan goed op elkaar afgestemd moeten worden om zowel dubbeltelling, groenwassen of het onrechtmatig dubbel verplichten van partijen te voorkomen.

De timing van de verschillende pilots zoals hierboven beschreven hangt natuurlijk sterk af van wanneer de waterstof waardeketen tot stand gebracht beoogt te worden. De pilots op zichzelf nemen al tijd in beslag. In gesprekken met verschillende stakeholders kwam naar voren dat de voorbereiding op zulke pilots al gouw jaren kan kosten. Daarnaast zullen gedurende de pilots ook nieuwe kwesties naar voren komen die weer nieuwe regelgevende maatregelen etc. vereisen, wat opnieuw ook weer jaren kan kosten. Oftewel, de tijd die het kost om pilots uit te voeren moet niet onderschat worden. Daarbij kan het aankondigen van pilots een politiek signaal afgeven, gezien het een richting geeft waar toekomstige regelgeving zich naartoe zou kunnen bewegen, wat daarmee al processen in gang zou kunnen zetten richting ontwikkelingen en investeringen benodigd om de waterstof waardeketen aan te jagen.

Voor zover als de timing van de introductie van de verschillende quotum pilots is overwogen, lijkt het erop dat de pilot voor bijmenging als vervoerbrandstof het eerst geïntroduceerd kan worden, omdat het slechts een nieuwe component zou zijn binnen een reeds bestaande regeling. Een volgende kandidaat zou de industriële pilot kunnen zijn. Niet alleen vanwege de recent voorgestelde verplichte doelstelling (zie volledige tekst voor meer details) van de Europese Commissie in 2030, maar ook omdat de voorstelde pilot in Nederland virtueel is, i.e. slechts op papier, gezien een fysieke test als te complex is beschouwd. Het derde voorgestelde pilot, een meer generieke bijmengverplichting voor schone waterstof in het publieke net, is wellicht de meest complexe gezien het gereedmaken van alle apparatuur voor een nieuwe gasmix in bepaalde delen van het net, en de veiligheidsvereisten waaraan moet worden voldaan. Om deze reden wordt voorzien dat deze optie het meeste tijd kost voordat deze mogelijk geïmplementeerd kan worden. Natuurlijk is de daadwerkelijke timing van de pilots en regelingen, dan wel of deze geaccepteerd worden, een beslissing voor de politiek. Echter, enkel gekeken naar technologische en regelgevende issues zou een mogelijk tijdsschema eruit kunnen zien zoals in onderstaand figuur. Zoals gezegd, kunnen de verschillende regelingen naast elkaar worden ingezet.



Figuur 7 – Overzicht tijdslijn pilots en implementatie

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Abbreviations

ACM	*Autoriteit Consument & Markt,* Authority of Consumers and Markets
AMvB	*Algemene Maatregel van Bestuur,* Order in Council
ATR	*Autothermal Reforming*
bcm	*Billion Cubic Meters*
BTX	Abbreviation for mixtures of Benzene, *Toluene and Xylene isomers*
CC(U)S	*Carbon Capture (Utilization) and Storage*
CHP	*Combined Heat and Power*
$CO_{2(-eq)}$	*Carbon Dioxide (equivalents)*
DRI	*Direct Reduced Iron*
DSO	*Distribution Grid Operator*
(EU)ETS	*(European Union) Emission Trading System*
FCEV	*Fuel Cell Electric Vehicle*
FCH JU	*Fuel Cells and Hydrogen Joint Undertaking*
FME	*Federatie voor de Metaal- en Elektrotechnische industrie,* Dutch employers organisation for technical industries
GJ	*Gigajoule(s)*
GO(s)	*Guarantee(s) of Origin*
GW(h)	*Gigawatt(-hour)*
H_2	*Hydrogen*
HBE(-~)	*Hernieuwbare Brandstof Eenheid,* Renewable Fuel Entity, A- Advanced, C-Conventional, O- Other, H- Hydrogen.
HDS	*Hydrodesulfurization*
HRS	*Hydrogen Refueling Station*
ILT	*Inspectie Leefomgeving en Transport,* Inspection on the Living environment and Transport
IPCEI	*Important Projects of Common European Interest*
kg	*Kilogram(s)*
kW(h)	*Kilowatt(-hour)*
LHV	*Lower Heating Value*
Lte	*Levering tot eindverbruik,* Taxed delivery for final consumption
MW(h)	*Megawatt(-hour)*
NEa	*Nederlandse Emissie Autoriteit,* Dutch Emission Authority
NECP	*National Energy and Climate Plan*
NEN	*Stichting Koninklijk Nederlands Normalisatie Instituut,* Dutch Normalisation Institute
Nm^3	*Normal Cubic Meter*
PJ	*Petajoule(s)*
PoS	*Proof of Sustainability*
RED(II)	*Renewable Energy Directive*
REV	*Register Energy voor Vervoer,* Energy for Transport Registry
RFNBO(s)	*Renewable Fuel(s) of Non-Biological Origin*
SDE(++)	*Stimulering Duurzame Energieproductie (en Klimaattransitie),* Stimulation of Renewable Energy production (and Climate transition)
SMR	*Steam Methane Reforming*
SodM	*Staatstoezicht op de Mijnen,* State Supervision on the Mines
TSO	*Transmission Grid Operator*
WVIP	*Waterstof Veiligheids Innovatieprogramma,* Hydrogen Safety Innovation Program

1. Introduction

1.1 General introduction

The main goal of this deliverable (D8.3) is to discuss how three mandatory hydrogen blending pilots could be introduced in the Netherlands that collectively may set the stage for mature hydrogen blending policies. Such initiative would be in line with the Dutch government's recently published hydrogen strategy [1]. The various mandatory blending schemes discussed below can be considered in isolation, but also jointly because it is foreseen that the three schemes discussed may be actually implemented in parallel without undue mutual disturbances.

For the information of the readership that solely focusses on this deliverable, it is worthwhile to mention that in HyDelta D8.1 'Admixing Literature review' a generic literature review on various hydrogen blending quota schemes was provided, as well as a clear description of the similarities and differences between physical and virtual schemes. In Hydelta D8.2 'Assessment Admixing Schemes' [2], it was shown how governments can impose mandatory blending quota in order to physically and possibly virtually enhance the use of clean, i.e. renewable-based or low-carbon, energy and feedstock. In blending schemes in which virtual compliance is accepted, trading green certificates is a key characteristic. Then clean energy providers may not only sell their product, but also the attached green certificates for use in the blending scheme. Parties falling under a mandatory blending scheme will have to comply physically or buy green certificates, or, if not, pay a penalty.

An advantage of introducing mandatory blending schemes is that mitigation results can be achieved without subsidies, since certificate price-based incentives are determined by the interplay of supply and demand on the market. Another advantage is that it enables to instantaneously create a market for clean energy, including hydrogen, which may set in motion investment to produce such energy. Moreover, mandatory blending will automatically lead to the development of a derived certificate market that may offer additional returns to suppliers of green gases. Introducing mandatory blending in the Netherlands at relatively short notice may therefore contribute to achieving by 2030 the Dutch National Climate Agreement's policy goals of 49% reduction in national greenhouse gas emissions compared to 1990 levels and realizing 3 - 4 GW of electrolysis capacity [3].

Next, first the key criteria for designing mandatory blending schemes will be discussed (Chapter 1 remainder). Thereafter the proposed blending pilots (Chapter 2) and the related roadmap (Chapter 3) will be worked out in greater detail.

1.2 Main objectives and pre-conditions of mandatory hydrogen admixing policies

As was argued already, one of the key impacts of introducing mandatory clean hydrogen blending schemes is to kickstart the development of a hydrogen market, thereby stimulating investment in clean hydrogen production, as well as its consumption and distribution. By scaling up such investment cost reductions are likely to come through due to scaling up supply chains either based on clean electricity, or on fossil fuels combined with carbon capture, utilization and storage (CCUS).

As was already concluded in HyDelta D8.1 ''D8.1 Admixing literature review'' [4], the choice which quota design is the most suitable one strongly depends on the political wishes and specific targets aimed for. In the end any blending quota scheme is a politically designed tool. Clearly changes in market regulation can and mostly will have a direct impact on the quota functioning and impact. To reduce the risk of unforeseen and/or unwanted effects on quota schemes, adjustments in regulations should therefore be predictable, while modifications or revisions should be prepared and reviewed carefully.

One of the risks associated with quota schemes is that unexpected fluctuations in certificate and/or electricity prices due to changing regulation or unforeseen market developments raise the cost of the scheme for its main stakeholders due to certificate price volatility. Long-term contracts and the introduction of floor and maximum prices for the certificates may help to limit such risks for those directly involved, but these risks will eventually need to be borne by any other market party.

When introducing a quota scheme and deciding about its specific design, the following issues and points of attention can be distinguished:

Issues in designing quota schemes

Opportunities and limitations of infrastructure and facilities already existing

In introducing mandatory quota schemes in industry one can, for instance, prioritise to focus such schemes on existing strong industrial sectors in trying to transform them into future-proof hubs for lower-cost and lower-carbon hydrogen. Also more generic schemes may benefit from the use of existing gas infrastructure thereby indirectly supporting the development of clean hydrogen sources of supply. In quota systems applied to mobility use of existing infrastructure and devices such as existing supporting transportation fleets, freight systems and corridors, may increase the ease to introduce such quota schemes, while the use of specific existing shipping routes in shipping quota may jumpstart international hydrogen commerce.

Make sure that the scheme is perceived as being reliable and transparent

The consistency of the coverage of a quota scheme must be guaranteed, and all checks and balances in monitoring, validation and verification have to be in place not only with respect to physical blending, but also with regard to the issuance and trading of certificates. Data need to be accessible and open to public scrutiny, legal provisions need to be clear, and timelines and chosen pathways have to be transparent and properly explained.

Make sure that quota targets can realistically be met

The quota should not lead to such shortages in resources that either physical blending cannot be realized, or certificate prices rise to socially unacceptable levels or levels of volatility. This point is especially relevant when introducing blending schemes: its speed and coverage will need to be designed such that ‘the market’ has sufficient time to adjust to the new policy regime.

Mandatory quota schemes should be in alignment with standards and regulations

Where regulations and permission requirements are: unclear, unsuitable for new applications, or inconsistent across industries and nations, project developers may face challenges when confronted with mandatory quota schemes. Schemes therefore need to be aligned with European and/or national regulations (e.g. with respect to cumulation of support, definitions, certification schemes, international consistency and coordination).

Points of attention in designing quota schemes

In the political discussions on quota schemes several issues may be brought forward and lead to discussions. Some of these that popped up in the public debate so far are the following.

Increased cost for end-consumers

Quota schemes may due to their impact on final energy prices contribute to energy poverty and also to carbon leakage (e.g firms leaving and shifting emissions to elsewhere), or both. Both effects may lead to concerns that one wants to address in designing and implementing quota schemes.

Additionality

Some specific GHG reductions may face a so-called additionality check in order to be recognised under specific schemes. In some public discussions it has, for instance, been argued that hydrogen will only be considered green if not only the power input is sufficiently based on renewables, but that there is also sufficient proof that the power used is additional, i.e. would otherwise not have been available because used for other purposes [5]. It is clear that proving additionality or non-additionality may be rather complex because in the end allocation of energy to different end uses will be determined by market forces [4]. To the extent that additionality criteria will be introduced in formal quota systems, this may clearly affect and complicate their implementation.

Double counting

Attributing the same performance qualification on purpose (or even without intention) to two distinct end-users is referred to as double counting (also known as double attributing or double claiming). Double counting may, for instance, occur if a producer receives Guarantees of Origin (GoOs) and is credited for the related green energy produced, while another party purchases the GoOs and also claims credits for the same produced energy. To avoid such double counting, the scheme's regulatory agency must verify that the same unit of energy from renewable sources is only counted once, but sometimes this is not easy if claims are made informally, e.g as part of expressions of marketing or pr.

Mandatory cancellation is the most common way for allocating the attributes of a certificate to a single end-user only. This way one can be sure that the certificate is not traded, given, sold, or utilized by another end-user. Such cancellation can, however, only be mandatory if the original owner of a certificate falls under a quota scheme; in all other cases the GoO can be traded, but the original owner loses the claim after having sold the certificate.

The role of physical blending and perception of greenwashing

There can be no virtual blending without physical blending anywhere else. Without any further restrictions it is, however, possible that of two parties subject to a quota scheme one party complies fully via physical blending, whereas the other party complies fully via virtual blending. In the political decision making around quota schemes it is conceivable that full virtual blending by individual parties, i.e. fulfilling its own quota completely by acquiring certificates, is considered undesirable by creating the risk of the undesirable public perception of greenwashing. In such cases all parties or groups of participants in a quota scheme may be forced to be to a certain extent involved in physical blending in order to get entitled to virtual blending for the remainder of their commitment.

2. Pilot proposals towards quota obligations including hydrogen

In this chapter three proposed quota system pilots supporting the hydrogen policy of the Dutch Government will be discussed. First some general characteristics also covered in the pilot proposals are introduced. Then, each of the three pilot proposals will be discussed in greater detail.

2.1 Proposed pilot schemes: general design characteristics

All proposed quota pilots share an underlying target specifying which share of final energy consumption should be greened via the envisaged hydrogen-based quota scheme. To the extent that both green and low-carbon (or blue) hydrogen is accepted within the quota, sub-targets for renewable hydrogen can be set to prevent it to be crowded out (too long) by blue hydrogen: without such sub-targets it is likely that only low-carbon hydrogen will be deployed until renewable-based hydrogen can compete with it. The definitions of green and low-carbon hydrogen in quota schemes should obviously be in line with the ones in the revised EU Renewable Energy Directive (RED) in order to prevent confusion about concepts.

In the proposed schemes the relevant committed market participants (consumers or suppliers) are required to buy and cancel hydrogen certificates on a yearly basis. So, to illustrate with the help of an example, without physical blending the number of renewable energy-based certificates one is, for instance, required to purchase this year equals the percentage value of the current year's renewable quota multiplied by the amount of hydrogen processed annually.

Furthermore, the proposed quota systems do differ in the way certificates are interlinked: in the industry-related quota proposal (for details, see next), Guarantees of Origins (GoOs) are used as quota certificates, while in the gas quota and fuel blending obligation (see also next) GoOs are just used to proof that the delivered energy is renewable, but separate linked certificates are used for quota commitment. Obviously, such certificates imply the automatic cancellation of the underlying GoO, because otherwise there would be a risk double counting. It should also be mentioned that according to state aid rules only GoOs and derived certificates indicating that no additional support (e.g. subsidy) is received, can be used as a basis to comply with a quota.

Pricing and trade

Introducing hydrogen certificates obviously may affect supply: to the extent that green hydrogen producers may sell their certificates next to the hydrogen itself the additional returns may act as an incentive to invest in green hydrogen generation from renewable sources.

Competitive market-based price setting of certificates is sometimes considered to be a key advantages of (virtual) quota schemes, while the high risk premiums associated with the often unpredictable certificate prices is at the same time recognised as a potential backdrop. Long-term contracts can be used by specific risk-averse parties to offset existing price volatility concerns but then risks will have to be absorbed elsewhere.

Market parties covered by a quota have to annually cancel a specific number of GoOs or related certificates, mostly by the end of the year. However, this leaves them with a few options to deal with that commitment:

- To produce their own renewable hydrogen in order to obtain certificates, possibly up to the point that they can develop into net sellers of such certificates;
- To physically use renewable hydrogen acquired from elsewhere if commercially feasible;
- To acquire certificates on the market.

As every party covered by the quota system will determine its optimal mix depending on its specific position in the market, their collective decisions will determine e.g. where as a result of the quota electrolysers will be located and where the physical hydrogen can be used most cost effectively, especially also in the initial phase which is where the pilots are concentrated on.

Penalties

In order to ensure that a demand for certificates is emerging, in any mandatory quota scheme a penalty mechanism must be in place for cases in which the legally required number of certificates threatens not to be met each year, such that the unit cost of not fulfilling the quota commitment surpasses the certificates' market price.

2.2 Quota proposals

In the general design characteristics discussed above, it remained open: what the obligated/committed market participants are; on what entity the quota is based; and how the quota scheme affects the physical use and infrastructure of hydrogen. In selecting the proposed Based on quota pilots these characteristics have been used to select three types of quota schemes that collectively are fairly representative for how a broad national hydrogen quota system could look like in which the various components can reinforce each other without the risk of serious mutual competition. The pilot proposals therefore differ in what sectors, market players and certificate systems are targeted, while at the same time mutual exchange of certificates is possible if one would like to allow for this. Table 3 provides an overview of the key characteristics of every pilot quota proposal, to be elaborated more in detail in the next sections.

Table 3 – Overview main characteristics of quota proposals

Proposal:	**1: Industry**	**2: Gases**	**3: Fuels**
Market sectors	(Specific) industrial applications (e.g. ammonia, methanol, refineries)	Gas suppliers	Fuel suppliers for transport applications
Obligated Target parties	End-user: Industries consuming hydrogen	Suppliers: Gas suppliers	Suppliers: Fuel suppliers that deliver more than 500.000 litres, kg or Nm^3 of fuel annually
Base of quota	% of total H_2 (kg) used in processes	% of total gas delivered	% of their total taxed fuels (GJ) supplied
Accepted quota energy carriers	• Renewable H_2 • (Low-carbon H_2)	• Renewable H_2 • (Biomethane) • (Synthetic methane)	• Current accepted renewable fuels • Renewable H_2

2.3 Quota scheme 1: *Hydrogen quota for industrial applications*

Market participants

Proposals for such a schemes suggest to introduce a clean hydrogen quota for key industrial players that typically already use large volumes of grey hydrogen as a feedstock or for specific energy purposes, in order to replace the grey hydrogen by renewable and possibly low-carbon hydrogen. In the Netherlands large industries such as refineries, chemical plants (e.g. ammonia and methanol), and metal processing factories currently already consume serious volumes of hydrogen, providing an excellent starting point for introducing quota schemes, as they are already used to handle hydrogen in their existing equipment. Moreover, industrial demand volumes are typically relatively large and spatially concentrated, which makes it often easier to connect to new hydrogen production locations.

A blending obligation supporting new use of industrial clean hydrogen could launch demand for it. In the FCH JU Hydrogen Roadmap [6], it is estimated that steel would be the main sector for new hydrogen applications, with DRI[1] accounting for more than 1% of European steel production by 2025, and 20% by 2050. Furthermore, the same report suggests that by 2050, 30% of methanol, olefins, and BTX from captured carbon could be produced by hydrogen instead of methane.

The potential importance of such schemes for the Netherlands' economy can be illustrated by the fact that the Dutch employers' organisation in the technology industry (FME), in collaboration with the Ministry of Economic Affairs and Climate Policy, has identified over 250 companies operating in the hydrogen sector [2]. Given the predicted high demand for sustainable hydrogen in industry in Northwest Europe, it would be particularly advantageous for the Netherlands to become the supply chain's cornerstone.

Quota Target

The quota will be imposed on specific industrial sectors (e.g. ammonia producers, steel producers, refineries) and will be based on a percentage of the total hydrogen (kg) that is used for a set of pre-defined processes, such as hydrodesulfurization (HDS), hydrogenation and chemical synthesis processes.

Distribution and transport

Hydrogen as a feedstock and energy carrier for the chemical, petrochemical and steel industry demands pure hydrogen. Therefore, it is expected that this sector would prefer dedicated hydrogen infrastructure over physically blended streams in natural gas. As was mentioned earlier, the Netherlands has five large industrial clusters characterised by large demands for hydrogen at central locations. Electrolysis production capacity will be established at places where renewable hydrogen can be produced and used most cost effectively. It is expected that these will be locations where a lot of renewable (e.g. offshore wind) electricity is available or near to demand locations (e.g. grid connected electrolysers at industrial clusters). For less cost-efficient locations, it may be cheaper to purchase certificates in order to comply to their quota. When the quota rises, and more volumes are demanded, at some point of time economies of scale could become sufficient to connect the biggest supply and demand locations via dedicated national infrastructure for pure hydrogen.

Practical outlook of the system

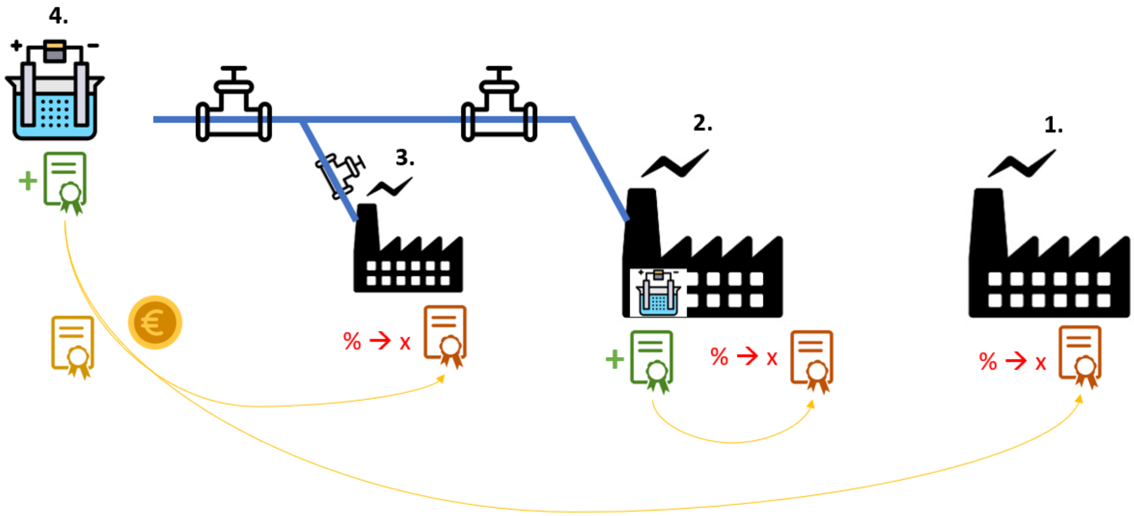
Figure 1 gives an overview of the practical outlook of the proposed system and its possible options for the parties involved. All these options as distinguished in the figure can be clarified as follows (numbers below correspond with numbers in Figure 1):

1. Some companies will decide that it will be hard for them to physically use renewable hydrogen in their production process. For example because they are not in a good position to source a lot of green power or if their current assets are too valuable to be replaced. In this case, purchasing the certificates on the market is enough to comply to the quota and pay their equal contribution. Moreover, it would even be possible that they purchase more certificates than they require, and sell part of these certificates to other parties for additional profits.

[1] Direct Reduced Iron (DRI) is the product of the direct reduction of iron ore in the solid state by carbon monoxide and hydrogen derived from natural gas or coal. (https://www.metallics.org/dri.html)

However, this all depends on what risks companies are willing to take and how the market will evolve.

2. Some companies will decide to install own electrolysis capacity in the plant, potentially (partially) replacing fossil production installations. In this way they can generate their own certificates and do not have to buy them on the market. Even when certificates are left over they can sell them on the market to other obligated parties. They can decide to connect to a hydrogen grid in order to guarantee supply when no renewable electricity is available, but another option would have been to do this with the old fossil assets.
3. Similarly to company (1), feedstock companies can purchase the certificates from the electrolyser operator (4) and create a physical connection to the producer in order to also take off the physical hydrogen. In practice, it could be expected that investors in renewable hydrogen production capacity want to reduce uncertainty in income, and therefore prefer long-term contracts with customers. When customers can guarantee that producers also can sell the physical hydrogen to them, they might have preference to close a long-term contract. This might be beneficial for obligated parties as well, as they potentially can sell the remaining certificates in the market.
4. Renewable hydrogen producers are not expected to receive enough income from the physical sold hydrogen (often still based on the fossil hydrogen price) to close their business case. Therefore, the quota enables them to receive additional income from the certificates, in order to close the unprofitable gap in their business case. The producer can determine if it will close long-term contracts with customers, in order to secure the income it gets, or sell their certificates via short-term contracts or directly on the market. Besides certificates sold in order to comply to the quota, additional certificates can be sold to parties who want to green a larger share of their consumption that they are obliged to do.



	Renewable hydrogen producer		Certificates are obtained which can be used to comply to the quota
	Physical hydrogen transport connection		Parties that are obligated to cancel an *x* amount of certificates, based on a percentage of their hydrogen use
	Industrial hydrogen user		Trade of certificates (in this quota similar to GoO's) from party A to party B, party A gets a price in return

Figure 1 – Overview of the practical outlook of proposal 1: the industrial quota

2.4 Quota scheme 2: *Hydrogen quota in the gas mix for all gas consumption*

Market participants

In this type of quota scheme gas suppliers involved have to comply with the quota obligation. Gas suppliers can obtain quota certificates by delivering renewable hydrogen to customers (proven by cancelled guarantees of origin), or purchasing these quota certificates from suppliers that supply more renewable hydrogen than they are obliged to do. The obligation commitment is put on the suppliers for the practical reason to overcome that every single household or small company has to purchase its own certificates. The supply is potentially not only met with green hydrogen but could be combined with other low-carbon gases such as biomethane, synthetic methane and/or low-carbon hydrogen, although it is probably advisable to use sub-quota or technology banding in order to be sure that the relatively more expensive renewable hydrogen production technologies will be deployed as well.

Quota Target

The quota will be set on gas suppliers and will be based on a percentage of total gas supplied, which includes hydrogen, biomethane and natural gas. The quota will probably have to be expressed in the energy content of the various gases(e.g. MWh or GJ).

Distribution and transport

As the obligated market parties are allocated in different sectors (e.g. built environment, industrial heating and industrial feedstock), the question rises what the market will determine as the most feasible place where the physical hydrogen will be used first. Thereby, it should be determined if additional instruments and policies should be in place to make the physical hydrogen accessible for all those sectors. For example, to blend hydrogen into (local parts) of the natural gas infrastructure or to modify natural gas grids to pure hydrogen grids. An important point of attention for this proposal is that the level of the quota depends on the actual amount of hydrogen that can be delivered by the (natural) gas grid. Therefore, the government should align the level of the quota with the broader scheme to decarbonise the gas grid (e.g. conversion of local grids as result of the 'Transitievisie Warmte', the 'Heat transition vision' that is made by municipalities). This quota should lever gas consumers and the gas grid to decarbonise gradually. When national hydrogen transport and storage infrastructure is available, a structured methodology can be designed for local grids to be converted to handle (partial) hydrogen flows. In this way the level of the quota can be increased aligned with the amount of local grids and end-users that are converted.

Together with this instrument, the fact that gas prices in the built environment are approximately 40% determined by taxes [7] can be used to stimulate individual customers to move towards renewable gases. If the system will lack support for individual households to move over, differentiation in taxes can be used to stimulate the use of renewable gases.

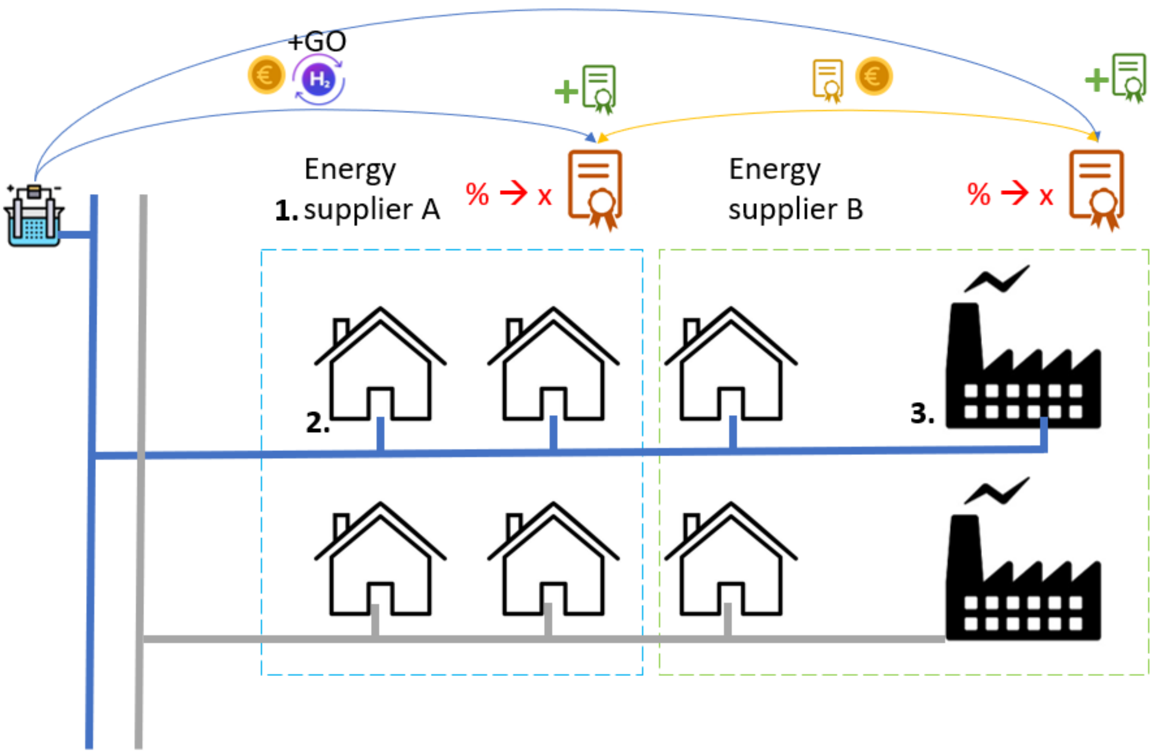
Practical outlook of the system

Figure 2 provides a representation of the system proposed in previous paragraphs. The role and choices of involved stakeholders will be explained below:

1. The energy suppliers closing contracts with energy users. In this quota, they should cancel a certain amount of certificates, based on the amount of gas supplied to their customers. Some energy suppliers are part of a larger holding that also owns generation capacities, but usually the energy suppliers will not be able the obtain the certificates themselves and therefore they should buy them on the market. They can purchase guarantees of origin from the producers of renewable hydrogen, and cancel them for every MWh of physical hydrogen delivered in order to obtain the quota certificates. If they deliver more renewable hydrogen than they

should to comply with the obligation, they can sell the leftover quota certificates to other suppliers. If they sell less renewable hydrogen than the obligation, they should purchase additional quota certificates in order to be able to cancel enough quota certificates at the end of the year. The additional price that they pay for the hydrogen, guarantees of origin, and quota certificates will be incorporated in the gas prices agreed with their consumers, independent if they actually use hydrogen or not. Suppliers can make the decision themselves how to distribute the additional costs over their sold contracts (e.g. what part is distributed over all the contracts and what part is distributed over premium contracts for renewable gases).

2. Houses that are connected to a (dedicated or blended) hydrogen grid all have contracts with different energy suppliers. They just pay the price for gas based on the contract conditions of their supplier. To the extent that specific households want to voluntarily raise the green profile of the gas they use, they may choose to get premium contracts containing a larger share of green gases than otherwise would be delivered.
3. This represents an industrial company that purchases its energy via an energy supplier. It faces the same conditions as the houses in point (2), as it is connected to a (partial or dedicated) hydrogen grid. If it would have been connected to a traditional natural gas grid, it would have faced similar conditions to (3).



	Renewable hydrogen producer	+	Certificates are obtained which can be used to comply to the quota
	Physical hydrogen (blue) and natural gas (grey) grid	% → x	Parties that are obligated to cancel an *x* amount of certificates, based on a percentage of their supplied/used gases
	Industrial plant and household that consume gas		Trade of certificates from party A to party B, party A gets a price in return
	Marks the consumers that have a contract with energy supplier *Y*	+GO	Trade of GoO certificates from party A to party B, party A gets a price in return

Figure 2 - Overview of the practical outlook of proposal 2: all gas consumption

2.5 Quota scheme 3: *Extension of the fuel blending obligation*

Market participants

The third proposal is an extension of the existing Dutch fuel blending obligation scheme (based on the European RED) for the mobility sector. This scheme prescribes fuel suppliers to cancel a specific amount of certificates in accordance with fuels sold to tank stations. The difference with previous proposals is that in the Dutch fuel blending obligation, suppliers can receive quota certificates, called HBEs, for every GJ of renewable fuel supplied (in previous proposals, the certificates were received by the producers of renewable hydrogen or other green and low carbon gases). In this way, similarly a demand for renewable fuels is created, but without trading the certificates directly with the producers. In this quota scheme, the actual suppliers of renewable fuels can trade part of their certificates to fuel suppliers who do not sell enough renewable fuel themselves in order to comply to their quota.

The current fuel obligation scheme involves three types of quota certificates: HBE-Conventional (HBE-C), HBE-Advanced (HBE-G) and HBE-Other (HBE-O). The quota involves multiple (sub-)targets. Besides the total quota of certificates that should be cancelled, there is an minimum amount of HBE-G that should be cancelled and a maximum HBE-C that counts for the overall quota. Currently, there is a category called renewable fuel of non-biological origin (RFNBO) but no type of fuel is currently addressed to this category. In September 2021 an internet consultation started to include renewable hydrogen to this category in order to obtain HBE-G's with a multiplier factor.

Another option would have been to incorporate an additional sub-quota for renewable hydrogen into the existing fuel blending obligation, with another type of quota certificates called 'HBE-H's' (i.e. a specific type of HBE for renewable hydrogen). However, as long as not enough hydrogen vehicles are on the road, there is no certainty that fuel suppliers have the opportunity to sell hydrogen to any customers. Therefore it is reasoned that the option of a specific hydrogen target only can be combined with a 'refinery route' for hydrogen, which enables fuel suppliers to obtain HBE-H's as well for renewable hydrogen used in refineries for the production of traditional fuels. In the roadmap section it will be discussed further how the effects of both options can be tested.

Quota Target

The sub-target for the cancelled HBE-G's is based on the percentage of the total taxed fuels (GJ) supplied by the fuel supplier. In addition to the existing fuels that obtain HBE-G's, hydrogen as RFNBO can be added.

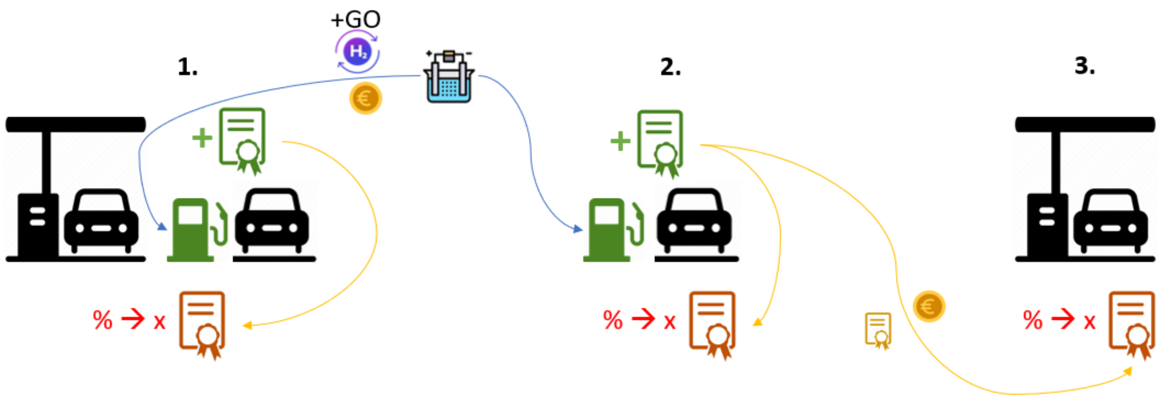
Distribution and transport

The challenge in this last proposal, more than the previous ones, is the development of physical infrastructure for hydrogen used as fuel for vehicles. Currently there is barely existing infrastructure that can be (re-)used in this sector. Moreover, when physically introducing hydrogen into the fuel blend end-users cannot use their current equipment any longer as well, which means that new Fuel Cell Electric Vehicles (FCEV) should be bought by consumers in order to allow the fuel suppliers to sell hydrogen. This would become one of the main challenges when introducing hydrogen as fuel for vehicles. Moreover, the development and delivery towards Hydrogen Refuelling Stations (HRS) is currently only deployed on a small scale.

Practical outlook of the system

In Figure 3, the described extended part of the fuel blending obligation is represented. This is done for: 1) a fuel station that is extended with a hydrogen pump, 2) a dedicated hydrogen refuelling station (HRS) and 3) a traditional pump who does not sell hydrogen.

1. In the Dutch fuel blending obligation, HBE's are received for every GJ of fuel supplied instead of the quota certificates received by hydrogen producers as described in previous proposals. This fuel supplier choses to receive its own HBE-G's by selling hydrogen (but it would also have been possible with selling (blends of) advanced biofuels). The fuel supplier should purchase the hydrogen from a producer including its GoO, as only proven green hydrogen can be used to obtain HBE's.
2. Fuel suppliers that do only own dedicated HRS, receive HBE-G's for all of their fuel supplied. As they only have to cancel HBE's for a certain percentage of their supplied fuels, they can sell the remaining HBE's to fuel suppliers who do not sell hydrogen.
3. Fuel suppliers who do not sell any hydrogen or other advanced biofuels should purchase the HBE-G's in the market in order to comply to their share of the fuel blending obligation sub-target.



	Renewable hydrogen producer		Certificates are obtained which can be used to comply to the quota
	Physical supply can be done by dedicated grid connection or tube trailer, not illustrated in this figure	% → x	Parties that are obligated to cancel an *x* amount of certificates, based on a percentage of supplied fuels
	Traditional fuels supplied to cars at pump		Trade of HBE certificates from party A to party B, party A gets a price in return
	Renewable hydrogen supplied to cars at pump	+GO	Trade of GoO certificates from party A to party B, party A gets a price in return

Figure 3 - Overview of the practical outlook of proposal 3: Extension of the fuel blending obligation

3. Roadmap of introducing mandatory hydrogen blending schemes

3.1 Introduction roadmap

The previous chapter described three mandatory hydrogen blending schemes for possible implementation in the Netherlands. This chapter will describe their roadmap, i.e. defining ways how to test the proposed schemes via pilots and elaborating on how the schemes subsequently could be rolled out to maturity. In doing so the focus will be on: the pilots' main pre-conditions, stakeholder involvement and the different roles of the key players. The main aim of the pilots is to investigate effectiveness of the mandatory schemes in practice and to assess if, and how their design can be improved in order to roll them out to a larger scale implementation.

3.2 General outline experiments

General requirements to start pilots with hydrogen quota mechanisms

Before real-life experiments for any of the proposed hydrogen quota schemes can be started, certain pre-conditions should be in place:

- The current Dutch Gas Law ('Gaswet') does not allow regional grid operators to use hydrogen in their grids [8]. To enable hydrogen pilots, a revised Gas Law and Energy Law ('Energiewet') should therefore include regulations providing clarity for grid operators as to under what conditions one is allowed to experiment and/or use hydrogen in their grids while protecting safety, security of supply and affordability for the end users. For the long term, the National Hydrogen Programme addresses these issues [9]. For the short term, however, in order not to slow down the deployment of experiments, a working group of the government and experienced parties such as: the Hydrogen Safety Innovation Program ('Waterstof Veiligheids Innovatieprogramma (WVIP)') [10], Authority of Consumers and Markets ('Autoriteit Consument & Markt (ACM)'), State Supervision on the Mines ('Staatstoezicht op de mijnen (SodM)'), and the Inspection on the Living Environment and Transport ('Inspectie Leefomgeving en Transport (ILT)') [11], may provide temporal guidelines for experiments involving hydrogen injection in the existing grids. Policy measures resulting from these consultations could be introduced via an Order in Council ('Algemene Maatregel van Bestuur (AMvB)'), and therefore do not require the long trajectory of laws [10]. Similar issues arise with respect to introducing generic blending of hydrogen in natural gas flows. The ministerial Regulation on Gas Quality [12], gas codes and various NEN-standards [13] will all have to be adjusted before significant hydrogen blending is made possible. Similar as with respect to conversion towards 100% hydrogen, one should first look for temporal solutions before larger-scale experiments can be implemented.
- European definitions provided by the Renewable Energy Directive (RED-II) are crucial to be able to define the criteria when hydrogen should count as 'renewable hydrogen'. Moreover, Guarantees of Origin (GoOs) should be developed to proof that hydrogen is produced in a renewable manner. Currently, the Dutch government is able to provide SDE++ subsidy for renewable hydrogen production, which indicates that also without these guidelines it would be possible to organise experiments by using own definitions. However, having the standards clear from the beginning onwards would be more preferable.
- The national government should organise a register in which the quota certificates can be issued, cancelled and exchanged during the experiments. Furthermore, a governmental authority should be set up to secure the fairness and reliability of the system. Potentially, this could be organised by the NEa, who currently operates the register used by the Dutch fuel blending obligation.

There are a number of other implications that should be considered too. First, the (lack of) availability of norms in hydrogen supply chains for different applications (e.g. built environment, mobility and industry). Currently, the NEN (Dutch norming institute) is creating norms for specific technologies along the value chains (e.g. fuel cells, electrolysers) and revising existing norms for infrastructure and applications. Second, the support provided during the pilots should be in accordance to the European State Aid legislations. Various existing European hydrogen projects already collaborate to be part of an initiative of Common European interest in order to receive the IPCEI status, which allows them to receive more state support than usually allowed.

3.3 Experiment 1: *Hydrogen quota for industrial applications*

Most of the hydrogen in the Netherlands is produced by reforming hydrocarbon gases with steam (Steam Methane Reforming – SMR). Natural gas is the main source, but also methane-rich residual gas from oil refining and naphtha cracking is used to produce hydrogen.

Various numbers can be found for hydrogen production in the Netherlands. In 2007, the Roads2HyCom project reported an annual production of 10.1 billion cubic meter (bcm), equivalent to 109 PJ, of which 7.6 bcm (82 PJ) is produced from natural gas and 2.5 bcm (27 PJ) is by-product hydrogen [14]. Much larger numbers were reported by DNV-GL in their 2019 report [15]. In this study they have reviewed and complemented the Roads2HyCom data using publicly available data and insights from own projects to identify ‘new’ or previously omitted production sites and sources. The study concluded that current hydrogen supply is much higher than previously assumed and amounted to 175 PJ in 2019.

Based on all available information, TNO estimated that in 2020 [16] the production capacity of all processes in which hydrogen played a role, added up to a possible annual amount of hydrogen in industry of total 18.5 bcm. This is equivalent to about 1.7 Mton/y of hydrogen, or 200 PJ/y based on lower heating value (LHV). These figures apply when processes are in operation 24 hours a day, 365 days a year, and include all hydrogen, whether available as pure hydrogen, in syngas or in residual gases (only hydrogen shares included).

Nevertheless, as rightfully identified by TNO in their report, the subject of hydrogen production has many dimensions and results can be interpreted and categorized in different ways. For instance, when acknowledging that plants do not operate at full capacity for 8760 hours per year, and assuming a 90% capacity factor to all generating plants, the estimate decreases to 16.7 bcm or 1,500 kton of hydrogen generated annually by the industry in the Netherlands, equivalent to roughly 180 PJ (LHV).

Furthermore, the total number will also diminish if one were to only consider processes that result in a flow of pure hydrogen (not a gas mixture), ending up with 116 PJ/y.

Ultimately, some studies only chose to discuss about hydrogen production when it is obtained from steam reforming, leading to a total hydrogen production of 104 PJ.

The results obtained by TNO applying a 90% capacity factor (7884 hours per year) are reflected in

Table 4 below and segregated its quality or source of production.

Table 4 - Overview of estimated annual amount of hydrogen circulating in the industry [16]

Quality type	Estimated amount of hydrogen		
	bcm/y	kton/y	PJ/y (LHV)
Pure [a)]	10,8	968	116
Syngas [b)]	1,1	102	12
Rich residual gas [c)]	3,8	338	41
Other residual gas [d)]	1	93	11
Total (hydrogen only)	**16,7**	**1.501**	**180**

a) SMR/ATR-natural gas and refinery gas; Shell Gasifier; by-product Chlor-alkali; water-electrolysis
b) SMR-natural gas for methanol
c) Naphtha and other catalytic reforming processes; naphtha steam cracking
d) Coke oven gas and Flexicoker fuel gas

Stakeholders of a hydrogen quota for industrial applications

Given that the industry clusters mapped out in the previous section currently have a deployed production chain, the scheme would impose a mandatory share of renewable hydrogen to be incorporated within their activities. These industries would become the key players within the scheme, since they would be the ones producing and consuming hydrogen, and thus generating tradable certificates along their activities. It should be taken into consideration that hydrogen currently is not a widely exchanged commodity. Current users of hydrogen usually consume natural gas in order to produce hydrogen themselves, or receive the hydrogen as by-product from other chemical processes, i.e. the hydrogen flows used in industrial feedstock applications are part of a larger web of interconnected processes and substances flowing through the (chemical) plant. Therefore, (partial) replacement of fossil hydrogen by renewable hydrogen implies a major modification on the total plant level as well.

> *The production chain is a web of organizations, people, and activities that share information and/or goods. This network is a logistics chain that ensures that the product or service is delivered to the end user. The network is responsible for converting raw materials and semi-finished goods into final goods.*

Nonetheless, for this experiment to take off and prove relevant enough to broaden its scope, not only the main industries constituting the supply and demand position are central in their role, but it is of paramount importance for the governmental bodies, municipalities, grid operators and energy suppliers to be involved from the beginning to assure that the experiment constitutes a coherent and reliant steppingstone that can be extended further upon its completion.

The national government plays the vital role of being the promotor of any scheme to be implemented on Dutch territory, and therefore ultimately responsible for its execution. The quota scheme must be aligned with the Climate Act and National Energy and Climate Plan (NECP). In turn, municipalities are the ones held accountable for support of activities on the regional level, such as permissions to produce or store hydrogen and rights of way for infrastructure. Next in line, are the grid operators (DSOs & TSO) and energy suppliers whom in close cooperation with the industry and end users must align their interests to find common national standards and internationally compatible norms for safe production, transport, storage, and consumption of hydrogen.

As large industries have an international playing field, European and other international legislations have a large impact. Some relevant existing and proposed international legislations for renewable and low-carbon hydrogen use in industries can be mentioned:

- The EU ETS and the proposed Carbon Border Adjustment mechanism will set the scene for the competitiveness of European industries against competitors all over the world;
- The European legislations for State Aid determine the boundaries to what degree industries can be supported by national governments in order to use or produce renewable and/or low-carbon hydrogen;
- The EU Renewable Energy Directive determines the definitions, requirements and targets for renewable energies, and therefore also renewable hydrogen. This is important for the establishment of Guarantees of Origin for hydrogen and the criteria for RFNBOs. Specifically, a target is proposed for member states to ensure that by 2030 50% of the hydrogen used for energy and non-energy purposes in industry should be contributed by RFNBOs. If this becomes reality it means that in the coming years enormous steps have to be taken in the Netherlands (and the rest of the EU) to green its hydrogen consumption.
- For underground storage of captured carbons, for example to enable low-carbon hydrogen production, international legislations and bilateral agreements between countries play a vital role. The CCS Directive(2009/31/EC) limits 'CO_2 transport' to pipeline transport only, excluding other options (e.g. ships)', and the London Protocol does not allow to 'export wastes or other matter to other countries for dumping or incineration at sea'. Moreover, bilateral contracts between countries should be in place to determine the responsibilities for the CO_2 stored underground when 20 years of storage have been past.

The experiment

In order to test if the proposed mandatory industrial hydrogen quota as proposed in section 3.3 will work out and to identify what specific issues should be taken into account, a physical real-life experiment seems not to be the most realistic and optimal option; rather a virtual pilot seems preferable. The main reasons are:

- In the industrial feedstock sector volumes of hydrogen produced and consumed are typically very large. A rather small quota in the spirit of a pilot will therefore not address the interesting main issue of plant adaptions that are required to implement larger volumes of clean hydrogen;
- The European Staid Aid rules make it very complex to allow for dedicated and large budgets for supporting the introduction of hydrogen at industrial scale via pilots. Yet, this support will be required in order to encourage industrial parties to join real-life blending experiments;
- Before a real-life hydrogen blending experiment can start, all specific quota system rules need to be in place and considered suitable to deal with the specific characteristics of all types of hydrogen feedstock industries. Preparing such complicated rules for testing via pilots is not only complex, but also time-consuming;
- Given the recent EU proposal to introduce a significant mandatory share of renewable hydrogen in industry already before 2030, there is, if the proposal will be accepted, probably too little time for real-life experiments with the system.

In the various interviews with stakeholders and experts about how mandatory hydrogen blending quota schemes for decarbonizing hydrogen could be introduced, the following points were mentioned as the most crucial ones.

- It should be made very clear what the quota scheme is based on:

  - Does the scheme only relate to (almost) pure hydrogen, or also to hydrogen flows in syngases?
  - Will certificates also need to be cancelled for hydrogen as by-product to be (re-)used?
  - If (imported) hydrogen- based chemicals such as ammonia is used, do certificates have to be cancelled for the hydrogen content in these chemicals?

  Also, there should be specific list of feedstock processes in which hydrogen is used, such as chemical synthesis (e.g. ammonia synthesis and methanol synthesis), hydrogenation and hydrodesulfurization processes, which list will have to be extended when new feedstock applications of hydrogen will evolve, such as hydrogen used for production of e-kerosine. Another important issue raised was if hydrogen used for production of fuels should be included in an industrial quota or included via a so-called 'refinery route' within the fuel blending obligation. In the proposed REDII hydrogen used by refineries is excluded from the 50% RNFBO target, which could be reason to include this hydrogen in the fuel blending obligation also at the Dutch national level.

- The second key point raised in the interviews was if domestic or imported low-carbon hydrogen will be accepted to fall under proposed hydrogen quota schemes. It is expected that low-carbon hydrogen can be deployed faster and can be more cost-effective on the short term. However, it cannot help to achieve a potential target for renewable hydrogen only. If, e.g. for the sake of speeding up low-carbon hydrogen will be included in a hydrogen quota scheme, one will have to decide if all hydrogen produced with less emissions than a certain benchmark will receive certificates (e.g. based on the CertifHy low carbon definition), or that less certificates are received to the degree that proportionally less carbon emissions are captured (e.g. a plant that only captures CO_2 from the synthetic gas stream, or typically some 60% of CO_2 emissions, receives certificates for 60% of its produced hydrogen, whereas a plant capturing CO_2 both from the synthetic gas stream and flue gases, or typically about 90% of its emissions, receives certificates for 90% of its produced hydrogen). It was recommended to choose the method that is best in alignment with potential European definitions and/or other international standards for low-carbon hydrogen.

  Apart from the above choices it was recommended to include in national hydrogen quota schemes sub-targets for renewable domestically produced hydrogen in order to provide potential investors in electrolyser capacity in the Netherlands sufficient market security. This is important, because Dutch electrolysis capacity is essential to comply with the national renewable electricity deployment targets, and to stimulate the national economy, learning curves and innovation.
- Thirdly, it was pointed out that due to the large volumes of hydrogen applied nationally as industrial feedstock, it can be rather risky to start hydrogen quota schemes without proper guarantees that sufficient clean hydrogen production capacities has been deployed in time. So, serious electrolyser capacities will need to be installed first before mature industrial hydrogen quota can be started.

In order to test how an industrial hydrogen blending quota could work out in the Netherlands' industrial circumstances while recognising the points of attention mentioned, it is proposed to start with a virtual instead of a physical experiment. So, a detailed set-up of an industrial clean hydrogen quota for a relevant industrial plant will need to be worked out to assess and test what the proposed quota means in actual practice:

- What is the vision of the plant on reducing emissions of their activities and how would the proposed quota contribute to or work against this vision? (what is the impact of the design of the quota, chosen definitions and accepted technologies?)

- How can existing processes be adapted to reach the vision and what timeline should be considered when adjusting (part of) the processes within the plant? (taking into account permissions, engineering, existing assets and commitments towards customers and suppliers)
- What are the most important aspects on which long-term clarity should be guaranteed? And what are the most important external dependencies and uncertainties that should be considered in the quota scheme design?

By extensively evaluating the impact of the proposed blending quota scheme on a small set of different industrial plants, the impact of the quota scheme choices on the market players is expected to be sufficiently tested. To illustrate how a virtual pilot could look like, a snapshot impact assessment of the YARA fertilizer plant in Sluiskil has been included in the box below :

Box 1 YARA Sluiskil-case

YARA Sluiskil is a large industrial plant located in Zeeland, and a well-known industrial producer and consumer of approximately 340kT of hydrogen per year in order to produce ammonia. Currently, the plant uses two billion m^3 of natural gas annually, of which about 80% as hydrogen and carbon feedstock and 20% as fuel gas. Around 75% high-caloric gas and 25% low-caloric gas, which will be switch to 100% high caloric gas in 2022. The higher levels of nitrogen in the low-caloric gas are beneficial, in terms that the 14% nitrogen in the low caloric gas issued together with the hydrogen for ammonia synthesis ($3\ H_2 + N_2 \rightarrow 2\ NH_3$). The plant consists of three Haber-Bosch trains in order to produce the ammonia. All three plants are world class and belong to the 10% most energy efficient ammonia plants in Europe. The ammonia is mostly used to produce different types of fertilizer and industrial products as AdBlue. Almost half of the end products in Sluiskil are exported to markets outside the EU. CO_2 generated in the hydrogen production process is captured and utilized. From the 2,2 million ton captured pure CO_2, 1,4 million ton is valorised, mainly for urea production (1 million ton). 400.000 ton is used for different markets as the food industry, in greenhouse horticultures or specific markets as dry ice production. The neighbouring 125 hectares of greenhouses are directly linked to the plant for about 40 thousand ton CO_2 and 1,2 petajoule heat supply. The CO_2 can be transported by trucks and dedicated CO_2 vessels. The remaining 800,000 ton captured pure CO2 is still emitted to the air, but will be liquefied and transported by dedicated vessels for CCS, from 2026 onwards. About 50% of the electricity that is used on site (total use 65MW), is produced onsite by CHP and waste heat. Also process water is re-used locally. The integrated plants on site are well balanced, based on the different energy levels in the exo- and endothermal processes.

The long-term vision of the plant is to take renewable hydrogen from the grid in order to produce ammonia in a sustainable manner. Actually, the same configuration as today, without carbon intake as feedstock. Moreover, there is potentially a large market for ammonia applications, such as shipping fuel or as hydrogen carrier molecule. However, already for the current demand for hydrogen, it would require large-scale hydrogen transport infrastructure and renewable electricity generation (approximately 2,2 GW of baseload electricity to produce the hydrogen use of the full plant, excluding the fact that most renewable sources do not produce baseload). The company experiments with this by taking hydrogen from a grid connection with Dow which has hydrogen as rest product of the cracking process. To establish this connection, an existing natural gas pipeline of Gasunie was used, which was the first converted natural gas pipeline for hydrogen in The Netherlands. Yara has plans to operate one of the ammonia production plants on the site partly with hydrogen produced by electrolysis and green electricity (The existing SMR plants can be operated at 70% baseload and 30% flexible operation).

Given the time it would take: to specify and determine the exact meaning of the 50% renewable hydrogen proposed in the revised RED, to get access to a secure supply of large renewable hydrogen volumes by regional production or even imported volumes, and to engineer and build the required modifications in all the processes at the site, even apart from cost implications it would be already hard to reach 50% renewable hydrogen from a practical point of view. Smaller percentages might, however, be possible given the pilot that is already in preparation. For example, the pilot with a 100MW electrolyser could replace 4% (75 thousand ton of ammonia) of the total ammonia production in Sluiskil, which say something about the scale of the plant in Sluiskil. Also, if low-carbon hydrogen (e.g. blue hydrogen) would be accepted, part of production could potentially already receive low-carbon certificates and this could be increased over time. However, also with respect to this option there are a lot of uncertainties. Nevertheless, Yara Sluiskil, which reduced their nett greenhouse gas emissions already with 65% since 1990 has an ambitious and concrete Climate Roadmap 2030 to keep her position as frontrunner of the largest and cleanest ammonia producers in the world.

The assessed implications of what a mandatory clean hydrogen quota will mean for one individual plant already illustrates some issues (e.g. infrastructure development, definitions for low-carbon and green hydrogen) that are likely to be similar for other plants/industries as well. Clarity by the authorities on definitions and the relevant regulatory framework when announcing mandatory quota will be vital in providing the guidance needed to the market parties involved. On the other hand, information from multiple industrial plants can be vital in getting insight in the pace at which an industrial hydrogen quota could successfully be introduced and developed. Such information can also be vital to determine issues such as: when hydrogen infrastructure should be deployed, how much initial domestic electrolysis capacity should be supported, and what this means for e.g. short- and long-term offshore wind capacity development. Obviously with regard to a lot of regulations the national government is also dependent on the European legislations, such as currently the revised RED and other legislations as part of the fit for 55 package (a large part of which is expected to be enacted by 1 January 2023).

Based on the information from the interviews and the literature, Table 3 presents a proposed timeline from a virtual experiment towards a full-scale hydrogen quota scheme. The virtual experiment could already be started by 2022. Even its announcement could already set in motion the deployment of initial electrolyser capacities needed to start the actual quota scheme. Currently, the Dutch government is proposing a temporal scale-up instrument for electrolysis comparable to the SDE++ subsidy, but then the budget is only for electrolysis projects. This instrument is expected to be opened in Q2 of 2022, and a budget of 250 million euro will be available that is expected to lead to a project portfolio of 50-100MW of electrolysis to be realised within 3 years. For being able to start the envisaged quota scheme for industry it is, however, probably needed – besides dealing with transport capacities - to open multiple subsidy rounds during the next year(s).

By 2023 there will probably be more clarity about the actual legislations, targets and definitions provided by the EU 'fit for 55' package, including by the revised RED. This regulation can then be incorporated in the final Dutch regulatory framework towards industrial hydrogen quota. Next, by early 2024, the starting date of the quota scheme - 1st of January in 2026 - can be made official, including its official legislations.

Table 5 – Overview timeline before the industrial quota can be started

Year	Virtual experiment	Temporary electrolyser scale-up instrument
2022	Develop a detailed policy proposal for the industrial quota and make the consultations at industrial sites	Instrument will be opened for projects
2023	Include developments in EU regulations and finalize the proposal	Open follow-up round with larger budget

2024	Announce the final scheme and starting date at the begin of the year and implement the legislations	
2025		All projects selected in 2022 should be deployed 3 years after acceptance
2026	Actual start of the scheme	

It is proposed that the owners of the electrolyser capacities deployed by the temporal scale-up instrument(s) will be given the choice for every MWh of hydrogen produced to either obtain a subsidized, or an unsubsidized hydrogen GoO. If the hydrogen certificate price is high, some initial project owners may choose to receive unsubsidized GoOs in order to be able to sell them later on to parties covered by the scheme. If, instead, the hydrogen certificate price is initially low, more initial projects are likely to opt for receiving subsidized GoOs. This may help stabilising certificate prices which in its turns may support acceptance of the full scheme by other stakeholders. When the quota scheme expands along the years and the number of initially subsidized projects decreases, the certificate price formation is gradually fully left to the market.

3.4 Experiment 2: *Hydrogen quota in the gas mix for all gas consumers*

In this section it will be assessed how a generic hydrogen quota in the gas mix in the grid could work out. First, the needs and roles of stakeholders are described, and thereafter how an experiment could be started. Finally, it will be discussed how a pilot can be extended to a full-scale quota scheme.

Stakeholders of a generic hydrogen quota in the gas mix

Energy suppliers are commercial parties closing contracts with energy users to supply energy against an agreed tariff scheme. Energy suppliers purchase their electricity and gas on the wholesale and spot markets to be able to balance their supply with the demand of their contracted energy users. In a quota scheme, they would be obliged to purchase quota certificates for the supplied volume of natural gas and pass these cost amounts through via their tariffs to their customers/end users.

Industrial gas consumers usually consume natural gas for heating purposes in their processes, or as feedstock. They can either close a contact with an energy supplier, or purchase energy on the wholesale markets themselves (mainly large industrial energy consumers for which energy costs comprise a large share of total production costs). Equipment for heating purposes mostly needs to be replaced before physical hydrogen can be consumed. For feedstock purposes, it is sometimes questionable if hydrogen could even be used as a substitute for natural gas.

Households are next to industrial users the other category of consumers connected to the grid. Insofar as households in a geographical area are connected to the same grid, one cannot differentiate between gas specifications delivered (at least without incurring the usually huge costs associated with introducing a second parallel grid). Households after inspection can replace their natural gas boilers by hydrogen boilers or hybrid heat pumps, but social acceptance, safety and security-of-supply perceptions can pose challenges to this transition.

Municipalities have the lead in the decision if a certain region is able to convert the grid (partially) to a hydrogen grid. They have to guide neighbourhoods and local industries towards a decision how to reduce their emissions for heating, given the national targets to implement the ‘Regional Energy Strategies’ and ‘Heat Transition program’ (‘Transitievisie Warmte en Wijkuitvoeringsplan’) to replace natural gas in 1.5 million Dutch buildings before 2030 and entirely stop using natural gas by 2050.

The **national government** is responsible for the nationwide regulations and therefore also for the decision if a generic hydrogen quota scheme will be implemented or not. Therefore, they are also the leading party, if such a scheme is to be introduced, in the development of preparatory pilots and the design of incentives to join. Besides the national government has the responsibility to update national legislation and standards to enable a safe and effective use of hydrogen in gas grids and user applications.

Grid operators are assigned by the national government to operate the (natural) gas grid system on transmission or distribution level. In order to use hydrogen in gas grids, they should be allowed to do so legislatively by the national government. Further, for the conversion of local grid accordance with municipalities needs to be secured. The investments to convert the grid and calculation of transport tariffs – according to legislations in place – towards the users, as well as and safe and reliable operation of the grid, are the responsibility of the grid operators themselves.

The experiment

The first step in establishing a generic quota pilot is for the national government to assign one region that determines the geographical scope of the pilot. The region assigned should be strategically located in order to ensure adequate supply of clean hydrogen and sufficient buffer capacity to deal with seasonal fluctuations of demand: e.g. at places where hydrogen production projects are planned, near large industrial hydrogen demand locations, or near national hydrogen transport and storage infrastructure. Areas near the port of Rotterdam or near the Eemshaven/Delfzijl region could be interesting pilot site candidates. In the first stages, the government should announce when the pilot would be started, what the conditions are and how long the pilot would run. Considering the starting date of the pilot: there should be enough time for step two and three to be performed, investors to make production capacity ready, and grid operators and end-users to make their infrastructure ready.

Figure 4 – Overview Dutch hydrogen projects in the built environment [17]

The second step for the national government would be to open a call for municipalities, neighbourhoods and industries in the selected regions to deliver a plan why and how their local grid should be (partially) converted towards hydrogen, e.g. similar to calls opened for the 'Program of Natural Gas free Neighbourhoods' ('Programma Aardgasvrije Wijken'). In the latter program, it became clear that, due to willingness of municipalities to comply to the Heat Transition Program and households to reduce their carbon footprint, a lot of plans applied to join this program. If financial support is guaranteed and risks are insured, it is an opportunity for households to green their homes against low investment costs. The plans should preferably be made in cooperation with and using the expertise of the grid operators. The government will then score the plans based on mainly the following proposed criteria:

- The potential of replacing natural gas by hydrogen on this location compared to other low-carbon heating alternatives (also on the long term);
- The willingness and commitment of end-users of the local grid to be converted towards (partial) users of hydrogen? (as there cannot be distinguished within the same grid);
- The technical potential of the local grid to be converted towards hydrogen, including the availability of supply sources and connection with other (national) transport and storage infrastructure;
- The final portfolio of converted grids should at least include partial blending of hydrogen into natural gas, and when economically and technically viable also 100% hydrogen grids, also to ease certificate trading. Further, they should both contain households and industrial parties, in order to increase the learning effect of the experiment.

It is recommended to include already existing hydrogen pilots into the experiment in order to reduce the costs and increase the speed at which the pilot can be started. When national hydrogen transport and storage infrastructure would increasingly be available, the scale of the experiment could be enlarged.

In a third step, energy suppliers with customers in the pilot region and industries purchasing gas on the wholesale markets themselves could apply to enter the experiment as 'obligated market parties'. The incentive to join would be based on a budget large enough to allow them to cover their additional costs for the hydrogen and guarantees of origin. In their application, potential obligated parties would have to state their gas consumption energy content (e.g. MWh) delivered or consumed in the region and their bid in terms of euros per MWh they expect to spend on the hydrogen and certificates. Via such a bidding process, the government can select the suppliers who are willing to pay the least to join the experiment. As argued before on can also choose to include the use of biomethane in order to comply to the quota during the pilot. In that case, it is recommended to specify a sub-quota for clean hydrogen to ensure that hydrogen technology will be deployed. Obviously also in the experiments only gases from unsubsidized production can be used to comply to the quota in order to avoid undue accumulation of subsidies and support measures.

The fourth step is to start up the physical and virtual trade and use of hydrogen successfully. Based on the project proposals and bids, the government should try to match the quota obligation with the amount of physical hydrogen that can be consumed as much as possible. The physical hydrogen consumed will always be a fixed percentage (100% or a fixed % of blended hydrogen into natural gas) if only to be able to calculate the amount of energy delivered based on the cubic meters of gas delivered. This is an important aspect to consider, as the volumetric energy density of hydrogen is just about one third of natural gas, while billing should be done based on energy content delivered. To enable flexible or fluctuating blends, new, more expensive measurement equipment should be installed at every end-consumer, which can be done for a small scale experiment but is not foreseen as viable for a large scale roll-out in the foreseeable future. Therefore, in this experiment blends should be based on fixed predetermined percentages as well.

After accepting the applied projects and parties that want to participate in the pilot, some time will pass until the starting date of the pilot arrives. This allows participants to prepare themselves. Once the pilot has actually started, the quota percentage can be increased every year and so the budget participating parties receive during the experiment to purchase their certificates. This creates: room for new producers to join the pilots, new parts of the grid to apply to be converted, or higher blends to be applied in the already converted grids (to be decided by the national government that regulates the pilot).

During the pilot, certain aspects should be monitored and evaluated to investigate how this mandatory quota would work out:

- The actual prices paid for the quota certificates: participants are asked to provide transparent information about this in a pre-determined way;
- Evaluations of investors in production technology: how the quota worked out on their business case;
- The behaviour of obligated parties to source their quota certificates and potential investors in renewable hydrogen production capacities;
- Perceptions of households and industries about: converting their equipment towards hydrogen, using hydrogen, and being part of the quota system (e.g. fairness of the system);
- Furthermore, it needs to be assessed if the main objective and pre-conditions stated in the introduction section of this document can be realised.

Table 6 – Summary of phases before, during and after the experiment

Phases		Explanation	Duration (start – end, months)
Preparing pre-conditions		Make all pre-conditions ready before the pilot actually can start	0 – 0
Pilot preparation	Step 1	Assign region(s) and announce starting date pilot	0 – 3
	Step 2	Open call for local grids to convert	3 – 9
	Step 3	Open application for energy suppliers and industry	3 – 9
	Step 4	Select converted grids and participating parties	9 – 15
Construction phase		Construction phase for required infrastructure	15 – 36
Running period of pilot		Run the pilot with increasing annual percentages	36 – 60
Evaluation phase		Evaluate the pilot and report lessons learned	60 – 72

Decisions towards a full-scale mechanism

When the initial pilot runs for several years and evaluations are made up, the following decisions can be made:

1. Implement a full-scale quota mechanism;
2. Test additional pilots with adjusted rules or larger scales before the actual decision towards a full-scale mechanism will be made;
3. Not to implement such type of mandatory quota.

In the first case, there should become an announcement when the full-scale quota mechanism would be started and what the minimum running time of the quota will be, in order to prepare the market (e.g. electrolyser investors, grid operators and municipalities) to develop the physical infrastructure. It is foreseen that the initial quota percentage will be very low, possibly that low that the volumes of the existing pilot are already enough to meet the quota in the initial year. Thereafter, the quota level can gradually increase in order to overcome large mismatches in supply and demand. When the full-scale mechanism is started, lessons and criteria for local grids to convert towards (partial) hydrogen grids will be reported. Municipalities can take these experiences into account, in their 'Heat Transition plans' that they are expected to develop and execute towards 2050.

Some compensation for potential losses needs to be guaranteed upfront to involved investors for the case in which the evaluation concludes that no comparable mandatory quota of this kind would be implemented. These investors should, for instance, be guaranteed that they could receive a subsidy with pre-determined conditions until their assets ages 15 years, or have the possibility to join a newly implemented support scheme until their assets ages 15 years.

3.5 Experiment 3: *Extension of the fuel blending obligation*

Pursuant to the Dutch Renewable Energy for Transport Order, suppliers of fuels destined to motor vehicles are required to deliver a specified percentage of renewable energy to transportation. This share is calculated as a proportion of the total energy content of petrol and diesel delivered to road and rail vehicles. Suppliers of motor fuels meet their obligations mostly by blending biofuels with fossil fuels. Companies that blend in fewer biofuels than the statutory proportion can still meet their requirement by transferring the 'outperformance' of other companies to their own administration.

Table 7 - Total mandatory share of renewable energy in the mandatory fuel obligation scheme

Year	2017	2018	2019	2020
	7.75%	8.5%	12.5%	16.4%

The experiment

Companies that supply fuel to the Dutch transportation sector are required to deliver an increasing share of renewable energy each year, rising to 16.4 % in 2020 (see Table 8). This is the annual obligation for petrol and diesel delivered to transport applications in the Netherlands.

Table 8 - Mandatory share of renewable energy with sub-target for the use of advanced biofuels (from waste and/or residues) and a limit on the use of conventional biofuels (from agricultural crops) (source: Dutch Emissions Authority)

Year	2018	2019	2020
Total	8.5%	12.5%	16.4%
Minimum advanced	0.6%	0.8%	1.0%
Maximum conventional	3.0%	4.0%	5.0%

As stated by the Dutch Emissions Authority[2], companies in the Netherlands that deliver more than 500,000 litres, kilograms and/or normal cubic metres (Nm^3) fuel to the transportation sector are subject to obligations based on the Energy for Transport legislation.

The aim of the experiment is to introduce an additional clean hydrogen quota obligation for fuel providers to transport vehicles. Since there is already a green fuel quota obligation dedicated to fuel providers for the transport sector, adding hydrogen to the list of fuels to be blended with renewable sources without extending the already existing quota size would enhance flexibility to comply, which can be favourable for committed parties.

Requisites

Companies will be obliged to register their total amounts of hydrogen (including its renewable shares) that has been delivered to transport destinations. This amount is known as the 'taxed delivery for final consumption' (Lte: *levering tot eindverbruik*), and they will comply with their registry obligation using the Energy for Transport Registry (REV: *Register Energie voor Vervoer*) administered and monitored by the Dutch Emissions Authority (NEa).

It will be mandatory for companies to register the delivery of hydrogen services to the following modes of transport:

- Road vehicles,
- Rail vehicles,
- Non-road mobile machinery,
- Agricultural and forestry tractors,

[2] Dutch Emissions Authority (Nederlandse Emissieautoriteit, NEa) https://www.emissionsauthority.nl/

- Recreational craft when not at sea.

Renewable fuel units (HBEs)

In order to meet their obligations, the obligated parties will be required to submit so-called renewable fuel units, known in Dutch as HBEs (Hernieuwbare Brandstofeenheden). When a delivery of renewable fuel is rightfully claimed by a party, a HBE is created by the Dutch Emissions Authority within the Energy for Transport Registry (REV) representing one gigajoule (1GJ) of renewable fuel. HBEs are traded, so obligated parties can either 'produce' them themselves or purchase them from other 'producers'.

Hydrogen produced by using renewable electricity would be awarded HBE Advance (HBE-G) units under the category of "Liquid or gaseous renewable fuel"[3]. Low-carbon hydrogen instead, if decided to be accepted, would carry the renewable fuel unit label HBE Other (HBE-O).

Table 9 - Origin of various types of HBEs

Type of HBE	**Created by claiming delivery of**	**Further description**
HBE Advanced	Liquid or gaseous advanced biofuel	Biofuel produced from feedstocks mentioned in Annex IX, Part A of the Renewable Energy Directive.
	Liquid or gaseous renewable fuel	Fuel where the energy-content comes from renewable energy sources other than biomass
HBE conventional	Liquid or gaseous conventional biofuel	Biofuel produced from agricultural and energy crops
HBE Other	Other liquid or gaseous biofuel	Biofuel produced from feedstocks mentioned in the Annex IX, part B of the Renewable Energy Directive
		Biofuel produced from feedstock NOT mentioned in Annex IX, part B of the Renewable Energy Directive and which do NOT come from agricultural and energy crops
	Electricity	The renewable part, based on the European determined forfeit

Obligated Companies will have to deliver a minimum share of HBE Advanced (HBE-G) and may use HBE Other (HBE-O) for the remaining share of their annual obligation.

Procedure

The proposed hydrogen obligation falls under and will have to be in compliance with the existing mandatory fuel obligation. According to this fuel obligation committed companies comply with their annual obligation by surrendering sufficient HBEs of the correct type in the Energy for Transport Registry (REV) on 1st April of the subsequent year, meaning that they must have sufficient HBEs of the correct type in their account to comply no later than 31st March.

On 1st April the REV debits the number of HBEs per type that equates to the annual obligation. Then, the REV debits the remaining HBEs, with the exception of the amount that the operator is allowed to carry over to the next year.

[3] Fuel where the energy-content comes from renewable sources other than biomass.

The REV debits the HBEs in a fixed order until the total annual obligation is complied with:

1. the number of HBE-G required for the sub-target,
2. the number of HBE-O available

CO2 reductions

The NEa assigns a reduction contribution to each HBE in kilograms of $CO_{2\text{-eq}}$: the "HBE reduction contribution". Thus, a company reduces CO_2 emissions by deploying the HBEs required for their annual obligation. The total amount depends on the hydrogen production technology used for each HBE.

Evaluation and continuation

After a year of having renewable hydrogen added to the fuel blending obligation, it should be evaluated what the effect is on the market. Next, two years should follow in which the 'refinery route ' [18] [19] - for hydrogen used for production of fuels - is included in the fuel blending scheme. Including the refinery route means that also HBE's can be obtained for renewable hydrogen that is used in refineries to produce (fossil) fuels [19]. Thereafter, three main choices that should be considered in the decision what the overall desired portfolio of support schemes are:

- Whether or not to include the discussed 'refinery route' into the fuel blending obligation and include a separate sub-target for all hydrogen used in fuels (e.g. pure delivery or also used in refineries to produce traditional and synthetic fuels);
- If all fuels for all types of transport should be included in the existing fuel blending obligation or a separate blending obligation will be established for fuels used for international shipping and aviation.
- The addition of low-carbon hydrogen obtained by means of carbon sequestration. This option would carry the renewable fuel unit label HBE Other (HBE-O) which will differentiate its contribution towards the quota to fulfil.

These choices will depend a lot on the decisions made by the European Commission as part of the 'fit for 55' package. It is desirable to give clarity to the market about the final design of the scheme as soon as possible.

3.6 Timeline of implementation of experiments

The timing of the various pilots discussed above obviously strongly depends on the expected overall development of the hydrogen value chain. Clearly in recent years, political pressure and policies and measures to speed up and scale up the introduction of hydrogen have gained significant momentum throughout the EU. In the same spirit discussions on and proposals towards mandatory blending schemes is getting more and more attention as well. Pilots towards mandatory blending in themselves already need time. In discussions with various stakeholders it was often expressed that even to prepare for a serious pilot may easily cost a few years. Next, pilots themselves will often reveal issues in actual practice that need to be resolved and may give rise to new regulatory measures etc., processes that again can easily take a few years. In other words, the process of preparing and introducing pilots should not be taken lightly timewise. At the same time pilots may have a considerable political signalling function to the extent that authorised pilots will readily be perceived by stakeholders as a precursor of a deep and lasting policy commitment towards introducing mandatory blending schemes at a much fuller scale. In other words, the announcement of pilots themselves already makes investors aware that they better prepare for the introduction in due course of mandatory blending schemes. All these issues will have to be considered in deciding on the timing of pilots or combinations of pilots.

Some pilots require more preparation time than others. Moreover, hydrogen production capacities can be used for multiple pilots. To illustrate,potentially the mobility and built environment could benefit from relatively large-scale production capacity deployment in the industrial feedstock sector. However, given the throughput time of the realisation of the industrial quota and the relatively fast possible adoption of the fuel blending obligation, a swift introduction of hydrogen quota in transportation could create a swift and early incentive to speed up green hydrogen production capacities.

The timeline to set up the pilots is shown in Figure 5. The experiment to extend the existing fuel blending scheme is expected to cost little time before implementation can start. Moreover, there is already being planned to start stimulating hydrogen by this scheme in 2022, as an extension of the existing fuel blending scheme is already proposed by the Dutch Government [18]. In this proposal, HBE-G's can be obtained by delivering pure hydrogen to consumers. This scheme in combination with the temporal scale-up instrument for electrolysis could be deploying the first renewable hydrogen production capacities. For the industrial applications, time is taken into account to provide the right infrastructure, clarity about legislation and deploy initial renewable hydrogen production capacities in order to have a kickstart in the coming years. The start of 2024 will be an important moment in this timeframe. Then, most clarity about EU regulations is expected to be given, and a clear outlook for the future fuel blending obligation and industrial quota should be given. This should give clarity to the market what the environment and conditions of the future markets will be in these sectors. Similar for the gas quota time is taken into account for participants to enable construction of new production capacities and conversion of existing infrastructure to become 'hydrogen ready'. Moreover, as local grids have to be converted including households, extra time should be taken into account for civilians to achieve social acceptance and trust in the guaranteed safety of the new equipment. Although, in the gas quota there is a realistic opportunity to implement this quota system already for biomethane in the next years.

After the pilots have been started, they will last for a given timeframe. It is imaginable that infrastructure (e.g. pipeline systems and electrolyser capacity) will be shared among the pilots, save the overall costs of quota fulfilment. This could lead to the first hydrogen ecosystems that could be expanded when the pilots are successful and the quota mechanisms will be continued. This will be decided by an extensive evaluation based on the overall purpose and pre-conditions as described in the introduction of this report.

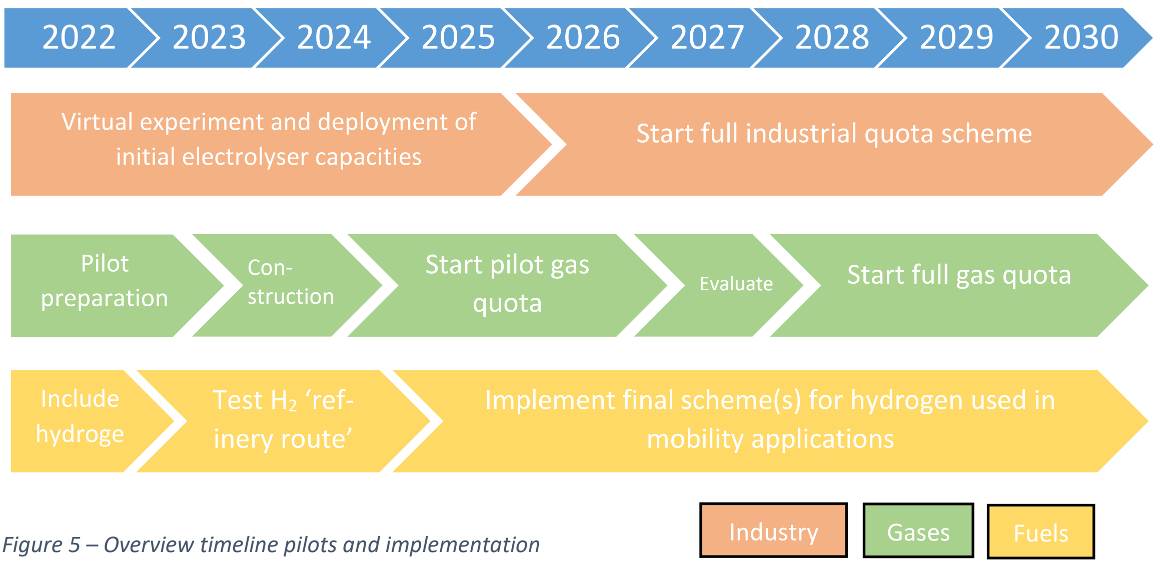


Figure 5 – Overview timeline pilots and implementation

3 Conclusions

Blending seems to be increasingly perceived as a promising instrument in the energy transition. Unlike subsidies, mandatory blending schemes do not require (significant) volumes of public resources; and unlike taxation direct transfers to the government are not needed. Blending instead creates an immediate market for the volumes to be blended, and therewith a powerful incentive for potential investors to produce the clean energy volumes required. Blending also can be introduced flexibly, not only because the authorities can introduce blending stepwise, but also – to the extent that virtual blending with certificates will be an accepted component of blending schemes – because committed parties are left free to blend either physically or with the help of certificates, thereby leaving certificate price formation to the market. Obviously, if blending schemes accepting certificates will be introduced, a well-functioning and reliable certificate market is a prerequisite.

In the European energy transition process proposals to introduce blending schemes as an important policy instrument to launch clean hydrogen as a key energy carrier and feedstock for greening are suggested not only by various stakeholders, but also by European and national authorities. A clear example is the proposal made in 2021 by the European Commission to introduce mandatory blending in the industry, by making it mandatory that starting 2030 the currently grey volumes of hydrogen will need to be replaced by clean hydrogen to a certain (50) percent. Although this proposal is still under discussion, it illustrates the policy direction that can be expected. Another example is the proposal by the Netherlands' government to introduce clean hydrogen into the national fuel blending obligation under the European Renewable Energy Directive.

In this report three administrative mandatory blending schemes are discussed from the perspective how such schemes could be initiated, if the political decision to that end would be made, without distorting the market or creating other undue impacts. The presumption is that any mandatory blending scheme cannot be introduced just overnight, but rather that such introduction would need to be preceded by pilots or experiments in order to test how the scheme will work out if actually implemented in practice.

The various blending scheme pilots have been compiled on the basis of various criteria and on extensive expert review. A first criterion for specifying a pilot case was to check if existing technical installations and infrastructure would allow for a relatively swift and easy introduction of a first blending testing scheme. If a pilot would require significant additional investment, this would slow down the introduction of the pilot too much. Also local acceptance was considered as an important precondition. A second criterion for the pilot was if a scheme could be introduced that would be reliable and controllable enough for being accepted even as an experiment. This criterion not only relates to the actual physical blending but also to the reliability of the related blending certificate trading. A third criterion in specifying the pilots was that in actual practice the quota could be met by sufficient volumes of supply of clean hydrogen. If already in a pilot stage one would have problems with filling a quota, this would destroy the pilot and undermine the credibility of a further roll-out. The fourth criterion was that the pilot was compatible with the existing rules and regulations with respect to safety, grid integrity, etc. To the extent feasible it will need to be checked if special regulatory regimes for pilots and experiments could apply.

Based on the above criteria, three blending scheme pilots have been discussed in this report. First, an industrial blending scheme pilot is discussed in which some dedicated industrial sectors will introduce a combination of physical and virtual blending of clean hydrogen as energy carrier and feedstock. This pilot is proposed to be virtual and applied to some preselected industrial clusters. Second, a generic mandatory blending scheme pilot is discussed in which the energy suppliers to the grid will either physically or with the help of certificates have to demonstrate that they blend an x percent clean hydrogen to the gas entering the grid. This pilot will be restricted to some specific preselected regions. Thirdly, a pilot has been worked out in which the existing national fuel blending obligation under RED will be amended such that clean hydrogen is part of the existing quota. Again, this scheme can be filled in by the committed parties (i.e. fuel suppliers) either physically, or with the help of certificates. An advantage of this scheme is that it benefits from the already existing quota, and therefore can be introduced probably relatively quickly. This pilot was specified for a limited number of fuel stations.

It is important to note that in all cases in which virtual blending with the help of certificates is accepted, physical blending by definition will need take place to the same extent (whether by 100% pure streams or into non-sustainable carrier flows, such as natural gas or fossil hydrogen). In other words, blending certificates can only be offered on the market to the extent that physical blending elsewhere surpasses the mandatory volume needed at the physical blending location. For the reliability of any blending scheme it therefore is extremely important to guarantee that certificate trading does not allow for undue expansion of quota rights beyond the volumes that are physically blended.

It is also important to note that different blending schemes as discussed in this report can exist in isolation but also in combination. All the three blending schemes discussed can go together, but obviously this would require a correct alignment in order to prevent either double counting or greenwashing, or that specific parties are overcharged.

Acknowledgements

In the process of drafting this report, several persons helped us to gather insights from different perspectives and provided thorough feedback about considered implications of the proposed quota schemes and their pilots.

From the perspective of potential investors and users of renewable or low carbon hydrogen, we would like to thank Gijsbrecht Gunter of YARA, Diederik Kuipers and Harry van Dijk of Deltalinqs, Joost Sandberg and Bernhard van Haersma Buma of Nobian, Flip Konings of OV bureau and Edward Doorten of Green Planet for their sector specific input and aspects that should be taken into account when introducing mandating policies. Also, insights from Johan Knijp and Sander Gersen of DNV GL were very useful to get a good understanding of using hydrogen for (high temperature) heating purposes in industries.

Beyond the perspective of users, we would like to thank John Neeft of RVO who provided feedback from a governmental perspective and Elbert Huijzer of Alliander who shared insights in the steps, technical limitations and choices to be made when converting a local gas grid towards (blended or pure) hydrogen. Moreover, the broad expertise of Cor Leguijt of CE Delft and Bert den Ouden of Berenschot was appreciated a lot and could be well used during the writing process of this report.

Next, we would like to thank Udo Huisman and René Schutte from Gasunie, Jelle Lieffering of GTS/Gasunie and, again, Elbert Huijzer of Alliander. They formed the Expert Assessment Group of the HyDelta consortium supervising this workpackage, and provided invaluable and constructive comments and suggestions.

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