Traceability E-Fuels 2035

Tobias Stoll, Hans-Jürgen Berner, André Casal Kulzer

Automotive Powertrain Systems
FKFS
Pfaffenwaldring 12, 70569 Stuttgart, Germany
Tobias.Stoll@fkfs.de
Hans-Juergen.Berner@fkfs.de
Andre.Kulzer@fkfs.de

Abstract: EU legislation provides for only local CO_2 emission-free vehicles to be allowed in individual passenger transport by 2035. In addition, the directive provides for fuels from renewable sources, i.e. defossilised fuels. This development leads to three possible energy sources or forms of energy for use in individual transport. The first possibility is charging with electricity generated from renewable sources, the second possibility is hydrogen generated from renewable sources or blue production path. The third possibility is the use of renewable fuels, also called e-fuels. These fuels are produced from atmospheric CO_2 and renewable hydrogen. Possible processes for this are, for example, methanol or Fischer-Tropsch synthesis. The production of these fuels is very energy-intensive and large amounts of renewable electricity are needed. Thus, national production of these fuels in the EU is inefficient in terms of cost and carbon footprint due to the low utilisation rate of renewable energy plants. Outsourcing these processes to regions where renewable energy production takes place under high utilisation rates and thus the amount of installed capacity can be reduced seems to make sense. Nevertheless, it is to be expected that the costs of the renewably produced fuel will be considerably higher than for the respective fossil equivalent. This makes the production and distribution chain susceptible to fraud by mixing it with, or substituting it for, fossil fuel. This problem can only be controlled by appropriate regulations and controls. This paper presents different options for product control and certification, both for the global and the EU trade area. It conceptually discusses different procedures for control, certification and fuel labelling. First, the draft for a global, certificate-based system for production volume control is presented. This draft enables independent trading of certificates and the product. This makes it possible to implement both pure certificate trading and product-linked certificate trading. Thus, each trading zone can implement the system that suits them best, without disturbing the control of the global production volume. In a second step, an automated monitoring system for tracking imported renewable fuels in the EU trading zone is presented. This is done via a second certification authority and continuous digital and governmental monitoring. In a third step, possibilities are presented with which the fuel or the refuelling in the vehicle can be monitored. Finally, a conclusion is given on the practicability of such a monitoring system.

1 Introduction

The use of e-fuels offers not only an alternative to battery electric and fuel cell electric vehicles after 2035, but also the opportunity for large-scale defossilisation of the existing fleet in the near future. In order to understand the opportunities created by e-fuels, the fuel circular economy is first presented in relation to the production of these fuels (**Figure 1**).

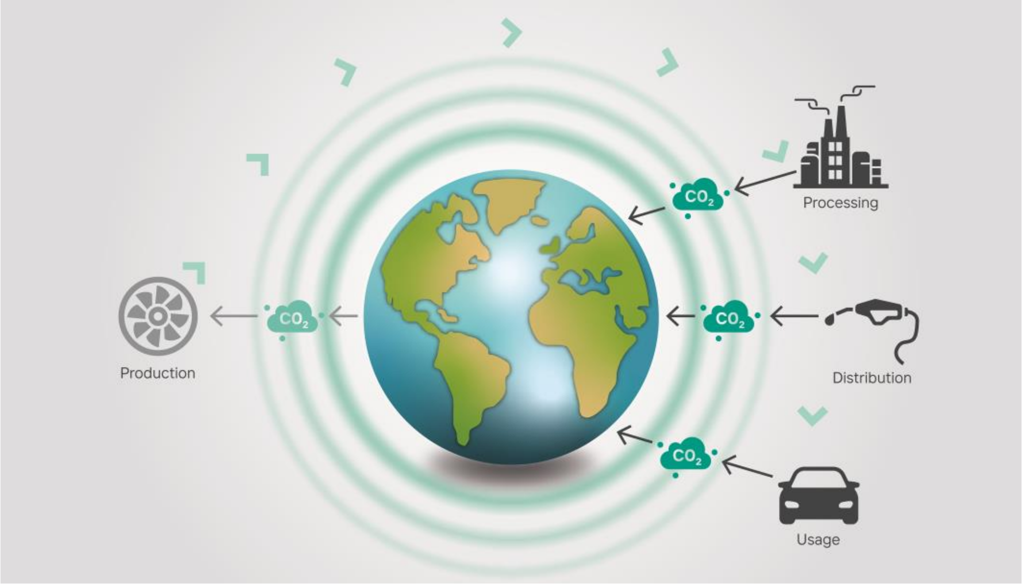

Figure 1: Circular fuel economy for e-fuels [1].

For the processing of the fuel, CO_2 must first be made available. This is done by extracting CO_2 from the atmosphere through so-called DAC (direct air capture) plants. The CO_2 extracted from the atmosphere in this way is then fed into the e-fuel production process. The extracted CO_2 serves as the single source of carbon for the fuel. This makes the fuel CO_2 neutral during combustion, since only the CO_2 extracted from the atmosphere is released again. However, this only describes the ideal case. In reality, fossil CO_2 emissions are caused by the construction and operation of the plants and by distribution of the fuel. In order to fully understand the production of e-fuel, a complete production plant for methanol-to-gasoline (MtG) fuel is shown in **Figure 2** as an example process. Ideally, the electrical power comes from renewable energy plants. The main part of the electrical energy is converted into hydrogen and oxygen together with desalinated seawater in an electrolyser (PEMEL). The hydrogen is then fed with the CO_2 from the DAC plant into a reverse water gas shift reactor (RWGS). Here, a so-called syngas is produced which is then passed through a methanol synthesis reactor (MS) and a methanol-to-gasoline reactor (MtG). The output of this process is crude gasoline.

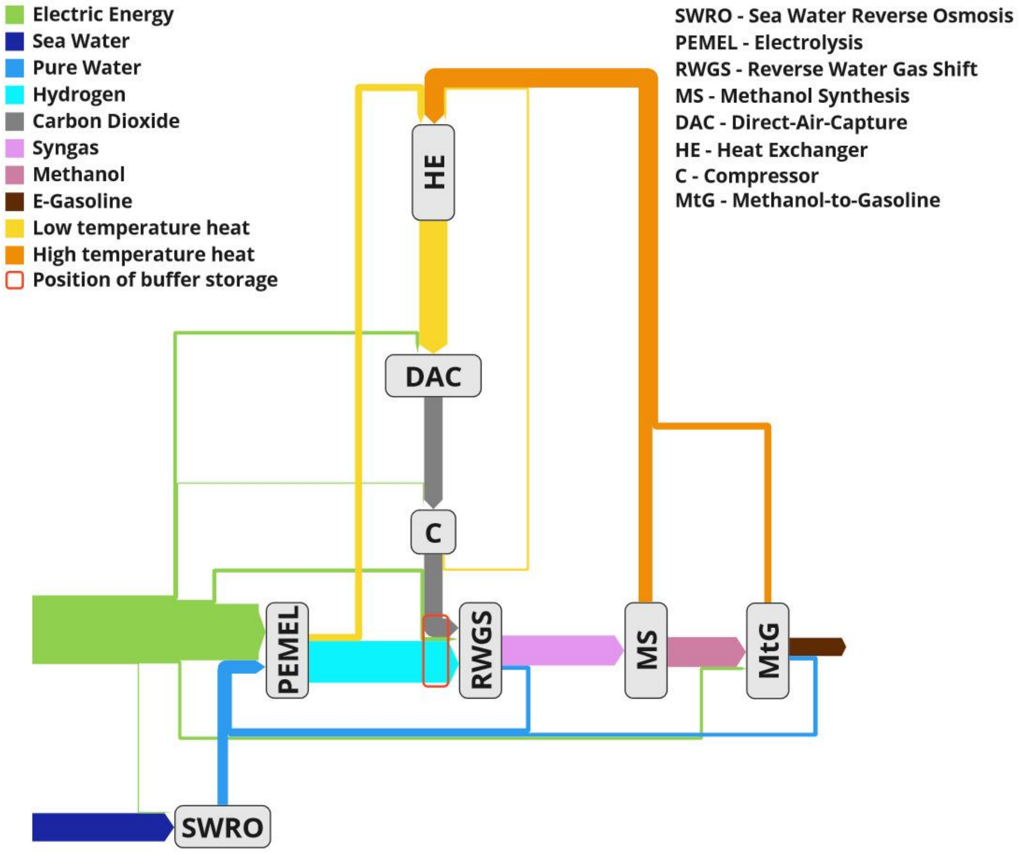

Figure 2: Process diagram of an MtG production plant.

In study [1], the production of e-fuels with off-grid plants is investigated in order to show their CO_2 footprint in comparison to fossil fuels. For this purpose, three representative locations for the optimal utilisation of renewable energies are considered: Chile for wind power, Morocco for photovoltaics and Iceland for geothermal energy. The complete production processes are then modelled and the distribution chain is estimated. These analyses are carried out for e-gasoline via the MtG method and for gasoline via the Fischer-Tropsch route. This procedure for e-gasoline via MtG process is shown in **Figure 3**. It should be mentioned here that distribution is much more complicated for the Fischer-Tropsch route, as only a synthetic e-crude oil is produced in the production plant, which is then refined into gasoline and other crude oil derivatives in Europe. Two independent institutes, the FKFS and the IABP, carried out the study. It compares the e-fuel production for the named locations and different production pathways. An accounting of the fuel costs and the greenhouse gas potential of the production paths investigated is carried out. The results of the cost analysis are shown in **Figure 4** and those of the greenhouse gas potential in **Figure 5**

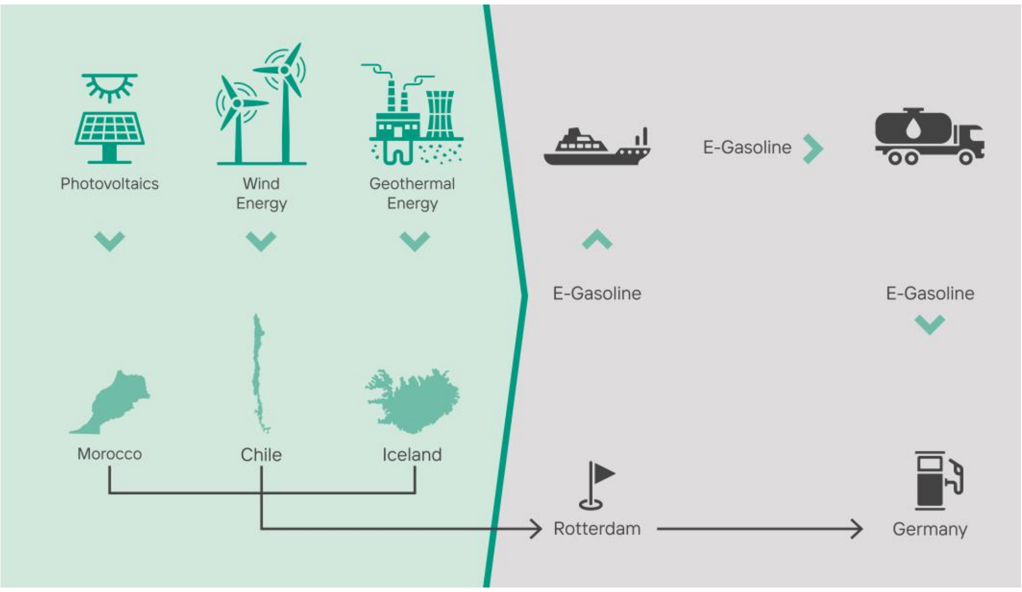

Figure 3: Production pathway for E-Gasoline produced with Methanol-to-Gasoline process for three representative production locations and distribution to fuel stations in Germany [1].

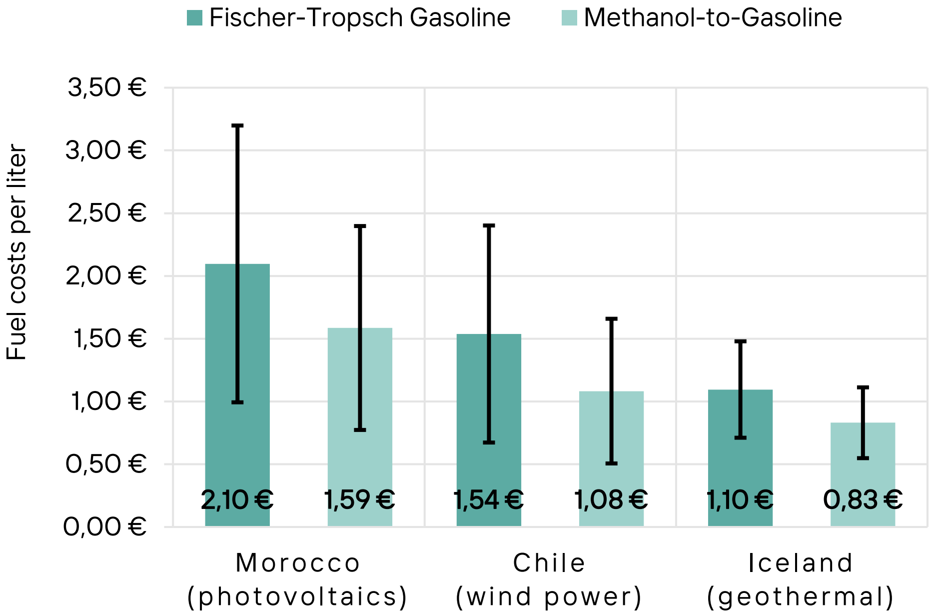

Figure 4: Gasoline costs per litre at the gas station without taxes, subsidies and margins for the MtG- and the Frischer-Tropsch-route [1].

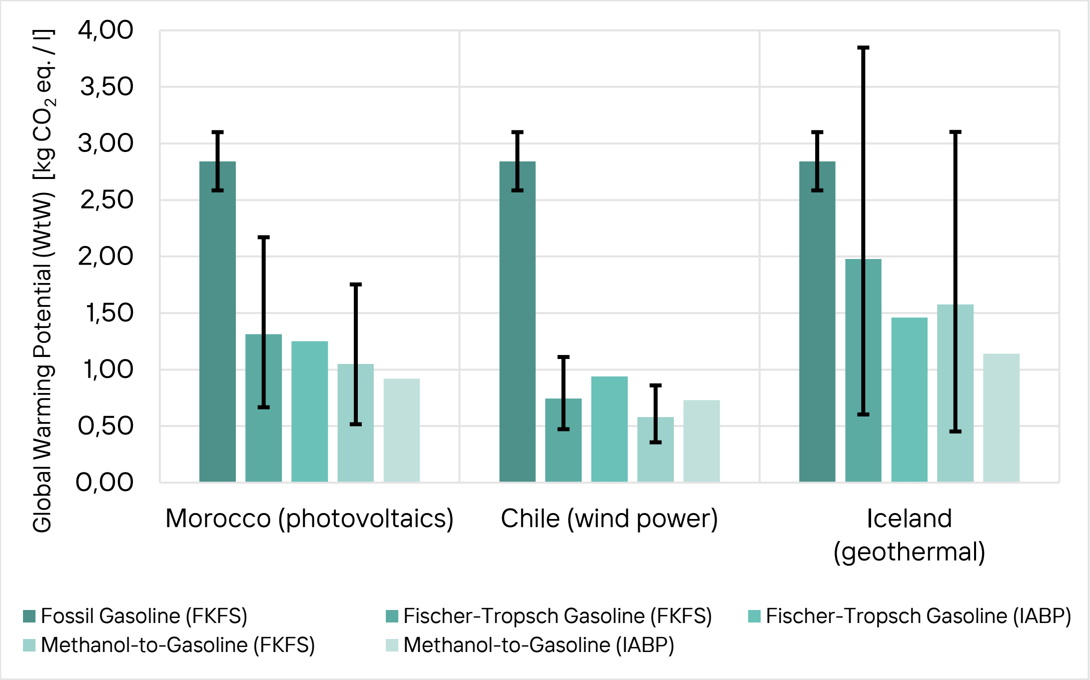

Figure 5: Global Warming Potential (Well-to-Wheel-Emissions) for e-gasoline produced with MtG- and the Frischer-Tropsch-route, executed by two independent research institutes (FKFS and IABP) [1].

As a best-case scenario, the MtG process could be identified for operation with wind power in Chile. A reduction in greenhouse gas emissions of up to 80 % in average value compared to fossil gasoline could be determined. The cost of fuel produced this way is calculated at 1.08 € / l. Taxes, subsidies and profit margins are not taken into account. For an estimation of the costs for the production of gasoline from fossil sources up to the gas pump, a rough estimate is made by using openly accessible AI-Tools [2]. For crude oil production, a share of 70 % conventional, 25 % off-shore and 5 % oil sand production is assumed. Furthermore, it is assumed that 1 litre of gasoline is produced from 0.87 litres of crude oil, according to density and lower calorific value of the two products. By-products such as diesel and heavy oil are also sold, equivalent to their lower calorific value. With this assumption, the price for crude oil production is estimated with 0.24 € per litre gasoline. The total transport of crude oil and gasoline is estimated at approximately 0.08 € per litre of gasoline based on [1]. The refining process is estimated with 0.07 € per litre of gasoline. This results in a production cost without profit margin, taxes and subsidies of approximately 0.39 € per litre of gasoline. The production costs for fossil gasoline calculated in this way only serves as a reference value and has to be seen as a rough estimation. With this estimate and the reference value for e-gasoline of 1.08 € / l from the study [1], the price for e-gasoline is about 2.8 times higher than for conventionally produced fossil gasoline.

This makes the use of e-fuel susceptible to fraud through the admixture or substitution of e-fuel with fossil fuel. This makes it essential to check the origin and production of the gasoline. In the following, a proposal is elaborated on how the authenticity of e-gasoline can be checked, both on an international and national level, in order to prevent possible fraud in the best possible way.

2 Global Market Concept

This chapter first presents a proposal for a global certificate system for monitoring e-fuel production. This enables both simple certificate trading and product-linked certificate trading on the global market. In this way, the decision on the certification system for imported e-fuels is left to the respective trading zone. The certificates can thus be traded independently of the product. For the product-linked certificates, the product (e-fuel) must be checked for authenticity when it is imported in order to prevent admixture or substitution. If the trading zone decides to trade in certificates only, the import check is not required. The concept for product-linked certificate trading is shown in **Figure 6**.

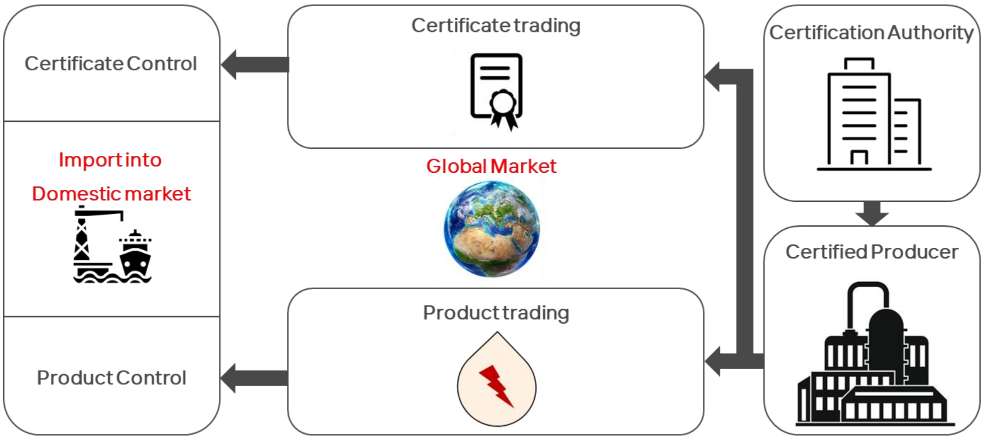

Figure 6: Example for import of globally produced e-fuels to a domestic market with product-linked certification.

With this system, a global and independent certification authority for the production or production sites for e-fuels is indispensable. Such a certification authority must continuously monitor the production volume of the respective production site and only issue certificates for verifiably produced volumes. This requires monitoring of the energy and mass flows of the individual processes of the plants, as well as remotely monitored and manipulation-protected measuring systems. The certificates generated in this way can then be freely traded by the producers or sold with the corresponding amount of e-fuel produced.

For certificate-based trade in the domestic market, the product must then be inspected and the certificates invalidated at customs. For this purpose, the importer must provide proof of the authenticity of the fuel and the corresponding quantity of certificates. The certificates are then invalidated and expire worthless. For example, a control point at the port of delivery is conceivable for checking the authenticity of the fuel. Possible control and monitoring mechanisms are conceivable to verify the authenticity of e-fuels. Security can be further increased by combining several mechanisms. Conceivable control mechanisms and their evaluation can be seen in **Table 1**.

Table 1: Possible control and monitoring mechanisms for proof of authenticity of e-fuels for import into domestic market from global market.

Methode	**Effectivity**	**Cost**
^{12}C- / ^{13}C- / ^{14}C-Method	**+**	**-**
^{1}H- / ^{2}H-Method	**+**	**-**
Combined C- and H-Analysis	**++**	**--**
Trace element analysis	**+**	**+**
Big data for analysing fuel properties	**(+)**	**+**

A first possibility to determine the production path of an e-fuel with measuring equipment is the ^{12}C / ^{13} C / ^{14}C method. Here, the ratios of the isotopes (^{12}C / ^{13} C / ^{14}C) are measured with an accelerator mass spectrometer. The following findings can be obtained from the isotope ratios:

- **^{14}C:** Age of the carbon source
- **^{13}C:** Biological or atmospheric origin of the carbon source
- **^{12}C:** Reference

To do this, the underlying mechanisms should first be understood. ^{14}C is first formed in the upper part of the Earth's atmosphere by cosmic radiation. If this is then removed from the Earth's atmosphere, the formation reaction stops. ^{14}C is an unstable isotope and decays with a half-life of about 5730 years [3].

The age or the period since the absorption of the isotope can therefore be determined by the amount of ^{14}C isotope in a sample. The underlying idea regarding the measurement of e-fuels is that they must have the atmospheric ^{14}C concentration due to the removal of CO_2 from the atmosphere, whereas fossil fuel should not contain measurable concentrations of ^{14}C. Since biologically produced fuels also remove CO_2 from the earth's atmosphere through the growth of plants, the ^{14}C method cannot clearly distinguish between biologically and electrically produced fuels [3].

^{13}C has a concentration of about 1 % in relation to the global total carbon content. However, this proportion can vary between the atmosphere or the environment and biological systems. Plants tend to absorb lower amounts of ^{13}C than ^{12}C, so the ^{13}C concentration in plants is lower than in the Earth's atmosphere. ^{13}C is a stable isotope and is therefore also present in fossil fuels, as these are primarily organic or biological in origin. Thus, the ^{13}C concentration can be used to determine whether a synthetic electric fuel or a biologically based fuel is present. The differentiation between biological and fossil fuel on the basis of the ^{13}C concentration is difficult. However, this distinction can be clearly measured by the ^{14}C method already presented. Thus, by measuring the carbon isotope ratios of an e-fuel sample in the accelerator mass spectrometer, a clear identification of an e-fuel is possible. The method is classified as manipulation-safe. However, due to the required technology and laboratories, it is also cost-intensive [3].

A second way to check the authenticity of e-fuels is to use the ^{1}H / ^{2}H method. Deuterium (^{2}H) is also formed in the earth's atmosphere and diffuses into seawater through rainfall. The concentration in seawater is almost constant. If the desalinated seawater is now used for the production of e-fuels, the deuterium can also be detected in the synthetic fuel. Assuming a half-life of 12.3 years, the age of the e-fuel can be determined relatively accurately. An accelerator mass spectrometer is also used as a measuring instrument. It is not clear whether the deuterium concentration of biological fuel differs from that of synthetic fuel, as the source of irrigation for the biomass is not always clear. Deuterium should not be detectable in fossil fuel due to its long period of residence in the deposit. Tritium (^{3}H) is unsuitable as an indicator because it is usually formed by radioactive radiation and does not occur naturally. The occurrence of tritium therefore depends on the location. By combining the ^{1}H / ^{2}H method with the ^{12}C / ^{13} C / ^{14}C method, the factors to be observed can be extended and the manipulation-safety increases even further. If there are different results for the age of the fuel for the different detection methods, this may indicate a falsification attempt. In general, the concentration limits should be observed during the analysis by the accelerator mass spectrometer [4].

Another test possibility is an analysis of the trace elements in a sample. With energy dispersive x-ray fluorescence analysis (ED-XRF), for example, a large number of trace elements can be measured. In this way, a specific profile of the sample can be generated which allows conclusions to be drawn about its origin. In the case of e-fuels, no trace elements should be detectable. In the case of fossil fuels and biofuels, trace elements should be present in the sample. The measured profile and the knowledge about the profile of certain sources can be used to draw conclusions about the source using, for example, AI algorithms. Here, it is necessary to identify whether and how fossil fuels differ from biofuels and whether the sample can actually be assigned to a specific source. Trace element analysis is considered to be manipulation safe at relatively low cost [5].

As an additional monitoring option and to enable traceability, AI algorithms with a corresponding database can be used in the background. For this purpose, profiles are created from the previously used measurement methods and compared with the database. The database should contain samples from all oil wells and e-fuel production plants worldwide. The measured profiles can in turn serve as a training data set for the algorithm, if the origin of the measured sample is known. This will eventually lead to complete traceability of the fuels. In addition, information about the fuel quality from the corresponding sources can be stored to support the importer in evaluating it. The effectiveness of monitoring with AI algorithms depends on the amount of data provided and the testing procedures used. It should be seen more as an additional control and analysis tool, as it cannot be used without the corresponding upstream testing procedures. The costs for additional AI-based monitoring are estimated to be low.

Whether and which of the monitoring mechanisms presented here can be implemented and prove to be useful remains to be seen. For this, the procedures must be tested extensively. If the procedures are effective, a cost/benefit analysis must be carried out to determine which procedure or combination of procedures is practicable.

3 Domestic Market Concept

This chapter presents a monitoring system for e-fuels trading in the domestic market. This is based on two instances: On the one hand, a certification authority that issues the certificates according to the verified and imported quantity, and on the other hand, the customs authorities of the respective countries that continuously check compliance with the regulations with random samples or in case of suspicion. The certification authority monitors the product linkage of the certificates with corresponding Industry 4.0-capable measuring devices, such as flow meters between the tanker and the filling station. The certificates are digitally carried with the product at all times and can thus be clearly assigned to a quantity. This means that sales of quantities exceeding the certified quantity can be stopped centrally and the responsible customs authority informed. This creates a seamless monitoring system from the importer to the gas station and thus to the end customer. An illustration of such a system is shown in **Figure 7**.

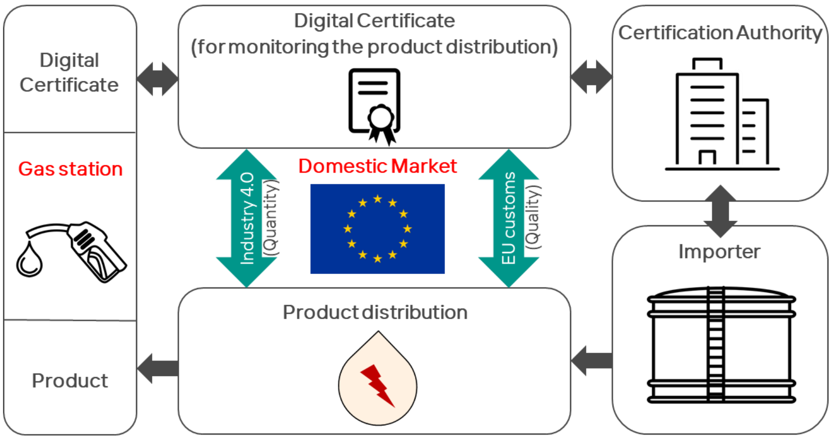

Figure 7: Example for possible e-fuel monitoring system in the domestic market from importer to gas station.

For a product-linked trade of e-fuels, the importer first carries out the procedure presented in chapter 2. If the test is successful, the fuel may be imported and the certification body issues digital certificates in the amount of the imported quantity. From now on, the certificates are digitally linked to the product. From this point on, e-fuels can only be traded with Industry 4.0-capable meters, which also automatically transmits the associated certificates. There can be any number of intermediaries on the way to the filling station. The certification body thus knows at any time the remaining quantity imported on the way from the importer to the gas station. Customs can carry out random checks on the authenticity of the e-fuels at any point in the supply chain.

In order to implement such a monitoring, various technical measures have to be taken. Furthermore, possibilities to improve the monitoring by the certification authority and customs are shown. The following monitoring methods are divided into measures for automatic monitoring by the certification authority and for manual monitoring by customs. It should be mentioned that the control methods by customs can also be applied in the case of a control at the end customer. The methods identified are listed in **Table 2**.

Table 2: Possible monitoring systems for continuous monitoring of e-fuels by certification authority and customs for certificate-based trading in the domestic market.

Methode	**Effectivity**	**Cost**
Real-time certificate monitoring	**++**	**+/o**
Industry 4.0 flow meters	**+**	**+/o**
Optical Marker (+ Optical Sensor)	**o/-**	**+**
Customs Control	**++/-**	**+**
Chemical marker (for e-fuels)	**o/-**	**o**
Chemical marker (for fossil fuels)	**++**	**o**

The possibility of real-time monitoring by the certification authority first requires an interface at which the traded quantities can be checked. For this, at least redundant flow meters of the two trading partners are necessary. If, for example, a tank truck or intermediary picks up a defined quantity of fuel from the importer, the quantity delivered is measured once and the quantity loaded is measured once. These two values must be the same. The corresponding certificates are then automatically transferred to the intermediary. This means that he is now in possession of the fuel and the corresponding certificates and the certification authority is informed about the whereabouts of the fuel. The use of such a flow meter requires a permanent internet connection to transfer the corresponding measurement data to the certification authority and to transfer the corresponding amount of certificates. In order to additionally check whether only e-fuels are traded, the e-fuel can be marked with an optical tracer, as proposed in [6]. An additional sensor in the flow meter to verify its authenticity can then measure this optical tracer.

The effectivity of real-time certificate monitoring is rated as very high. The use of Industry 4.0-capable flow meters is considered sufficient. If a higher level of security is desired, the e-fuel can be additionally marked with an optical marker and the flow meter can be extended with an optical sensor. The costs of such a monitoring system is considered acceptable.

The possibilities for control by the customs authorities are limited, as the implementation or detection must be relatively simple, as no laboratories are available for an initial control. The marking of heating oil can be used as an example. There are many possible markers that can be detected with a quick test with water and are still detectable even at very high dilutions. This offers a possibility for the customs authorities to detect mixed or fossil fuel with a quick test. An exact determination of a possible admixture can be verified in the laboratory in case of suspicion [7]. This gives rise to two possibilities. The first possibility is to mark the e-fuels. This can also be done, for example, in combination with the optical monitoring described before. However, the effectiveness of this option is considered to be low, as a laboratory is needed each time to determine the exact concentration and the marker can simply be added in the appropriate concentration. The marking of conventional fuels, i.e. gasoline and diesel, is considered a more practical solution. If fossil fuel is added, even small quantities can be detected by customs using the rapid test. By adding markers to fossil fuels, a high effectivity of customs controls can be expected. The costs for marking the fuels are considered acceptable. The costs for customs controls depend on the frequency of the controls.

With these methods, complete monitoring of the distribution of e-fuels from the importer to the filling station seems possible for trade in the domestic market. Another interface is the purchase of fuel by the customer at the gas station. Here, too, there is an increased need for monitoring due to the regulation for the exclusive use of e-fuels in new vehicles from 2035. A first important pillar is that the certificates carried with the e-fuel are transferred to the customer in devalued form. In this way, the refuelled quantity can be continuously monitored and compared with the fuel consumption of the vehicle. Should a deviation occur, the vehicle or the data can be accessed by a control instance in accordance with a future legal situation and appropriate actions can be taken. The described system for the refuelling process and the delivery of the e-fuel to the end customer is presented in **Figure 8**. For the implementation of these measures, different methods are needed or the fraud protection can be increased by combining measures. Possible methods and their evaluation for the refuelling process and in-vehicle monitoring are shown in **Table 3**.

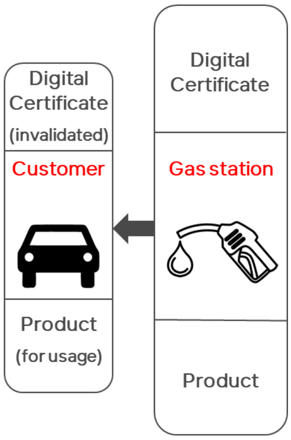

Figure 8: Example for possible e-fuel monitoring system for delivery to the customer and use in the vehicle.

Table 3: Possible monitoring methods for the delivery of the e-fuel to the customer and in-vehicle monitoring.

Methode	Effectivity	Cost
Digital handshake (transfer of inv. certificates)	++	+
Special fuelling nozzle	-	++
On-board sensors	+	o

Communication between the filling station or gas pump and the vehicle is necessary for the transmission of certificates to the vehicle. For this purpose, a digital interface or a digital handshake must be implemented. Another possibility to improve fraud resistance is a constructive solution for the nozzle. In this case, the fuelling nozzle for new vehicles from 2035 onwards can be designed in such a way that only the nozzle for e-fuels is suitable, but not the nozzle for fossil fuels. On the other hand, the nozzle for e-fuels must also be suitable for vehicles with an initial registration before 2035. The monitoring in the vehicle is carried out by the OBD and the transmitted certificates. Further monitoring of the e-fuels in the vehicle should be based on the implemented control measures and offers a variety of possibilities. Based on the control measures presented for the global and domestic market, technical solutions for control mechanisms in the vehicle are for example, fuel sensors in combination with AI algorithms, which can detect and identify fuel components or tracers.

Whether and which of the monitoring mechanisms presented here can be implemented and prove to be useful remains to be seen. For this, the procedures must be tested extensively. If the procedures are effective, a cost/benefit analysis must be carried out to determine which procedure or combination of procedures is practicable.

4 Conclusion

E-fuels produced with sustainable electricity offer the possibility of a strong defossilisation of the transport sector at marketable prices. However, this is usually only the case if they are produced in regions with high full load hours for renewable energy plants. The e-fuels produced in this way are thus traded on the global market. If a product link or a product-linked certificate is required, measures must be taken to verify the origin of the fuel. An import into the domestic market requires a check of the fuel's origin at the port of entry and requires laboratories and test centres for a clear identification of the origin or the production process. If this fuel is now to be monitored seamlessly in the domestic market, a product-related certificate must be carried at all times with the quantity of fuel traded. This enables the end customer to obtain the corresponding e-fuel at the pump.

This paper shows that complete monitoring of the origin and production from the manufacturer to the end customer is technically feasible. For this purpose, two possible approaches for a product-linked certification of e-fuels are presented. The first approach refers to the import from the global market for large quantities that are delivered by tanker, for example. In this case, the delivered fuel is analysed using various laboratory techniques close to the port. Acceleration mass spectroscopy for carbon is used as the main method to identify the carbon source. Further methods are presented to increase the forgery resistance. After the measurement and verification of the authenticity of the e-fuel, certificates must be cancelled in the amount of the delivered quantity. The second approach relates to the trading of fuel in the domestic market. Here, a permanent link between fuel and digital certificates is proposed. This coupling is made possible by Industry 4.0-capable measurement technology. Furthermore, procedures are presented for a sample-like control by the customs authority. The delivery to the customer and the control of an exclusive use of e-fuels will be made possible through various measures and OBD monitoring.

The measures presented for the global and domestic market show that such an implementation is also feasible at reasonable cost. However, both control authorities and complex technical equipment are required. A high level of fraud protection is achieved with the systems presented. However, the technical feasibility of the measures must be investigated in practice in order to obtain a more accurate picture of the feasibility and costs. In the end, it remains to be seen whether it makes sense to link the certificates to the e-fuel product and thus justify the costs, or whether it makes more sense to integrate them into the existing CO_2 certificate trading system.

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