Metrology research for hydrogen standardisation: a cross-cutting approach

Training course

Hydrogen purity measurements according to ISO 14687-2 and risk assessment for fuel cells

Training course - 07 November 2018

Air Liquide R&D – Versailles - France

Hydrogen quality

Hydrogen

- Overview of hydrogen quality requirements
- Quality control plan
- Monitoring / Sampling

- Overview of hydrogen quality requirements – 5 min
- Quality control plan
  - Presentation – 15 min
  - Exercise – 20 min
  - Restitution – 10 min
- Monitoring / Sampling
  - Presentation – 10 min
  - Exercise – 10 min
- Summary / Discussion / Questions – 5 min

- Overview of hydrogen quality requirements
- Quality control plan
- Monitoring / Sampling

Hydrogen quality for fuel cell electrical vehicles

Hydrogen

Compliance

- Full scope according to standards ISO 14687; SAE J2719:2011; EN 17124
- Nozzle or agreed location

Quality control

- Defined scope according to ISO 19880-8
- Nozzle or agreed location

Analysis

- Fit for purpose of analytical methods
- Accuracy / uncertainty (ISO 21087)
- Delay / price

Existing normative documents for fuel cell vehicles

Hydrogen

Topic	Standard	Content
Hydrogen Fuel Quality for Fuel Cell Vehicles	SAE J2719:2011	List of contaminants
Quality characteristics of hydrogen fuel for transport applications	ISO 14687-2: 2012 → ISO/DIS 14687	List of contaminants Nozzle sample
Hydrogen fuel - Product specification and quality assurance	EN 17124:2018	List of contaminants Nozzle and other location Risk assessment “Level 1” value Routine analysis
Fuel quality control	ISO/DIS 19880-8	Nozzle and other location Risk assessment “Level 1” value Routine analysis
Gas analysis - Analytical methods for hydrogen fuel - Proton exchange membrane (PEM) fuel cell applications for road vehicles	ISO/DIS 21087	Analytical method fit for purpose Method validation Reporting

Technical challenges linked to ISO 14687

	ISO 14687: 2012 / SAE J2719:2011		ISO/CD 14687 / EN 17124	
	Max. admissible value [µmol/mol]	notes	Max. admissible value [µmol/mol]	notes
Water	5		5	
Total hydrocarbons (TC)	2	Due to CH_4, TC > 2 µmol/mol	2 except CH_4	including oxygenated organic species
Methane	-		100	
Oxygen	5		5	
Helium	300		300	
Nitrogen	100	N_2+Ar<100	300	
Argon	100	N_2+Ar<100	300	
carbon dioxide	2		2	
Carbon monoxide	0.2		0.2	CO+HCHO+HCOOH < 0.2µmol/mol
Total sulphur compounds	0.004	H_2S, COS, CS_2, mercaptans (NG)	0.004	H_2S, COS, CS_2, mercaptans (NG)
Formaldehyde	0.01		0.2	CO+HCHO+HCOOH < 0.2µmol/mol
Formic acid	0.2		0.2	CO+HCHO+HCOOH < 0.2µmol/mol
Ammonia	0.1		0.1	
Halogenated compounds	0.05 (total)	i.e. HBr, HCl Cl_2, organic R-X	0.05	HCl, organic R-Cl
Max. particulate conc.	1 mg/kg		1 mg/kg	

Technical challenges linked to ISO 14687

	ISO 14687: 2012 / SAE J2719:2011		ISO/CD 14687 / EN 17124	
	Max. admissible value [µmol/mol]	notes	Max. admissible value [µmol/mol]	notes
Water	5		5	
Total hydrocarbons (TC)	2	Due to CH_4, TC > 2 µmol/mol	2 **except CH_4**	including oxygenated organic species
Methane	-		**100**	
Oxygen	5		5	
Helium	300		300	
Nitrogen	100	N_2+Ar<100	**300**	
Argon	100	N_2+Ar<100	**300**	
carbon dioxide	2		2	
Carbon monoxide	0.2		0.2	**CO+HCHO+HCOOH < 0.2µmol/mol**
Total sulphur compounds	0.004	H_2S, COS, CS_2, mercaptans (NG)	0.004	H_2S, COS, CS_2, mercaptans (NG)
Formaldehyde	0.01		**0.2**	**CO+HCHO+HCOOH < 0.2µmol/mol**
Formic acid	0.2		0.2	**CO+HCHO+HCOOH < 0.2µmol/mol**
Ammonia	0.1		0.1	
Halogenated compounds	0.05 **(total)**	i.e. HBr, HCl Cl_2, organic R-X	0.05	**HCl, organic R-Cl**
Max. particulate conc.	1 mg/kg		1 mg/kg	

Technical challenges linked to ISO 14687

Hydrogen

	ISO 14687: 2012 / SAE J2719:2011		ISO/CD 14687 / EN 17124	
	Max. admissible value [µmol/mol]	notes	Max. admissible value [µmol/mol]	notes
Water	5		5	
Total hydrocarbons (TC)	2	Due to CH_4, TC > 2 µmol/mol	2 except CH_4	including oxygenated organic species
Methane	-		100	
Oxygen	5		5	
Helium	300		300	
Nitrogen	100	N_2+Ar<100	300	
Argon	100	N_2+Ar<100	300	
carbon dioxide	2		2	
Carbon monoxide	0.2		0.2	CO+HCHO+HCOOH < 0.2µmol/mol
Total sulphur compounds	0.004	H_2S, COS, CS_2, mercaptans (NG)	0.004	H_2S, COS, CS_2, mercaptans (NG)
Formaldehyde	0.01		0.2	CO+HCHO+HCOOH < 0.2µmol/mol
Formic acid	0.2		0.2	CO+HCHO+HCOOH < 0.2µmol/mol
Ammonia	0.1		0.1	
Halogenated compounds	0.05 (total)	i.e. HBr, HCl Cl_2, organic R-X	0.05	HCl, organic R-Cl
Max. particulate conc.	1 mg/kg		1 mg/kg	

Price: 2000 – 6000 € / sample
Delay: 2 – 8 weeks

- Overview of hydrogen quality requirements
- Quality control plan
- Monitoring / Sampling

Hydrogen quality

Compliance

- Full scope according to standards ISO 14687; SAE J2719:2011; EN17124
- Regulatory requirements (Frequency defined as part of ISO 19880-8)

Quality control

- prescriptive approach or Risk assessment
- Frequency and list of key contaminants

Analysis

- Price
- Accuracy
- Delay

Prescriptive approach methodology

Quality analysis of the contaminants listed in ISO 14687:

1 - Potential sources of contaminants
- o Sampling procedures
- o Characteristics of hydrogen production method(s)
- o Characteristics of hydrogen transport method(s)
- o Non-routine procedure (for example maintenance, major production system change)

2 - Analysis of possible contaminants
- o Possible quantification

→ Quality control defined

Prescriptive approach methodology

- **Production type**
- **Sampling point**
- **Frequency**
  - Reduced frequency
  - Online monitoring / operation control
  - Not satisfied → analysis once a day

Category: Distribution				
Facility type	Sampling/ Monitoring point	Contaminant	Threshold (µmol/mol)	Reduced frequency
Production of hydrogen from hydrocarbons utilizing steam reforming, catalytic reforming, partial oxidation, or ATR, purification using refining equipment, and distribution	Downstream of the purifier	TS[a]	0,004	Annual[b]
		THC as C1	2	Annual[b]
		CO	0,2	Annual[b]
		N_2+Ar	100	Annual[b,c]
		H_2O	5	Annual[b]
		O_2	5	Annual[b,c]
Electrolysis of Na Cl for hydrogen, purification, and distribution	Downstream of the purifier	Halogens	0,05	Annual[b]
		N_2+Ar	100	Annual[b]
		H_2O	5	Annual[b]
		O_2	5	Annual[b]
Purification of coke-oven gas, and distribution	Downstream of the purifier	TS	0,004	Annual[b]
		THC as C1	2	Annual[b]
		CO	0,2	Annual[b]
		Halogens	0,05	Annual[b]
		N_2+Ar	100	Annual[b]
		H_2O	5	Annual[b]
		O_2	5	Annual[b]
		NH_3	0,1	Annual[b]
		HCHO	0,01	Annual[b]
		HCOOH	0,2	Annual[b]
Purification of byproduct hydrogen from ethylene plants, and distribution	Downstream of the purifier	TS	0,004	Annual[b]
		THC as C1	2	Annual[b]
		CO	0,2	Annual[b]
		N_2+Ar	100	Annual[b]
		H_2O	5	Annual[b]
		O_2	5	Annual[b]

Hydrogen

Prescriptive approach methodology

- **Supply type**
- **Sampling point**
- **Frequency**
  - Reduced frequency
  - Online monitoring / operation control
  - Not satisfied → analysis once a day

Category: Fueling station				
Facility type	**Sampling/Monitoring point**	**Contaminant**	**Threshold (µmol/mol)**	**Reduced frequency**
With off-site supply of transported compressed or liquid hydrogen	End of nozzle	Those not analysed by the distributor		Annual[b]
		N_2+Ar	100	Annual[b, c]
		H_2O	5	Annual[b,d]
		O_2	5	Annual[b,e]
With off-site supply from hydrogen pipelines	Downstream of the deodorant equipment	(Those listed for the odorant)		Annual[b,e]
	End of nozzle	Those not analysed by the distributor		Annual[b]
		N_2+Ar	100	Annual[b,c]
		H_2O	5	Annual[b,d]
		O_2	5	Annual[b,e]
With on-site supply of hydrogen produced from hydrocarbons utilizing steam reforming, catalytic reforming, partial oxidation, or ATR and purification using refining equipment	Downstream of the purifier	CO	0,2	Continuous and Annual[b,f]
	End of nozzle	TS[a]	0,004	Annual[b]
		THC as C1	2	Annual[b]
		CO	0,2	Annual[b]
		N_2+Ar	100	Annual[b,c]
		H_2O	5	Annual[b,d]
		O_2	5	Annual[b,e]
With on-site supply from hydroelectrolysis and purification using refining equipment	Downstream of the purifier	N_2+Ar	100	Annual[b]
		H_2O	5	Continuous and Annual[b,f]
		O_2	5	Continuous and Annual[b,f]
	End of nozzle	Halogens	0,05	Annual[b]
		N_2+Ar	100	Annual[b]
		H_2O	5	Annual[b]
		O_2	5	Annual[b]

Quality control - risk assessment

Risk assessment methodology

1. Probability of contaminant existence

2. Impact of hydrogen contaminants on FC systems

Risk assessment of hydrogen contaminants

3. Implementation of barriers

Quality control plan

Quality control - risk assessment

Hydrogen

Severity class: impact on fuel cell electrical vehicles

Table 2: Definition of severity classes

SEVERITY CLASS	FCEV Performance impact or damage	Impact categories		
		Performance impact	hardware impact temporary	Hardware impact permanent
0	No impact	No	No	No
1	Minor impact temporary loss of power No impact on hardware Car still operates	Yes	No	No
2	Reversible damage Requires specific procedure, light maintenance. Car still operates.	Yes or No	Yes	No
3	Reversible damage Requires specific procedure and immediate maintenance. Gradual power loss that does not compromises	Yes	Yes	No
4	Irreversible damage Requires major repair (e.g. stack change). Power loss or Car Stop that compromises safety	Yes	Yes	Yes

Quality control - risk assessment

Severity class: impact on fuel cell electrical vehicles

Impurity		Severity Class for 0 ppm ≤ Concentration < ISO Value	ISO 14687-2 Threshold Value[2] [ppm]	Severity Class for ISO Value ≤ Concentration < Level 1 Value	Level 1 Value [ppm]	Severity Class for Level 1 Value ≤ Concentration ≤ 100%
Total non-H_2 gases		0	300	1	300	4
Total Nitrogen and Argon	N_2, Ar	0	100	1[3]	300[3]	4
Oxygen	O2	0	5	No test data available	No test data available	Without test data for proposed level 1 value validation already SC4 if ISO Spec exceeded
Carbon dioxide	CO_2	0	2	1	3	4
Carbon monoxide	CO	0-2	0,2	2-3[4]	1	4
Methane	CH_4	0	100	1	300	4
Water	H_2O	0	5	4	NA	Already SC4 if ISO Spec exceeded
Total sulfur compounds	H_2S basis	0-4	0.004	4	NA	Already SC4 if ISO Spec exceeded
Ammonia	NH_3	0	0.1	4	NA	Already SC4 if ISO Spec exceeded
Total hydrocarbons	CH_4 basis	0-4	2	1-4[4]	NA	Already SC4 if ISO Spec exceeded
Formaldehyde	CH_2O	0	0.01	2-3[4]	1	4
Formic Acid	CH_2O_2	0-2	0.2	2-3[4]	1	4
Total halogenated compounds		0-4	0.05	4	NA	Already SC4 if ISO Spec exceeded
Helium	He	0	300	1	300	4
Maximum particulates concentration (liquid and solid)		0-4	1 mg/kg	4	NA	Already SC4 if ISO Spec exceeded

Guideline from ISO 19880-8

Influence on the severity class is complex and long term

Probability of occurrence of contaminants

Occurrence class	Class name	Occurrence or frequency	Occurrence or frequency
0	Very unlikely (practically impossible)	Contaminant above threshold never been observed for this type of source in the industry	Never
1	Very rare	Heard in the industry for the type of source / supply chain considered	1 per 1000000 refueling
2	Rare	Has happened more than once per year in the industry	1 per 100000 refueling
3	Possible	Has happened repeatedly for this type of source at a specific location	1 per 10000 refueling
4	Frequent	Happens on a regular basis	Often

Risk acceptability matrix

		Severity				
		0	1	2	3	4
Occurrence as the combined probabilities of the occurrence along the whole supply chain	4					
	3					
	2					
	1					
	0					
Key	Unacceptable risk: additional barriers are required		Further investigation needed: existing barriers or control may not be enough		Acceptable risk area: Existing control acceptable	

Guideline from ISO 19880-8

System defined

Risk acceptability matrix

		Severity				
		0	1	2	3	4
Occurrence as the combined probabilities of the occurrence along the whole supply chain	4					
	3					
	2					
	1					
	0					
Key	Unacceptable risk: additional barriers are required	Further investigation needed: existing barriers or control may not be enough		Acceptable risk area: Existing control acceptable		

Add barrier / Control

Each HRS will have different controls or barriers:

- Online sensors (i.e. hygrometers, CO sensor)
- Purification system
- Procedure (i.e. purging procedure after maintenance)
- Trained staff
- ....

Each HRS will have a different risk assessment

Hydrogen fuel quality and risk assessment

1. Probability of contaminant existence

To be done for each HRS

2. Impact of hydrogen contaminants on FC systems

Risk assessment of hydrogen contaminants

3. Implementation of barriers

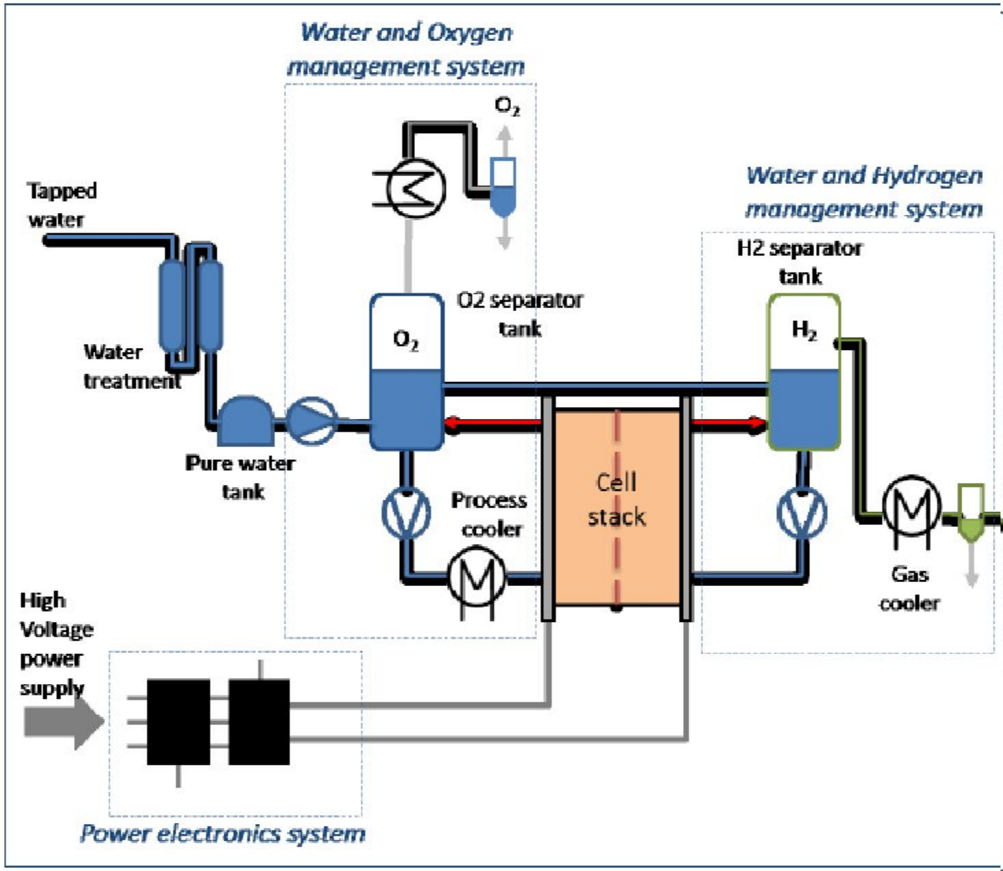
Reduce the probability of contaminant existence at the HRS

Quality control plan for HRS

- Probability of contaminants presence on PEM water electrolyser
- Implementation of barriers
- Monitoring

Example / Exercise
PEM Water electrolyser

Compounds	ISO 14687-2 threshold [µmol/mol]	PEM water electrolysis (analysis) Results [µmol/mol]	Probability of occurrence [0-4]
Water H_2O	5	> 100	
Methane CH_4	2	< 0.02 – 0.1	
Non CH_4 hydrocarbons	2	< 0.02 – 0 .09	
Oxygen O_2	5	18- > 500	
Helium He	300	< 9	
Nitrogen N_2	100	1.2 – 4.5	
Argon Ar	100	< 0.5	
Carbon dioxide CO_2	2	0.2 – 5.4	
Carbon monoxide CO	0.2	< 0.02	
Total sulphur compounds	0.004	< 0.0036	
Formaldehyde HCHO	0.01	< 0.005	
Formic acid HCOOH	0.2	< 0.1	
Ammonia NH_3	0.1	< 0.1	
Total halogenated	0.05	< 0.005	

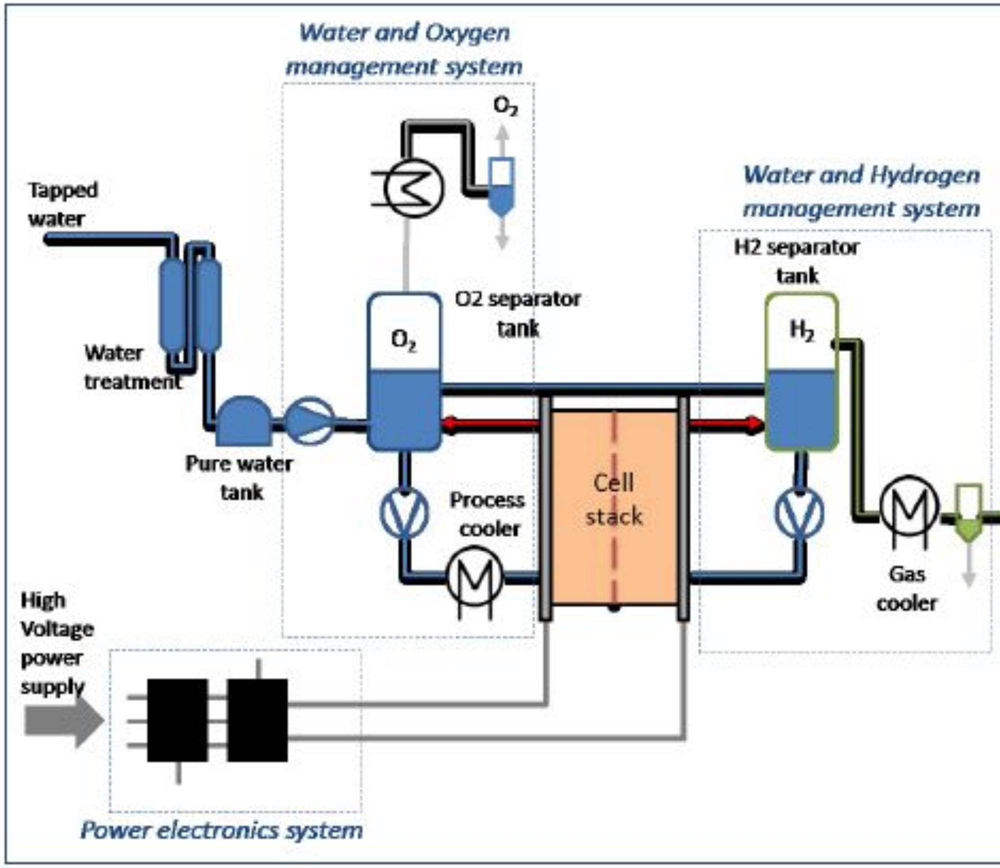


Question 1: What is the probability of contaminants presence on PEM water electrolyser (reply directly in the table)?

Example / Exercise
PEM Water electrolyser

Hydrogen

Compounds	ISO 14687-2 threshold [µmol/mol]	PEM water electrolysis (analysis) Results [µmol/mol]	Probability of occurrence [0-4]
Water H_2O	5	> 100	
Methane CH_4	2	< 0.02 – 0.1	
Non CH_4 hydrocarbons	2	< 0.02 – 0 .09	
Oxygen O_2	5	18- > 500	
Helium He	300	< 9	
Nitrogen N_2	100	1.2 – 4.5	
Argon Ar	100	< 0.5	
Carbon dioxide CO_2	2	0.2 – 5.4	
Carbon monoxide CO	0.2	< 0.02	
Total sulphur compounds	0.004	< 0.0036	
Formaldehyde HCHO	0.01	< 0.005	
Formic acid HCOOH	0.2	< 0.1	
Ammonia NH_3	0.1	< 0.1	
Total halogenated	0.05	< 0.005	

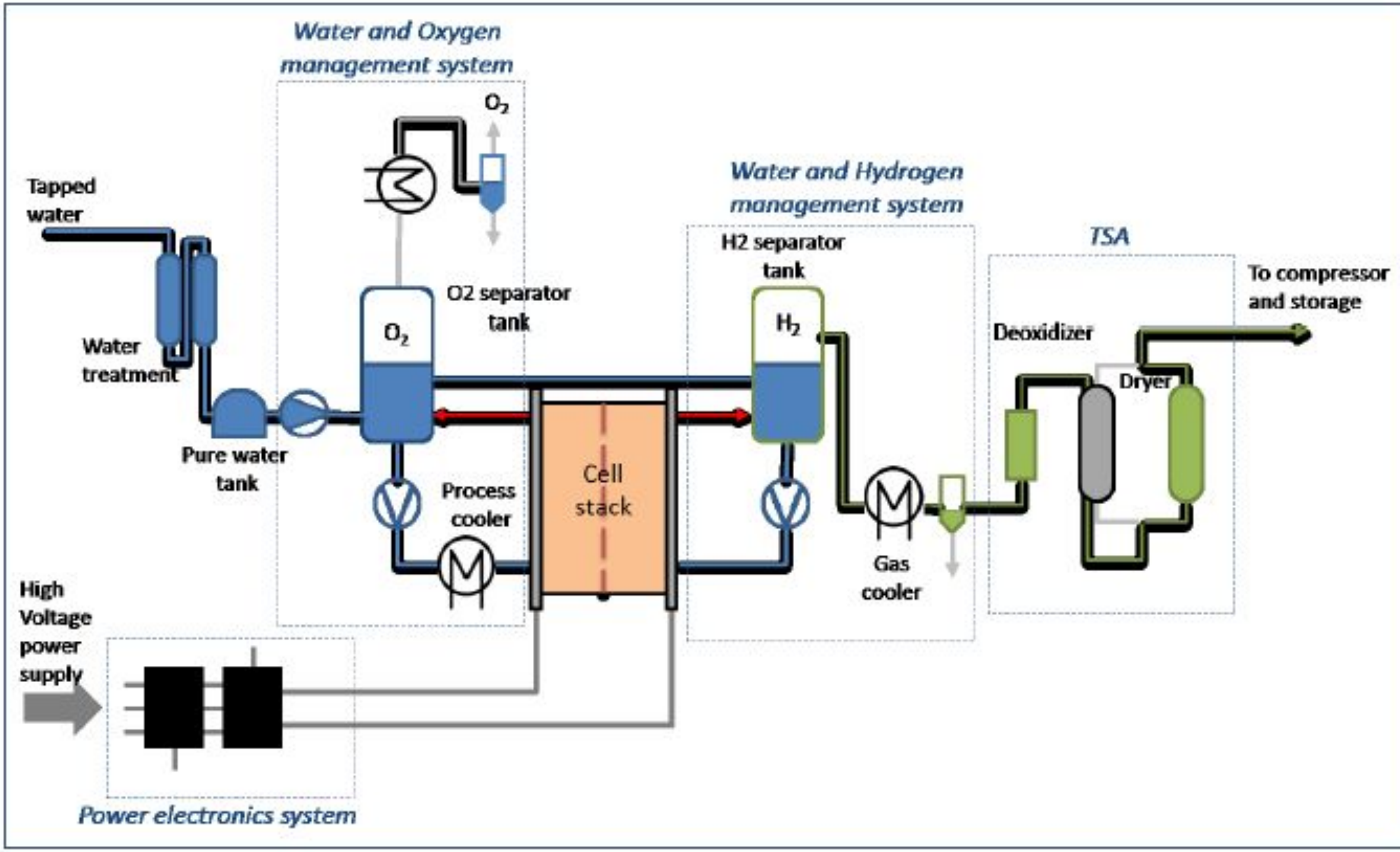


Question 2: What controls and barriers can be implemented based on your probability of occurrence?

Example / Exercise
PEM Water electrolyser

Compounds	ISO 14687-2 threshold [µmol/mol]	PEM water electrolysis (analysis) Results [µmol/mol]	Probability of occurrence [0-4]	Controls and barriers	Probability of occurrence after control and barrier [0-4]
Water H_2O	5	> 100			
Methane CH_4	2	< 0.02 – 0.1			
Non CH_4 hydrocarbons	2	< 0.02 – 0 .09			
Oxygen O_2	5	18- > 500			
Helium He	300	< 9			
Nitrogen N_2	100	1.2 – 4.5			
Argon Ar	100	< 0.5			
Carbon dioxide CO_2	2	0.2 – 5.4			
Carbon monoxide CO	0.2	< 0.02			
Total sulphur compounds	0.004	< 0.0036			
Formaldehyde HCHO	0.01	< 0.005			
Formic acid HCOOH	0.2	< 0.1			
Ammonia NH_3	0.1	< 0.1			
Total halogenated	0.05	< 0.005			

Example / Exercise
PEM Water electrolyser



Question 3: What controls and barriers would you add on this system?

Reply directly on the schematic

Question 4: What differences do you observe between your probability of occurrence and this results?

Probability of impurity presence	PEM water electrolysis process with TSA
Frequent	None identified
Possible	None identified
Rare	N_2, O_2, H_2O
Very Rare	CO_2
Unlikely	He, Ar, CO, CH_4, HCHO, HCOOH, NH_3, sulfur compounds, hydrocarbons (except CH_4), halogenated compounds

Differences:

Explanations:

Example / Exercise
PEM Water electrolyser

Discussion / Feedback from groups

Hydrogen quality

Hydrogen

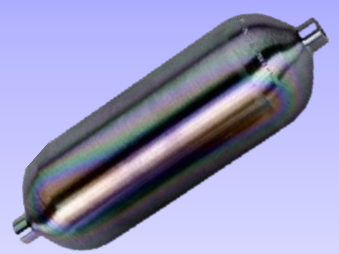
- Overview of hydrogen quality requirements
- Quality control plan
- Monitoring / Sampling

Monitoring / Sampling

Hydrogen quality monitoring

- **Online analysers / Sensors**
  - Pressure
  - Flow
  - Location
  - Maintenance
  - Calibration

- **Sampling**
  - Pressure
  - Flow
  - Location
  - Sampling material
  - Sampling procedure



Hydrogen quality monitoring

- **Online analysers / Sensors**
  - Pressure
  - Flow
  - Location
  - Maintenance
  - Calibration

Humidity
O_2
CO
CH_4
CO_2

- **Sampling**
  - Pressure
  - Flow
  - Location
  - Sampling material
  - Sampling procedure

Hydrogen quality monitoring

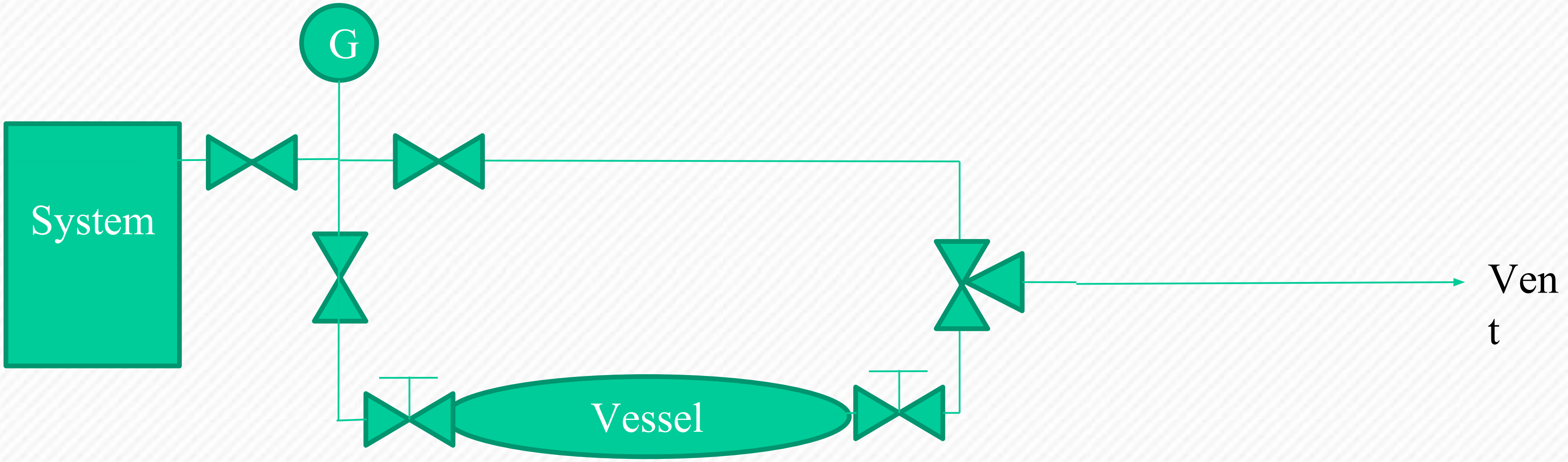
- **Online analysers / Sensors**
  - Pressure
  - Flow
  - Location
  - Maintenance
  - Calibration

Humidity
O_2
CO
CH_4
CO_2

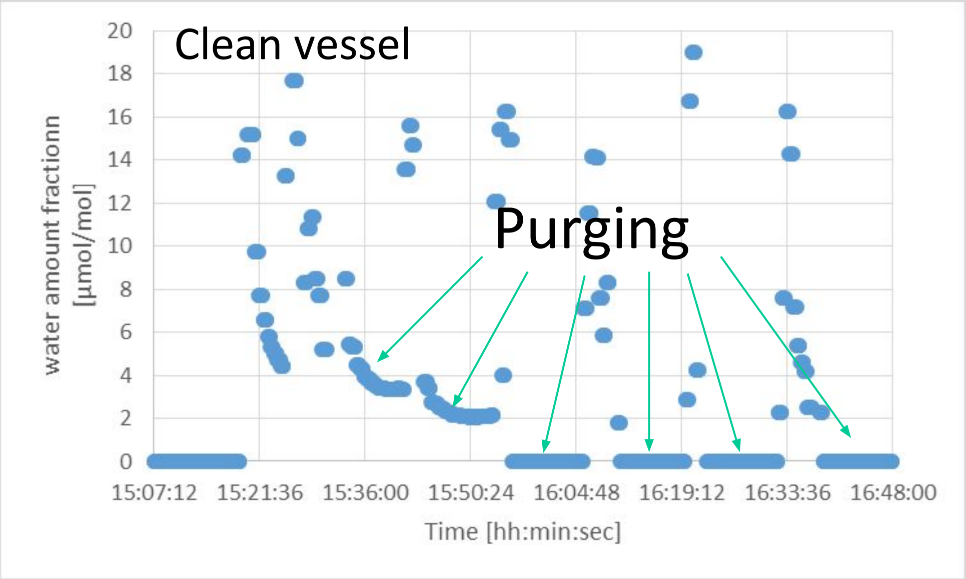
- **Sampling**
  - Pressure
  - Flow
  - Location
  - Sampling material
  - Sampling procedure

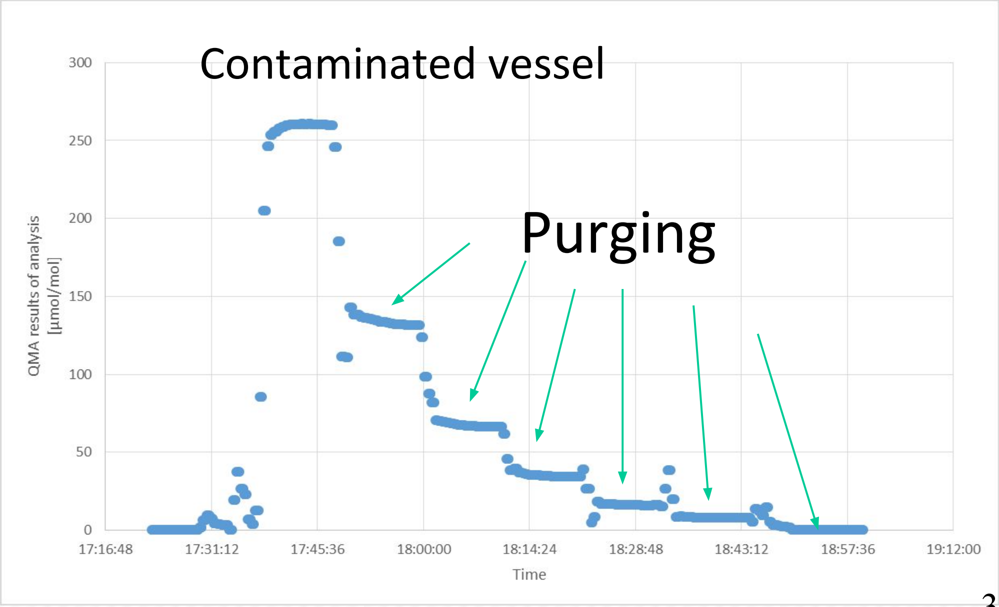
→ **Eliminating contamination**

Monitoring / Sampling



Monitoring / Sampling
Humidity – water vapour





- Cycling purge
- Purge through cylinder
- Cleanliness of cylinder
- Absence of leak

Monitoring / Sampling

Hydrogen

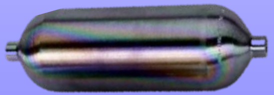
Hydrogen quality monitoring

- **Online analysers / Sensors**
  - Pressure
  - Flow
  - Location
  - Maintenance
  - Calibration

Humidity
O_2
CO
CH_4
CO_2

- **Sampling**
  - Pressure
  - Flow
  - Location
  - Sampling material
  - Sampling procedure

- Material of sampling system (passivated)
- Leak check
- Purge
- Procedure
- Trained staff
- Cylinder (transportable, passivated)



Example of issues with analytical results

		Results with expanded uncertainty (k=2)	Results with expanded uncertainty (k=2)	Results with expanded uncertainty (k=2)	Results with expanded uncertainty (k=2)
CO	µmol/mol	< 0.02	< 0.02	< 0.053	< 0.053
CO_2	µmol/mol	4.2 ± 0.3	< 0.01	0.101 ± 0.004	0.443 ± 0.010
CH_4	µmol/mol	< 0.02	< 0.01	< 0.02	0.031 ± 0.006
Non methane hydrocarbons	µmol/mol	0.08 ± 0.01	0.111 ± 0.024	< 0.05	< 0.05
H_2O	µmol/mol	> 500	> 250	2.48 ± 0.25	< 0.6
Total sulphur compounds	µmol/mol	< 0.002	< 0.0030	< 0.002	< 0.002
O_2	µmol/mol	> 520	1.59 ± 0.45	35 ± 2	0.45 ± 0.13
N_2	µmol/mol	3.7 ± 0.8	1.86 ± 0.2	134 ± 2	2.0 ± 0.5
Ar	µmol/mol	< 0.5	< 0.5	1.43 ± 0.10	< 0.5
Total halogenated (HCl)	µmol/mol	< 0.005	< 0.005	< 0.005	< 0.005
CH2O	µmol/mol	< 0.005	< 0.005	< 0.005	< 0.005
CH2O2	µmol/mol	< 0.1	< 0.1	< 0.1	< 0.1
NH3	µmol/mol	< 0.1	n.a.	< 0.1	< 0.1
He	µmol/mol	< 5	< 9	< 5	<5

Question 1: What potential issues do you find in these analysis? Highlight the results of analysis that are suspicious

Question 2: Is there results of analysis that were contaminated by the sampling process?

Example of issues with analytical results

		ISO 14687-2 threshold	Results with expanded uncertainty (k=2)	Results with expanded uncertainty (k=2)	Results with expanded uncertainty (k=2)	Results with expanded uncertainty (k=2)
CO	µmol/mol	0.2	< 0.02	< 0.02	< 0.053	< 0.053
CO_2	µmol/mol	2	4.2 ± 0.3	< 0.01	0.101 ± 0.004	0.443 ± 0.010
CH_4	µmol/mol	2	< 0.02	< 0.01	< 0.02	0.031 ± 0.006
Non methane hydrocarbons	µmol/mol	2	0.08 ± 0.01	0.111 ± 0.024	< 0.05	< 0.05
H_2O	µmol/mol	5	> 500	> 250	2.48 ± 0.25	< 0.6
Total sulphur compounds	µmol/mol	0.004	< 0.002	< 0.0030	< 0.002	< 0.002
O_2	µmol/mol	5	> 520	1.59 ± 0.45	35 ± 2	0.45 ± 0.13
N_2	µmol/mol	100	3.7 ± 0.8	1.86 ± 0.2	134 ± 2	2.0 ± 0.5
Ar	µmol/mol	100	< 0.5	< 0.5	1.43 ± 0.10	< 0.5
Total halogenated (HCl)	µmol/mol	0.05	< 0.005	< 0.005	< 0.005	< 0.005
CH2O	µmol/mol	0.01	< 0.005	< 0.005	< 0.005	< 0.005
CH2O2	µmol/mol	0.2	< 0.1	< 0.1	< 0.1	< 0.1
NH3	µmol/mol	0.1	< 0.1	n.a.	< 0.1	< 0.1
He	µmol/mol	300	< 5	< 9	< 5	<5
Reply question 2			Normal results or contaminated during sampling	Normal results or contaminated during sampling	Normal results or contaminated during sampling	Normal results or contaminated during sampling
Reasons						

Hydrogen monitoring

- Sampling
  - Pressure
  - Flow
  - Location
  - Sampling material
  - Sampling procedure

→

- Material of sampling system (passivated)
- Leak check
- Purge
- Procedure
- Trained staff
- Cylinder (transportable, passivated)

→

Typical issues:

- Air (ratio N_2 / O_2 / Ar)
- Humidity (high content)

→

- Leak check
- Purge
- Procedure
- Trained staff

Hydrogen quality
Summary / Questions / Discussions

- **Overview of hydrogen quality requirements**
  - ISO 14687 Hydrogen quality
  - ISO 19880-8 Hydrogen quality control

- **Quality control plan**
  - Prescriptive
  - Risk assessment → for each HRS
    - Severity (fixed)
    - Probability of contaminant presence
      - Depend on system and barriers

- **Monitoring / Sampling**
  - Online
  - Sampling
    - Sampling system (passivated); cylinder (transportable, passivated)
    - Leak check
    - Purge
    - Procedure and trained staff

Hydrogen

Follow us at https://projects.lne.eu/jrp-hydrogen/

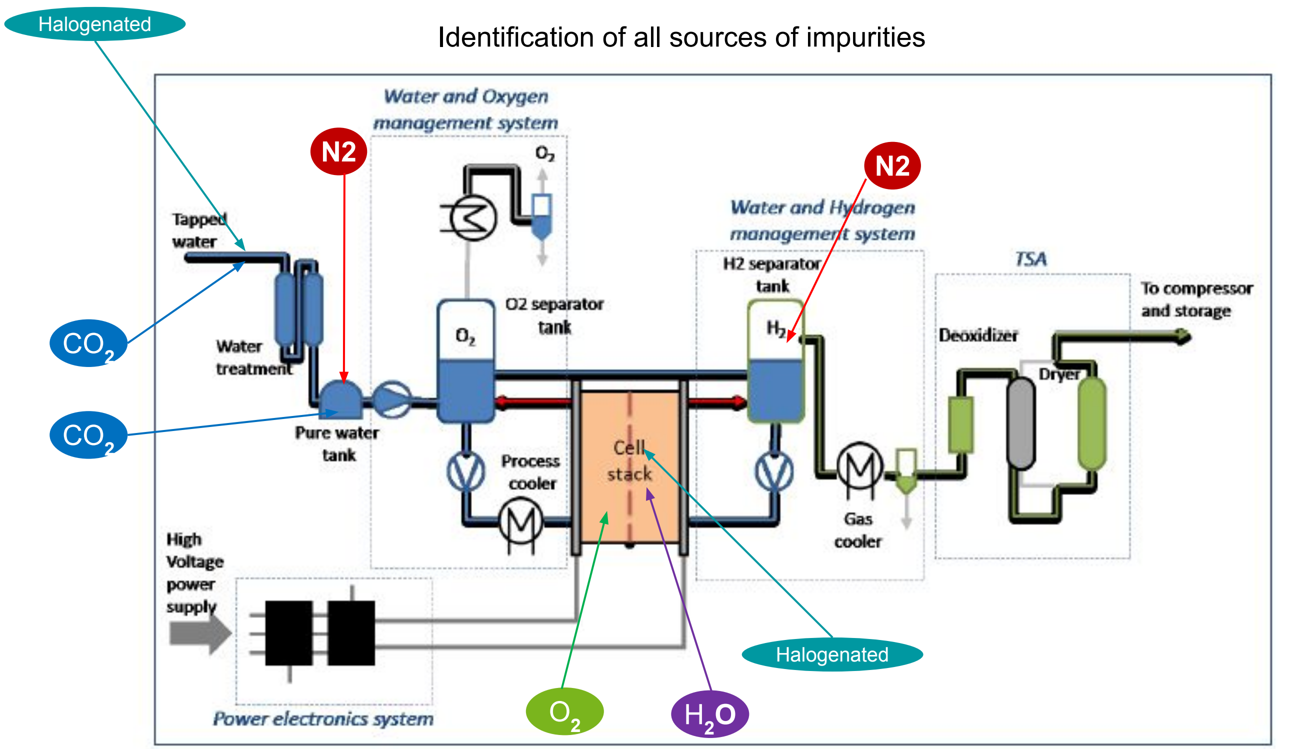
frederique.haloua@lne.fr

EMPIR EURAMET

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

2 – PEM Electrolysis + TSA

Identification of all sources of impurities



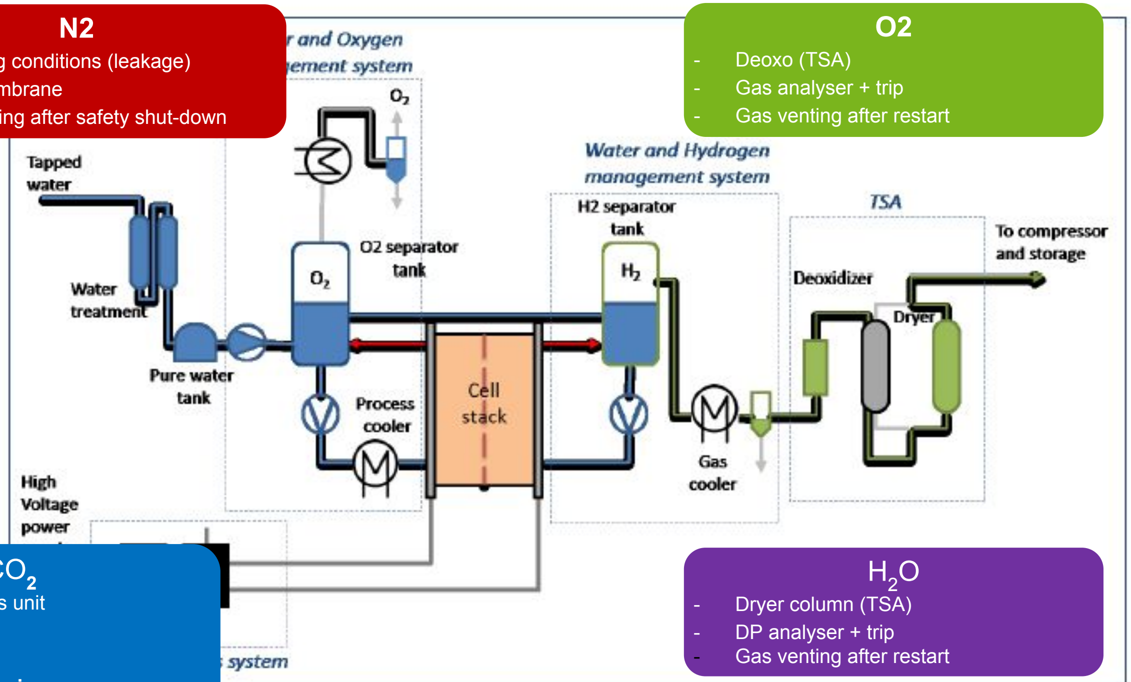
Design of AH2GEN's PEM Water Electrolyser process with TSA

2 – PEM Electrolysis + TSA

Identification of all existing barriers

N2
- Operating conditions (leakage)
- PEM membrane
- Gas venting after safety shut-down

O2
- Deoxo (TSA)
- Gas analyser + trip
- Gas venting after restart



Design of AH2GEN's PEM Water Electrolyser process with TSA

CO_2
- Reverse osmosis unit
- CO2 filter
- PEM membrane
- **Ion exchange resin**

H_2O
- Dryer column (TSA)
- DP analyser + trip
- Gas venting after restart