# HyCoRA – Hydrogen Contaminant Risk Assessment Grant agreement no: 621223

# D3.3 Results from the 2nd HRS measurement campaign

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**Summary**

The planned second HRS measurement campaign was decided to divide into two separate campaigns. During the two sample-collection campaigns, a total of 20 gas samples have been collected from various HRSs in Norway, Germany, Denmark and Sweden. The samples were sent for analysis to Smart Chemistry in USA. The samples were collected using the "Linde qualitizer" sampler, and the sampling setup was proven to work flawlessly on all the different fueling station technologies that were covered. No manual override of safety features on the fueling stations were required.

13 of the 20 samples were within the required limits for all impurities. One sample had too high hydrocarbon content, three did not meet the fuel index requirements (mainly due to $N_2$), five samples all from SC2 had to high $O_2$ content and one sample had too high $CO_2$ content. Often a sample violated more than one of the requirements in the standard.

In addition, two different ways to collect simultaneously particulate and gas samples were tried out. The samples were collected with a HYDAC PSA70 Sampling equipment that was placed either before or after the Linde sampler. The results indicate that sampling of gas and particulates should be performed separately.

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# Contents

# 1 Introduction

The HyCoRA "second sampling campaign" was split into two separate campaigns. This was due to the limited availability of gas cylinders for sampling, and thereby the originally planned second sampling campaign was divided into two campaigns, referred hereafter as second and third, ten samples each.

The second sampling campaign was conducted between 2016-06-06 and 2016-06-11. The hydrogen refuelling stations (HRSs) were selected with a preference for their commissioning date in order to investigate the possible sourcing of impurities from newly commissioned HRS to the fuel quality.

The third sampling campaign was conducted between 2017-03-30 and 2017-04-07. No specific objective for selection of HRSs was obvious based on previous results. HRSs in Scandinavia were chosen.

# 2 Second HRS sampling campaign

## 2.1 Selection of HRS

HRSs were chosen for their commissioning date to investigate impact on fuel quality from HRS components. Especially, $C_4Cl_4F_6$, greases, particulates and inerts have been discussed as potential contamination from HRS and a higher probability of occurrence has been assumed at commissioning and maintenance of HRS.

Sampling in context with HRS maintenance could not be planned. Finding a set of a ten HRS with public access and reasonable driving distance turned curtailed the HRS list too much to add HRS maintenance schedules. On a general note: whereas public access to HRS's has been adequate, information sharing with HRS operators has not been sufficient for planning of sampling with response to maintenance.

## 2.2 Sampling

The sampling campaign was conducted in a similar manner as the first: an ICE vehicle with empty sample cylinders was ferries down to Germany. Samples were then collected on the road from Germany, via Denmark and Sweden, back to Norway. Samples were transferred to smaller cylinders provided by Smart Chemistry and shipped.

The ten Spectraseal 10 L cylinders used for sampling were prepared by a sequence of evacuation to 1 mbar, and pressurization to 10 bar with Hydrogen 5.0 three times before a final evacuation.

The Linde sampling instrumentation was used as previously described in HyCoRA D3.1[1]. In contrast to the first sampling campaign described in D3.2[2], particulate sampling was conducted in series with the gas sampling. If enough fuel cell electric vehicles (FCEVs) were available, sampling from separate refuellings would have been conducted. Instead, a combined sampling during one refuelling of a FCEV was conducted. The sequence of the

[1] D3.1 Hydrogen sampling unit tested and certified
[2] D3.2 Measurement of hydrogen quality variation at various HRS with different fuel feedstock.

sampling was much debated, and it was eventually decided to sample particulates upstream the gas sampler.

An opportunity for redundanct presented itself in Århus where the particulate sampler needed maintenance in the form of spare gaskets. Gas sampling was conducted separately (HY-8). After new gaskets was obtained, a combined sampling was conducted (HY-12). In this way, particulate sampling was performed without interference from gas sampling, and the impact of particulate sampling on gas sampling can be evaluated by comparing the results from the gas sampling of HY-8 and HY-12. The difference between these two laboratories would of course include the repeatability in analysis by Smart Chemistry.

*Table 1.HRS sampling table.*

| HRS | Date and Time | Feedstock | Storage | Sample ID |
|---|---|---|---|---|
| Hamburg, Bramfelder Chaussee (DE) | 06.06.2016 | Steam methane reforming (SMR) | Compressed | HY-2 |
| Berlin, Holzmarktstrasse (DE) | 07.06.2016 | SMR | Liquid | HY-3 |
| Berlin, Heerstrasse (DE) | 07.06.2016 | SMR | Liquid | HY-4 |
| Berlin, Detmoldstrasse (DE) | 08.06.2016 | SMR | Liquid | HY-5 |
| Geiselwind (DE) | 08.06.2016 | SMR | Liquid | HY-6 |
| Kolding (DK) | 09.06.2016 | Water electrolysis (on-site) | Compressed | HY-7 |
| Århus (DK) | 09.06.2016 | Water electrolysis (trucked in) | Compressed | HY-8 |
| Køge (DK) | 10.06.2016 | Water electrolysis (trucked in) | Compressed | HY-9 |
| Gothenburg (SE) | 11.06.2016 | Water electrolysis (trucked in) | Compressed | HY-10 |
| Århus (DK) | 09.06.2016 | Water electrolysis (trucked in) | Compressed | HY-12 |

Analysis of the samples were conducted by Smart Chemistry. The details of the analytical methods applied is described in HyCoRA D3.1.

## 2.3 Analytical results

### 2.3.1 Analysis of gas samples

An overview of the analytical results from Smart Chemistry is shown in Figure 1. The violations of ISO 14687-2 / SAE J2719 is indicated in red. Limit of Detection (LoD) and standard tolerance level is given in the two rightmost columns.

| ppm mol | HY-2 | HY-3 | HY-4 | HY-5 | HY-6 | HY-7 | HY-8 | HY-9 | HY-10 | HY-12 | LOD | Tol |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Commissioned | 2013 | 2015 | 2015 | 2015 | 2015 | 2016 | 2016 | 2015 | 2015 | 2016 | | |
| Fuel Index | 99.99396 | 99.99750 | 99.99259 | 99.99634 | 99.99371 | 99.99384 | 99.99199 | 99.96163 | 99.95574 | 99.99180 | | 99.97 |
| H2O | | 1.5 | | | | | | | | | 1 | 5 |
| THC (C1) | 0.12 | 0.04 | 0.13 | 0.07 | 0.36 | 0.30 | 0.84 | 0.42 | 5.1 | 0.88 | | 2 |
| O2 | 4.9 | 5.0 | 4.9 | 11 | 5.7 | 5.2 | 4.1 | 5.4 | 13 | 5.4 | 1 | 5 |
| He | | | 51 | | 40 | | | | | | 10 | 300 |
| N2 & Ar | 56 | 19 | 16 | 26 | 18 | 56 | 75 | 378 | 419 | 76 | | 100 |
| N2 | 55 | 19 | 16 | 26 | 18 | 56 | 75 | 378 | 416 | 76 | 5 | |
| Ar | 0.57 | | | | | | | | 3.1 | | 0.4 | |
| CO2 | | | | | | | | | 5.7 | | 0.1 | 2 |
| CO | 0.0047 | 0.0011 | 0.0040 | 0.0014 | 0.0048 | 0.0032 | 0.0025 | 0.0016 | 0.015 | 0.0023 | 0.0005 | 0.2 |
| TS | 0.000026 | 0.000024 | 0.000020 | 0.000017 | 0.000032 | 0.000034 | 0.000039 | 0.000013 | 0.00011 | 0.00015 | | 0.004 |
| HCHO | | | | | | | | | | | 0.001 | 0.01 |
| HCOOH | | | | | | | | | | | 0.001 | 0.2 |
| NH3 | | | | | | | | | | | 0.01 | 0.1 |
| TH | 0.00048 | 0.0019 | 0.00042 | < 0.001 | 0.00048 | 0.026 | 0.015 | 0.023 | 0.0033 | 0.0049 | | 0.05 |

*Figure 1. Overview of analytical results from Smart Chemistry.*

Two of the HRS's had too high nitrogen levels, that is causing a violation in both nitrogen and fuel index. This is illustrated in Figure 2.

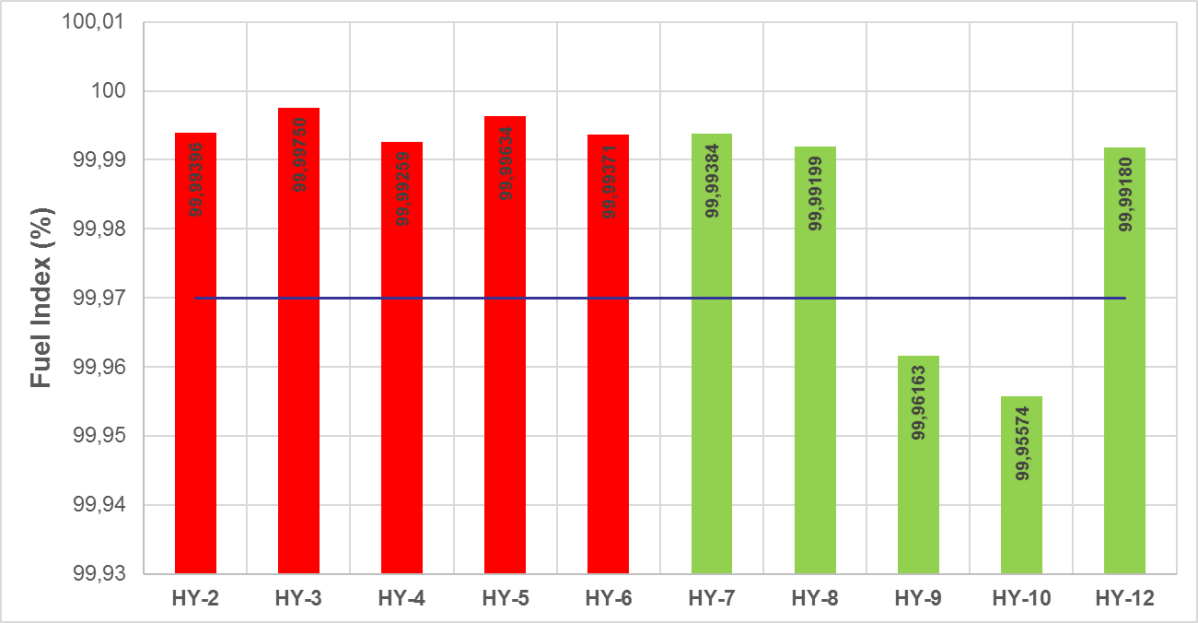


*Figure 2. Fuel index results. SMR and WE feedstocks indicated in red and green respectively.*

The nitrogen violations are found amongst the HRS with water electrolysis (WE) feedstock. As can be seen from Figure 3, the main contribution to lowering of the fuel index is nitrogen. Two HRS's with steam methane reforming (SMR) contain significant amounts of He, albeit well below the tolerance limit.

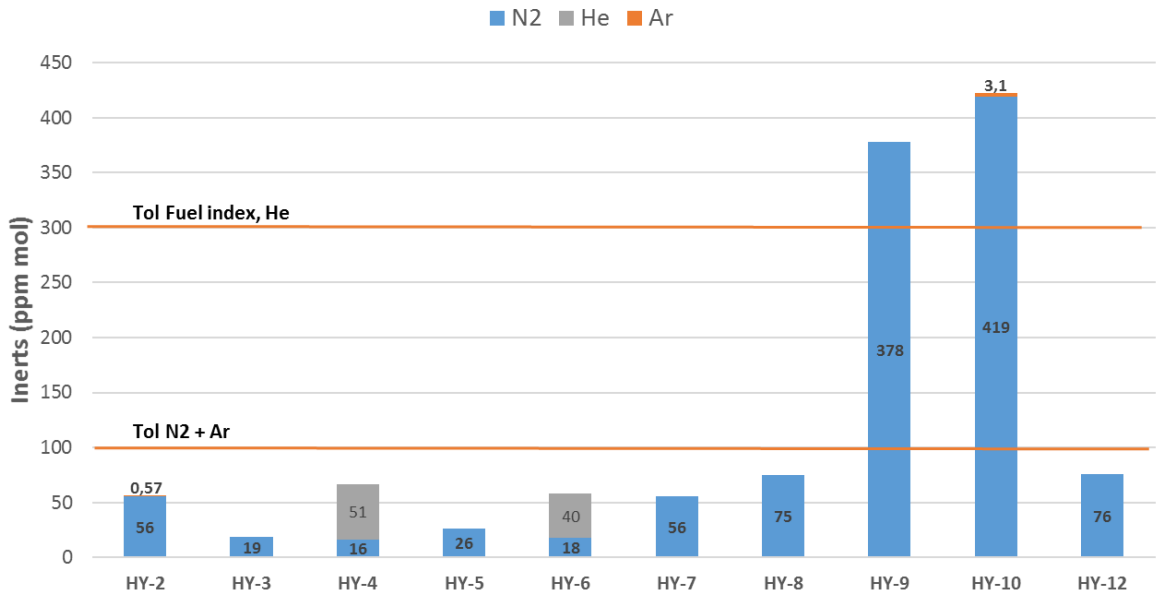


*Figure 3. Inerts results.*

Oxygen levels were high, and close to the tolerance limit of 5 ppm mol, for all samples. This was not observed in the results from the first sampling campaign. HY-2 was also sampled then, and did not at the time show high oxygen level. The reason for this surprising result is not known.

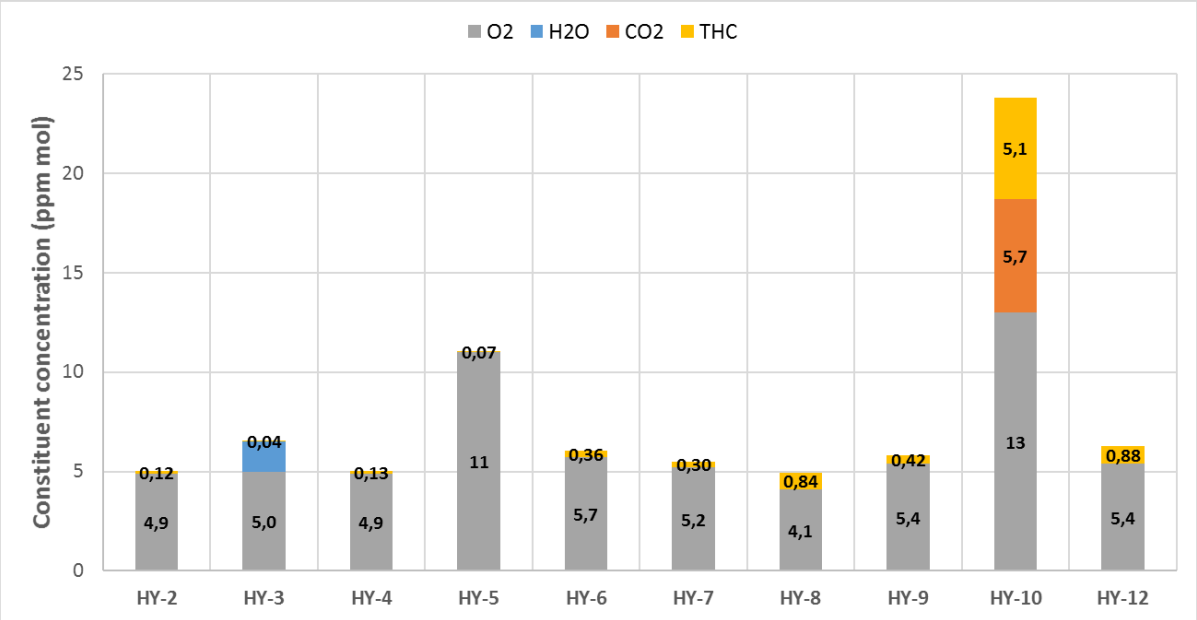


*Figure 4. Results of other constituents. The THC budget in this chart contains $CH_4$, which has a tolerance of 100 ppm mol.*

As can be seen from Figure 4, sample HY-10 also has a violation of the $CO_2$ budget. The THC budget is higher than the tolerance of 5 ppm mol due to the inclusion of $CH_4$ in this budget. This is not a violation as $CH_4$ has a tolerance of 100 ppm mol summed with nitrogen.

Sulfur was distributed amongst the three species $H_2S$, COS and $CS_2$ in the first sampling campaign. The results from the second sampling campaign, illustrated in Figure 5, show the presence of two additional species found in sample HY-12: tert-butyl mercaptan and tetrahydro thiophene. The COS levels are prominent when compared with the results from the previous sampling campaign. The results are nevertheless on ppt level and well below the tolerance of 4 ppb mol total sulfur.

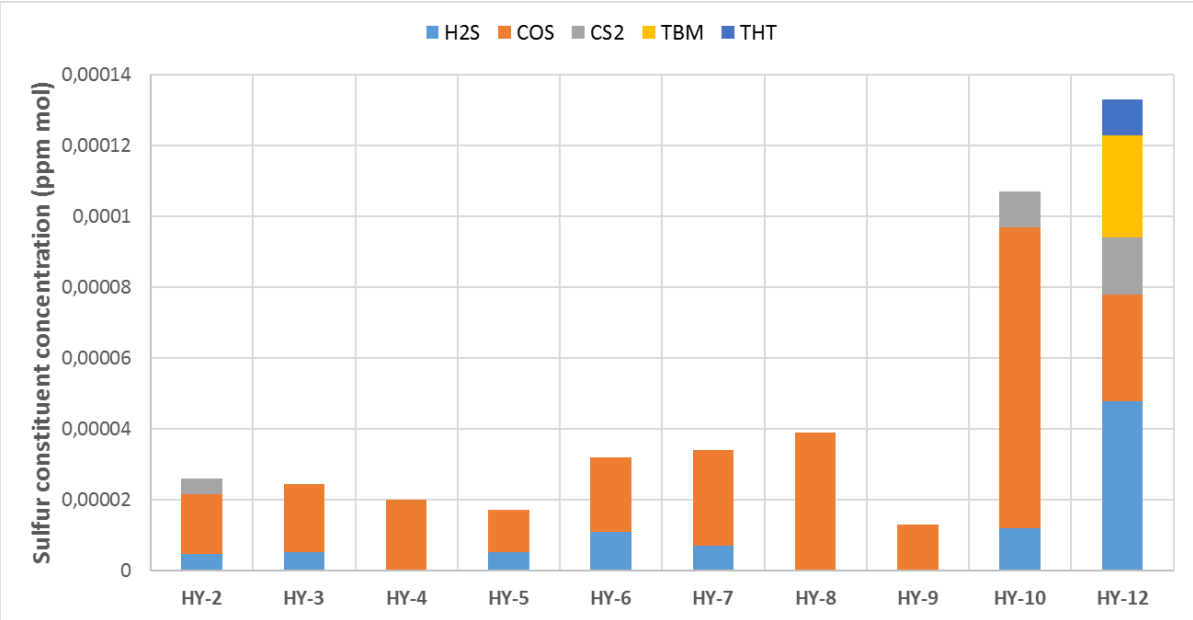


*Figure 5. Sulfur results.*

The results for total halogenates are shown in Figure 6. Unlike for the first sampling campaign, the tetrachlorohexafluorobutane organohalide was not found in all samples. For the three samples HY-7, 8 and 9, a decomposition of the molecule to four individual chlorine atoms (HCl basis) would violate the total halogenated tolerance at 50 ppb mol. A requirement is therefore that this molecule is stable in a fuel cell environment. This has not been confirmed.

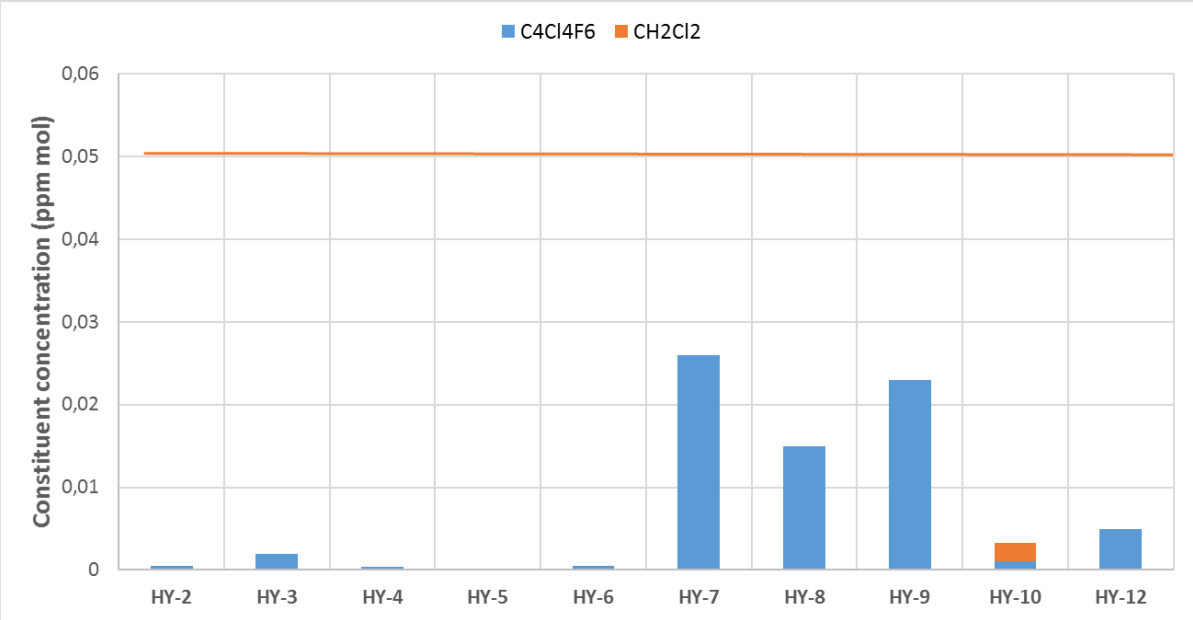


*Figure 6. Results of total halogenates.*

The presence of dichloromethane in sample HY-10 was surprising, as this species had never been detected. Samples HY-9, 10 and 12 was sent to external analysis by NPL and SYFT[3]. Both laboratories confirmed the presence of dichloromethane in sample HY-10. NPL did not detect the presence of tetrachlorohexafluorobutane in any of the samples.

Figure 7 shows the speciation of the total hydrocarbon budget. Acetone was found in all samples. The levels are well below the 2 ppm mol tolerance limit. The speciation is slightly different from what was observed in the first sampling campaign.

[3] D2.1 New methods and traceable standards.

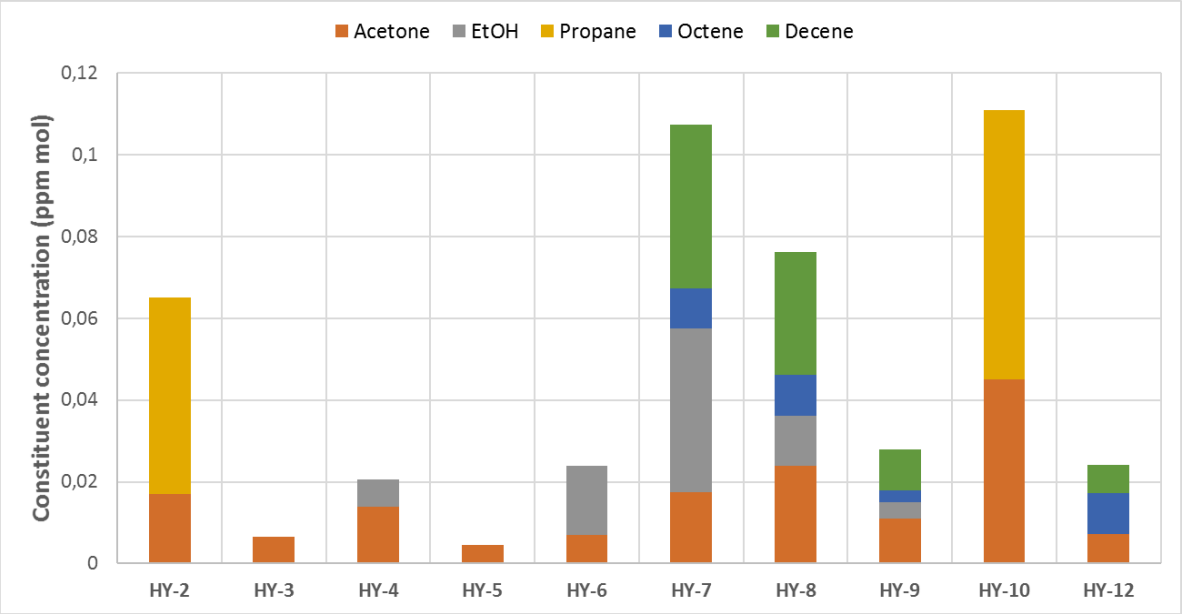


*Figure 7. Results of organic constituents.*

For all samples, a significant but low level of CO was found in all samples. This is consistent with the results found in the first sampling campaign.

**Comparison between parallel samples HY-8 and HY-12**

The samples HY-8 and HY-12 were collected from the Århus HRS on the same day. The latter gas sample was collected while collecting a particulate sample upstream the gas sampling instrument. The results in Figure 1 indicate good correlation between the analytical results for nitrogen, CO and THC. For sulfur, the total concentration of sulfur is much higher in sample HY-12. The speciation is also much more diverse in this sample. It can be speculated that the new gasket for the particulate sampler could be a source of sulfur contamination.

**Conclusion**

From the analytal results, it is not possible to conclude that newly commissioned HRS's have higher impurity levels.

### 2.3.2 Analysis of particulate samples

Particulate sampling were conducted for all gas samples with the exception of sample HY-8. For saple HY-10, the metering of hydrogen was not available for a calculation of the gravimetric results.

An uncertainty budget was calculated for the results where the uncertainty of the gravimetric analyis and the metering of dispensed hydrogen was taken into account. An one-sided conficence interval of 95 % was calculated. This is shown in Figure 8. The high uncertaintainty in all results can be ascribed to the conditioning of the filter prior to initial measurement (water content of filter at at given atmosphere). With the exception of sample HY-2, the result and the confidence interval is not in violation with the 1 mg/kg tolerance. For sample HY-2, the higher result and its confidence interval prevents the same conclusion at this confidence level.

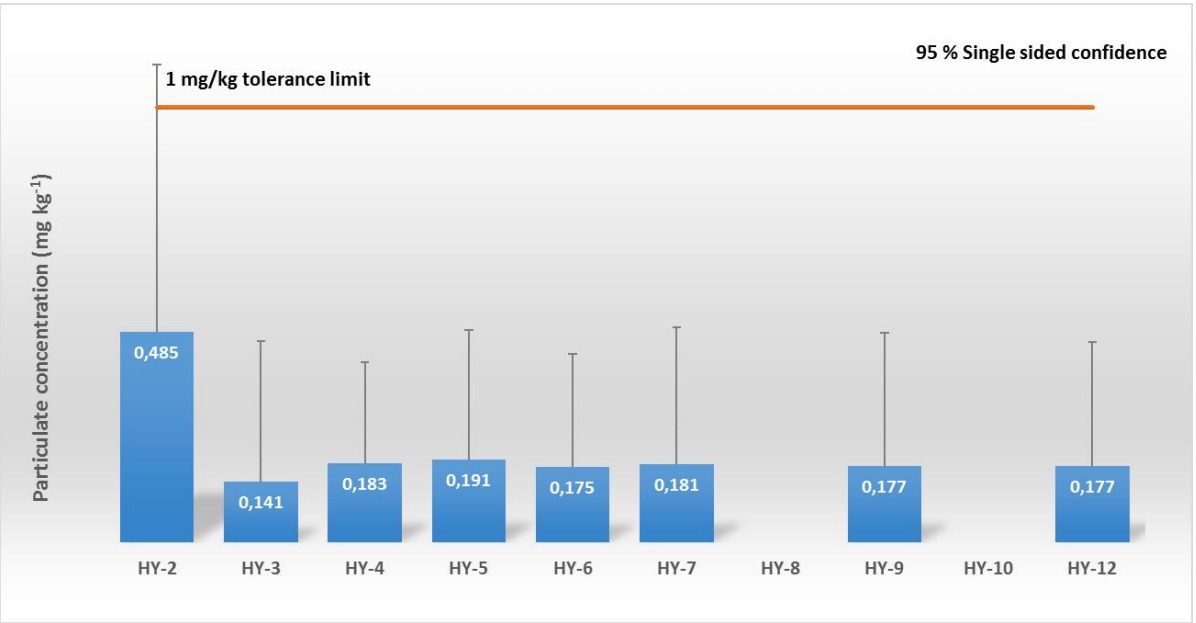


*Figure 8. Results of gravimetric analysis of particulate sampling.*

All samples were qualitatively analysed by SEM EDS. Some SEM micrographs of particulates trapped is shown in Figure 9.

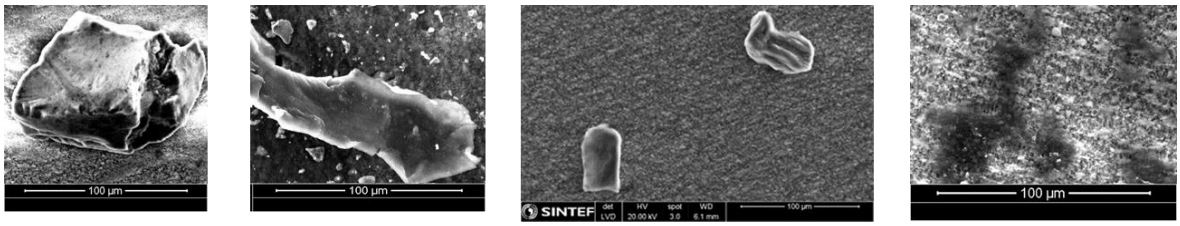


Figure 9. Micrographs of particulates. To the left inorganic particulates and to the right organic particulates and oil/grease.

An overview of the findings is shown in Table 2.

*Table 2. Qualitative results from SEM EDS analysis, a complete sample from Gothenburg was not obtained, but there was still particulates to analyse. Filter 8 from Århus was only inserted into the filter holder, but never used.*

| Filter | Total | Stainless steel | Ni-P | Other metals | Oxides | Organic particles | Organic residues |
|---|---|---|---|---|---|---|---|
| **01 – Test sample** | high | ++ | ++ | + | + | + | - |
| **02 – Bramfelder Caussee** | medium | + | + | + | + | + | + |
| **03 – Holzmarkstrasse** | low | - | - | - | + | ++ | - |
| **04 – Heerstrasse** | medium | + | ++ | + | + | ++ | ++ |
| **05 – Detmoldstrasse** | low | - | - | + | + | ++ | - |
| **06 – Geiselwind** | medium | + | ++ | + | - | ++ | ++ |
| **07 – Kolding** | low | + | - | + | - | ++ | - |
| **08 – Århus 1 (aborted)** | low | - | - | - | + | + | - |
| **09 – Køge** | low | - | ++ | - | + | - | + |
| **10 – Gøteborg (Aborted)** | low | ++ | + | - | + | + | - |
| **11 – Århus 2** | high | + | ++ | - | + | + | - |

A micrograph of a 0.2 micron filter with high contrast indicate pinhole formation of particulate filters. This is illustrated in Figure 10. Micrograph of pinhole formation. This could be indicative of particulate matter losses through the filter. This is currently being discussed the manufacturer of the particulate sampling adapter, HYDAC.

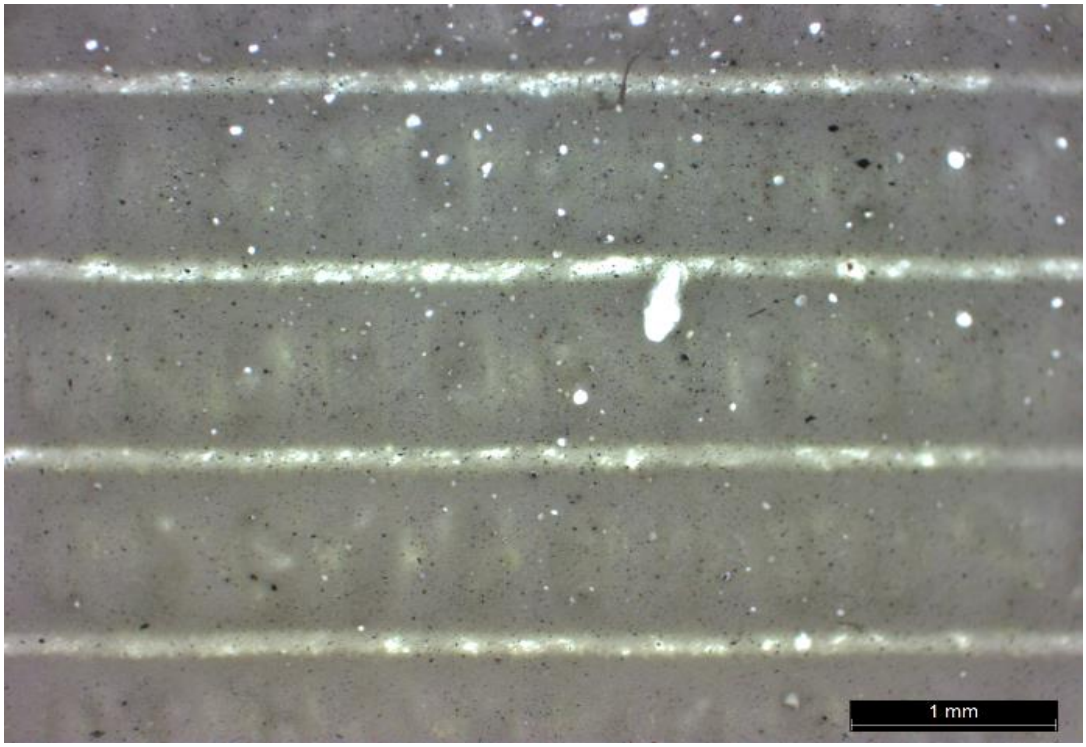


*Figure 10. Micrograph of pinhole formation.*

# 3 Third HRS sampling campaign

## 3.1 Selection of HRS

The topics of the first and second sampling campaign were feedstock and commissioning date respectively. In neither campaign, it was possible to correlate fuel quality with the topic for sampling. For the third sampling campaign, the discussions during the project meeting did not conjure up a topic. Since Norway, the closest alternative was neglected in the second campaign and Sweden had added a few new HRS's to their roster. Additionally, since the Gothenburg HRS was seen to contain a large spectre of impurities, a revisit was desirable.

## 3.2 Sampling

Samples were collected in Norway on individual dates since all HRS were within short driving distances from Oslo. The samples from Denmark and Sweden were collected on a round trip where the empty sample cylinders were transported on ferry to Denmark. The route was then completed on road. The transportation of pressurized hydrogen on ferries does not have clear regulations which makes it difficult to get a formal approval for transport of hydrogen samples.

The route is shown in Figure 11.

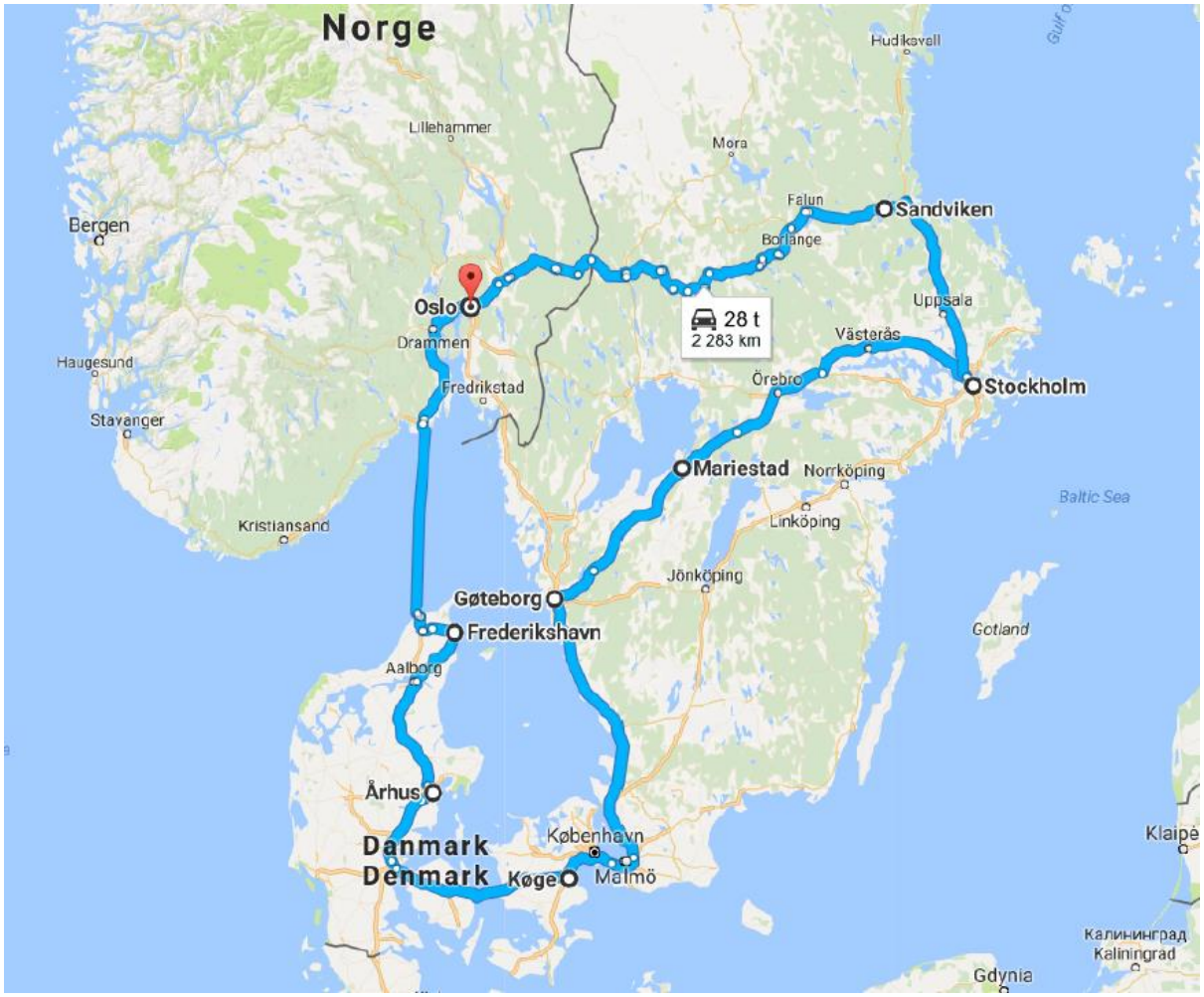


*Figure 11. Route for sampling campaign 3.*

The sampling instrumentation and strategy was the same as for the previous sampling campaign with one exception: particulates were now sampled downstream of the gas sampler. From discussions after dissemination of results from the second measurement campaign, it was suspected that condensing gas species could be trapped on the particulate filter. To investigate this, the filter was placed to downstream.

The collected samples are shown in Table 1.

*Table 3. HRS samples collected.*

| HRS | Date | Feedstock | Storage | Sample ID |
|---|---|---|---|---|
| Gaustad (NO) | 30.03.2017 | Water electrolysis | Compressed | HY-1 |
| Lillestrøm (NO) | 30.03.2017 | Water electrolysis | Compressed | HY-2 |
| Gardermoen (NO) | 30.03.2017 | Water electrolysis | Compressed | HY-3 |
| Porsgrunn (NO) | 31.03.2017 | Chlor-alkaline | Compressed (350bar) and booster | HY-4 |
| Århus (NO) | 05.04.2017 | Water electrolysis (trucked-in) | Compressed | HY-5 |
| Køge (DK) | 05.04.2017 | Water electrolysis | Trucked in | HY-6 |
| Gothenburg (SE) | 06.04.2017 | Water electrolysis | Trucked in from Finland) | HY-7 |
| Mariestad (SE) | 06.04.2017 | Water electrolysis | Trucked | HY-8 |
| Sandviken (SE) | 07.04.2017 | Water electrolysis | Trucked in (on site supply not ready) | HY-10 |
| Gausstad (NO) | 20.04.2017 | Water electrolysis | Compressed | HY-9 |

Like the second sampling campaign, a sample parallel was provided by sampling the Gaustad HRS twice.

## 3.3 Analytical results

### 3.3.1 Analysis of gas samples

*Table 4: Overview of analytical results from Smart Chemistry*

| ppm mol | HY-1 | HY-2 | HY-3 | HY-4 | HY-5 | HY-6 | HY-7 | HY-8 | HY-9 | HY-10 | LOD | Tol |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fuel Index | 99,99894 | 99,999 | 99,99803 | 99,94969 | 99,99539 | 99,99457 | 99,99719 | 99,99866 | 99,99781 | 99,99714 | 0 | 99,97 |
| H2O | 0 | 0 | 0 | 1,3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 5 |
| THC (C1) | 0,22 | 1,7 | 1 | 47 | 1,2 | 0,27 | 0,42 | 0,15 | 0,8 | 0,72 | 0 | 2 |
| O2 | 0 | 0 | 4,1 | 1,8 | 3,1 | 4,8 | 3,4 | 0 | 4,2 | 4,4 | 1 | 5 |
| He | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 13 | 0 | 0 | 10 | 300 |
| N2 & Ar | 0 | 8,3 | 15 | 452,3 | 41,48 | 49,41 | 24 | 0 | 17 | 23,4 | 0 | 100 |
| N2 | 0 | 8,3 | 15 | 448 | 41 | 49 | 24 | 0 | 17 | 23 | 5 | 0 |
| Ar | 0 | 0 | 0 | 4,3 | 0,48 | 0,41 | 0 | 0 | 0 | 0,4 | 0,4 | 0 |
| CO2 | 0 | 0 | 0 | 0,37 | 0 | 0 | 0,36 | 0 | 0 | 0,2 | 0,1 | 2 |
| CO | 0,0022 | 0,001 | 0,00087 | 0,0093 | 0,003 | 0,0017 | 0,0015 | 0,0027 | 0,0035 | 0,0023 | 0,0005 | 0,2 |
| TS | 0,000016 | 0,00001 | 0,000016 | 4,2E-06 | 0,000015 | 0,000016 | 0,00002 | 0,000022 | 0,000017 | 0,000018 | 0 | 0,004 |
| HCHO | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,001 | 0,001 |
| CH3COOH | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,001 | 0,2 |
| NH3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,01 | 0,1 |
| TH | 0,00067 | 0,0026 | 0,0037 | 0,0062 | 0,0028 | 0,0035 | 0,002 | 0,0038 | 0,0042 | 0,01 | 0 | 0,05 |

Only one of the analysed samples had a fuel index below the required 99.97%, that was sample number 4, and as can be seen from Figure 13 the high amount on $N_2$ in the sample caused the dilution to a fuel index of 99,94. Dilution effects from He and Ar had only minor contributions. The HY-4 sample violates both fuel-index and $N_2$+Ar limits.

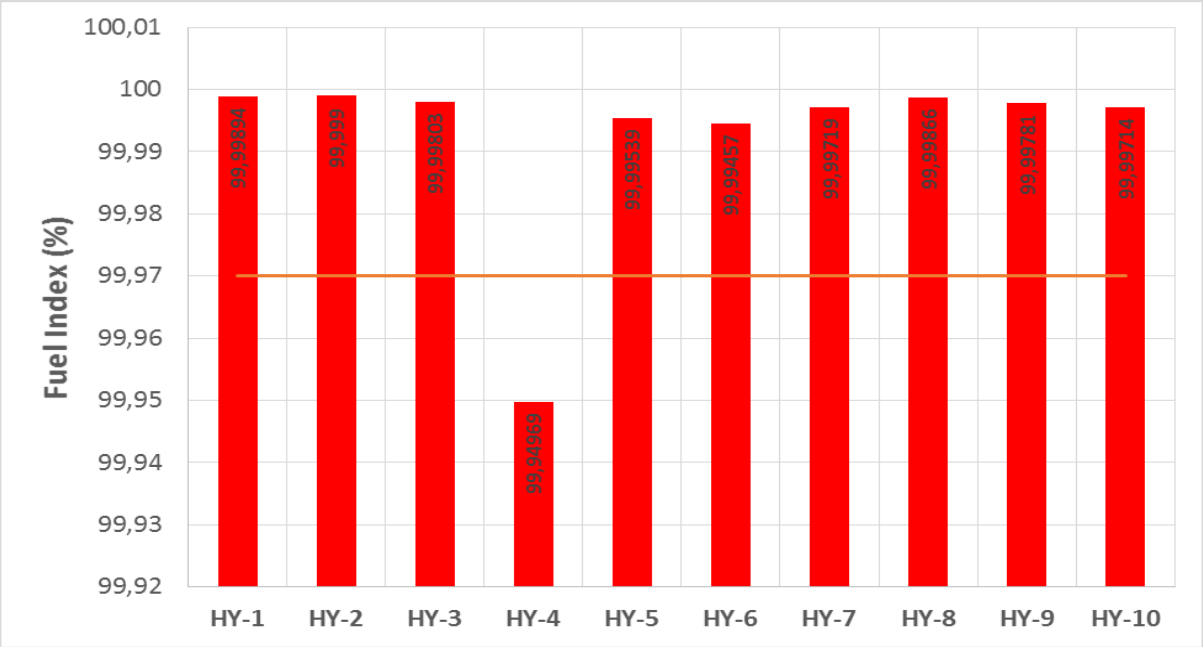


*Figure 12: Fuel index results. Only one station falls below the requirement of 99,97%*

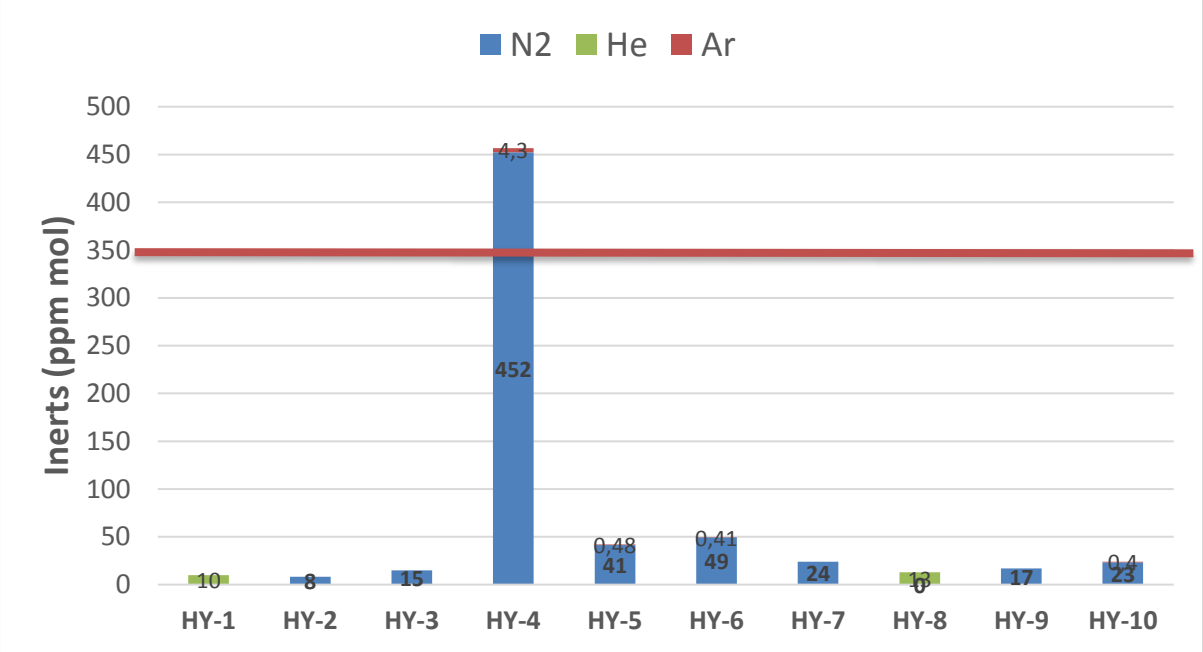


*Figure 13: Inerts results.*

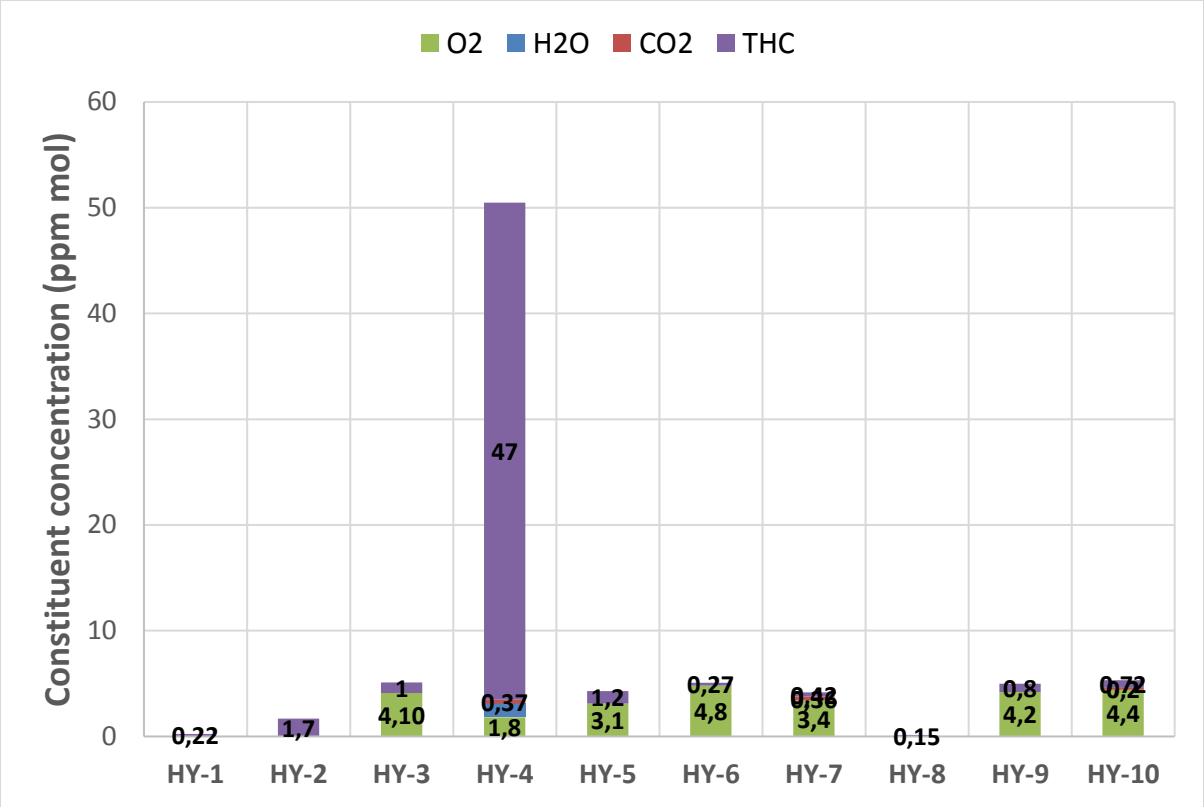


*Figure 14: Results of other constituents, The THC budget in this chart contains $CH_4$, which has a tolerance of 100 ppm mol.*

From Figure 14 the amounts of $O_2$, $H_2O$ and $CO_2$ are within the tolerances of respectively 5 ppm, 5 ppm and 2 ppm for all the samples. It can be noted that $O_2$ in 4 of the samples are above 4 ppm, and hence close to the limit.

The Hy-4 sample again exceeds the limits of total hydrocarbon (THC) significantly. When looking at Figure 15 where the different constituents of THC is plotted methane contributes to only 17 ppm, while each one of ethane (5.6 ppm, C1 basis), propane (8.7 ppm, C1 basis) and N-butane (15 ppm, C1 basis) alone would exceed the 2 ppm C1 basis limit. None of the other samples have THC levels above 2 ppm, even when including methane.

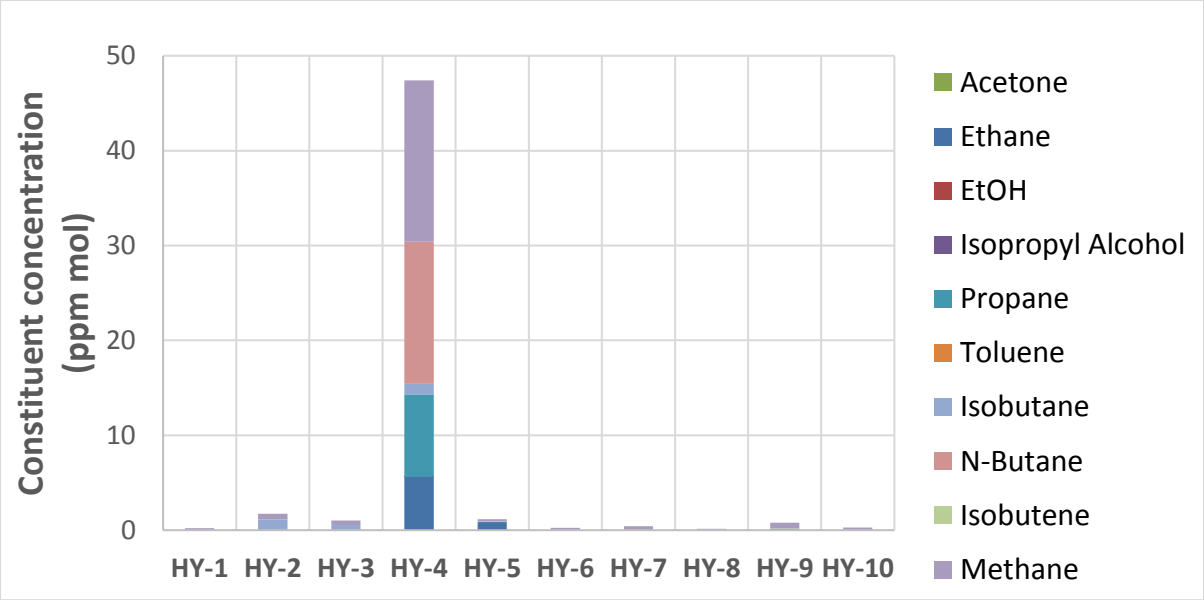


*Figure 15: Distribution of the different hydrocarbons constituting THC*

In SC2 all the samples contained measureable amounts of acetone, in this campaign, however, only one of the samples, HY-8, had any detectable amount of acetone, and it was estimated to be 0.0075 ppm.

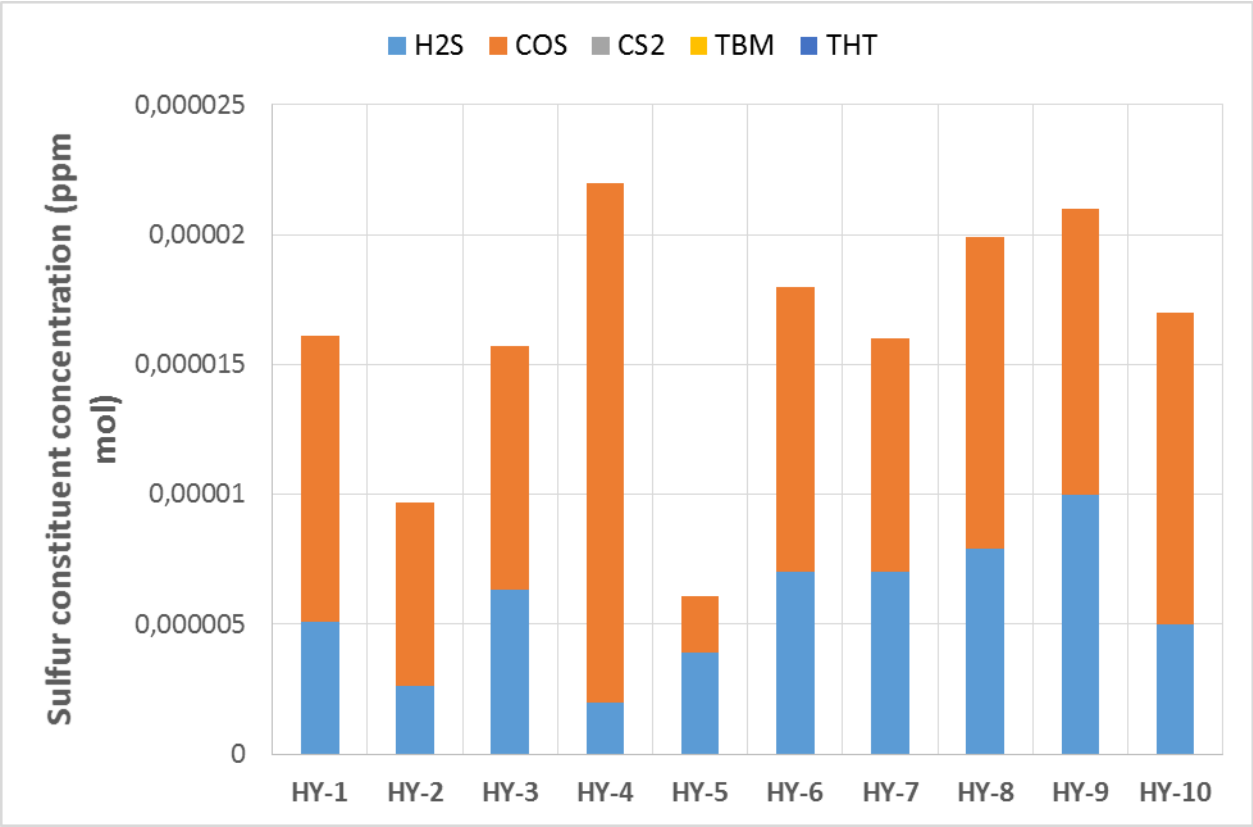


*Figure 16: Sulfur results, only $H_2S$ and COS were above the detection limits in these samples*

All the collected samples were well within the total sulfur limit of 0,004 ppm

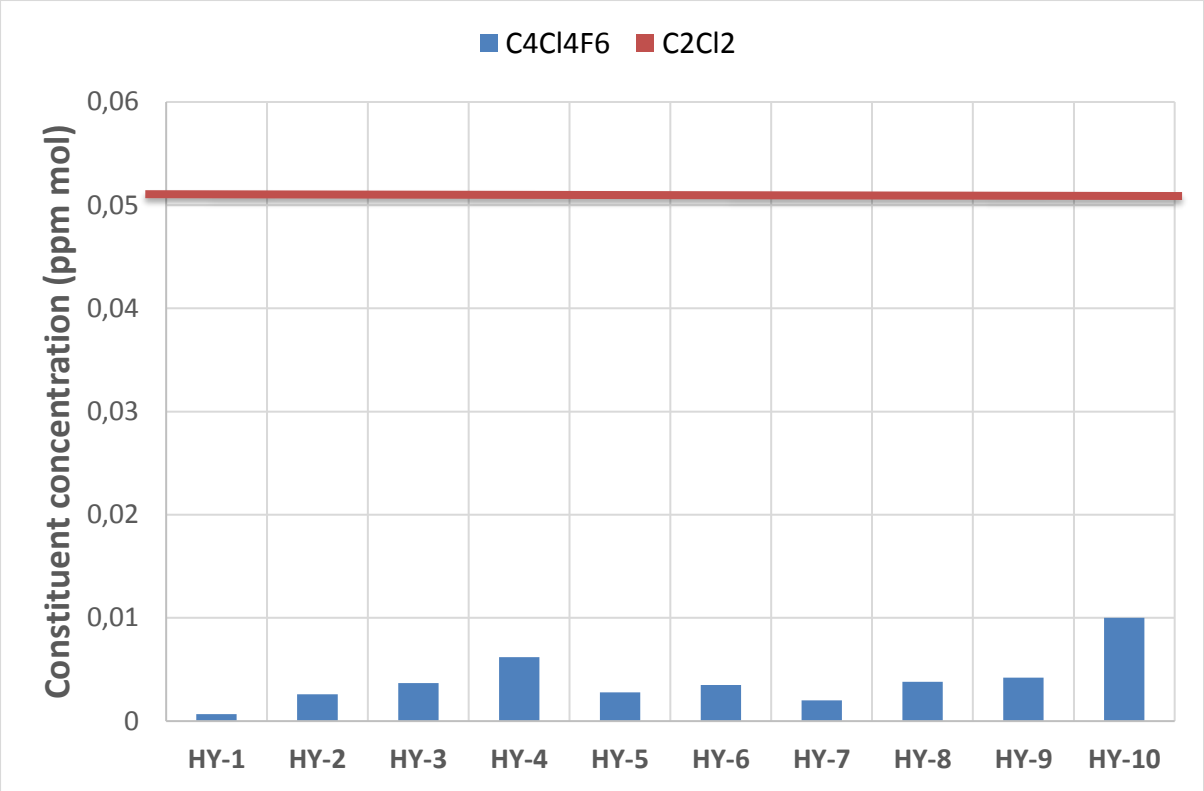


*Figure 17: Total halogenates analysis.*

All of the samples collected in SC3 had a total halogenate content of that were well below the required limit. Tetrachlorohexafluorobutane ($C_4Cl_4F_6$) was reported in all samples, and was the only halogenate compound reported in SC3. $C_4Cl_4F_6$ has been reported in most, but not all samples collected in SC1 and SC2 as well. In SC2 dichloromethane was found in one sample, none of the samples from SC3 were reported to contain dicholoromethane.

Gothenburg (HY-7 in SC3) was revisited because it had elevated impurity values when we visited the station in SC2. In the sample collected in SC3 all the values where well within the requirements, and the station does not seem to have any significant deviations in the impurity concentration.

Sample Hy-4 have significant quality deviations for both inert gases (N2) and hydrocarbon components. The significant deviations led us to investigate possible sources for contamination that could have been introduced into the bottle. The bottle used for the Hy-4 sample in SC3 was the same bottle that was previously used to contain the Hy-6 sample in SC2. In that sample, total hydrocarbons were 0.36 ppm. Between the sampling campaigns there was no other use of the bottle, and the SC2 sample was still on the bottle at a significant pressure (>10bar) until the bottle was evacuated and conditioned for SC3. We have therefore no reason to suspect any contamination from the bottle. The Hy-4 sample was collected the day after the first 3 samples, so the equipment had been recently used, and the high hydrocarbon content of the sample does not fit with air leaking into any of the check valves.

Historically Porsgrunn (HY-4 sampling location) has had high $N_2$ values, but such high hydrocarbon values have not been seen before.

**Conclusion**

The samples collected indicates a generally good quality of the available hydrogen, and stations such as Gothenburg which had some species above the limits in SC2 seems to have reduced the impurities. Porsgrunn, however, is still high in inerts, and is now above the limits for several hydrocarbons.

### 3.3.2 Analysis of particulate samples

The filters were the same kind of filters that were used in SC2: 0.2 μm. Due to a more efficient drying procedure the standard deviations on the filter weights were drastically reduced in SC3.

The lack of any detected particles could be caused by the placement of the particulate sampler downstream of the gas sampler. This is a topic that should be investigated further, and for now, gas and particulate samples should be taken independently.

Another challenge is that some of the Swedish stations does not have a metering device to record how much $H_2$ that is filled. The requirements for particulates is 1mg/kg$H_2$, which is impossible to determine without knowing how much $H_2$ that is filled.

The new drying procedure have improved the standard deviation significantly. Despite that all the filters had a weight decrease between 0.1 mg and 0.25 mg, which probably is a systematic deviation caused by drying, the presence of any particulate concentration close to the limit of 1mg/kg $H_2$ would have been detected easily. In addition, the uncertainty of weight determination is estimated by using 2x Std.Dev to be from 0,06 mg to 0,1 mg.

If we assume that a standard filling takes 3.5 kg $H_2$, then we get a systematic error of 0.03 to 0.07 mg / kg $H_2$ due to drying of the filters, and a standard deviation caused by weighting of less than 0,029 mg/kg $H_2$. This should have made it possible to see any significant weight gain of the filters, if particulates were captured.

*Table 5: Filter weights before and after sampling. All weights is the average of 3 independent weights recorded*

| | Mean before [mg] | Mean after [mg] | Difference [mg] | 2x Std Dev [mg] | kg $H_2$ filled | Weight gain per kg $H_2$ [mg] | 2xStd Dev / kg $H_2$ [mg] |
|---|---|---|---|---|---|---|---|
| HY-5 | 100,403 | 100,153 | -0,250 | 0,066 | 3,915 | -0,064 | 0,017 |
| HY-6 | 97,210 | 96,933 | -0,277 | 0,098 | 3,900 | -0,071 | 0,025 |
| HY-7 | 100,520 | 100,430 | -0,090 | 0,057 | NA | NA | |
| HY-8 | 100,687 | 100,540 | -0,147 | 0,10 | 3,266 | -0,045 | 0,031 |
| HY-9 | 99,963 | 99,893 | -0,070 | 0,10 | NA | | |
| Field Blank | 99,937 | 99,830 | -0,107 | 0,059 | NA | | |

# 4 Conclusions

From the 20 samples collected, seven had one or more impurity that had a higher concentration than allowed by the standard, all of these collected in the first sampling campaign. $O_2$ seems to be generally high, five of the samples had values exceeding the limit, and in addition, several more of the samples collected were close to the limit of 5 ppb.

Only one of the samples exceeded the total hydrocarbon content. All the samples where within the limits for sulphur and halogenates.

Three samples had too high amount of inert gases, mainly caused by high $N_2$ content.

The sampling setup seems to work fine for gas collection, all the gas samples were collected without any issues and the Linde Qualitizer worked flawlessly on all the different fuelling stations.

Simultaneous collection of gas and particulate samples lead to challenges, and should be validated further. If particulates are collected after the gas sampler, no particulates were found, while if the particulates are collected before the gas sampler, uncertainties around introduction of small levels of impurities still exists.