Hydrogen Measurement WGMSC 2026

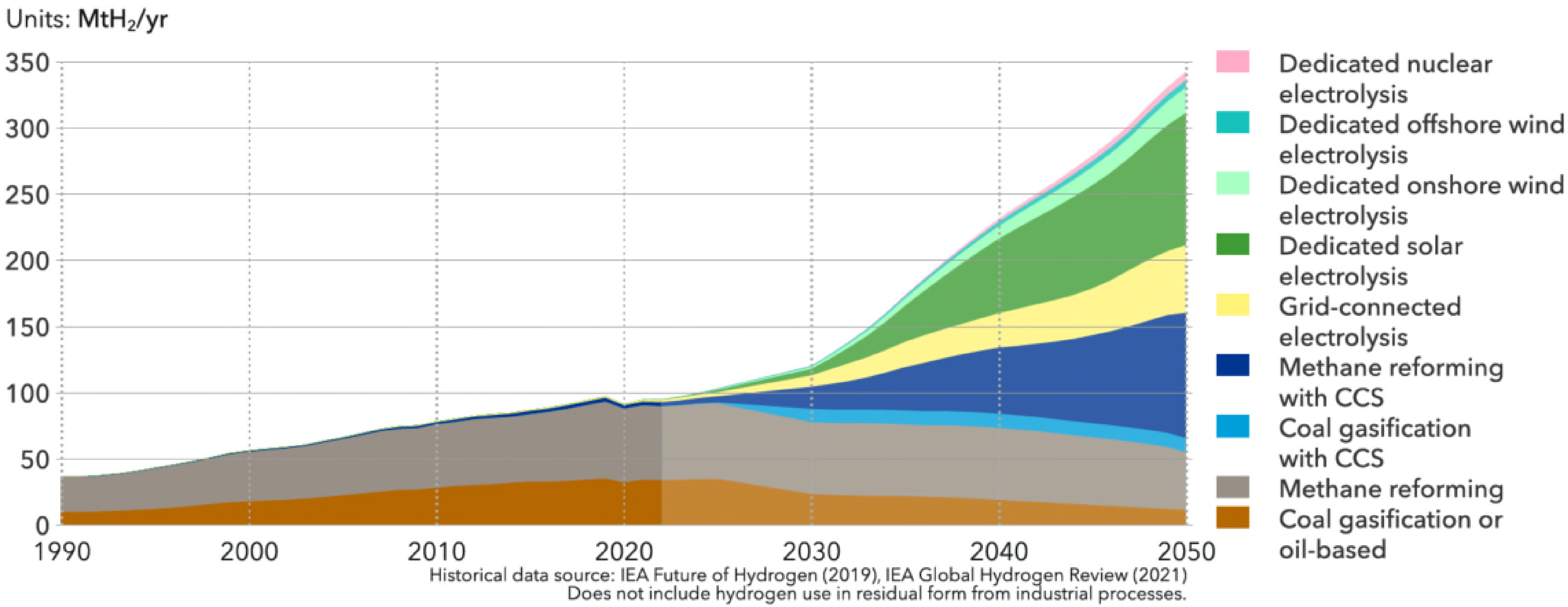
Sam Miller

Colors of Hydrogen

Green	Water electrolysis process by employing renewable electricity from wind / solar
Blue	Steam Methane Reforming or Auto Thermal Reforming of natural gas. CO2 is captured and used or stored sequestered (CCUS)
Turquoise	Thermal splitting of methane via methane pyrolysis Experimental process that produces solid carbon
Gray	Steam Methane Reforming of natural gas. CO2 is produced and eventually released to the atmosphere
Brown/Black	Coal gasification (lignite – Brown, Bitumious – Black). CO2 and carbon monoxide are produced as by-products and released to the atmosphere.
Purple	Nuclear power and heat through combined chemical/thermal electrolysis splitting of water.
Pink	Electrolysis of water by using electricity from a nuclear power plant.
Red	High-temperature catalytic splitting of water using nuclear power
White	Naturally occurring hydrogen.

Hydrogen production

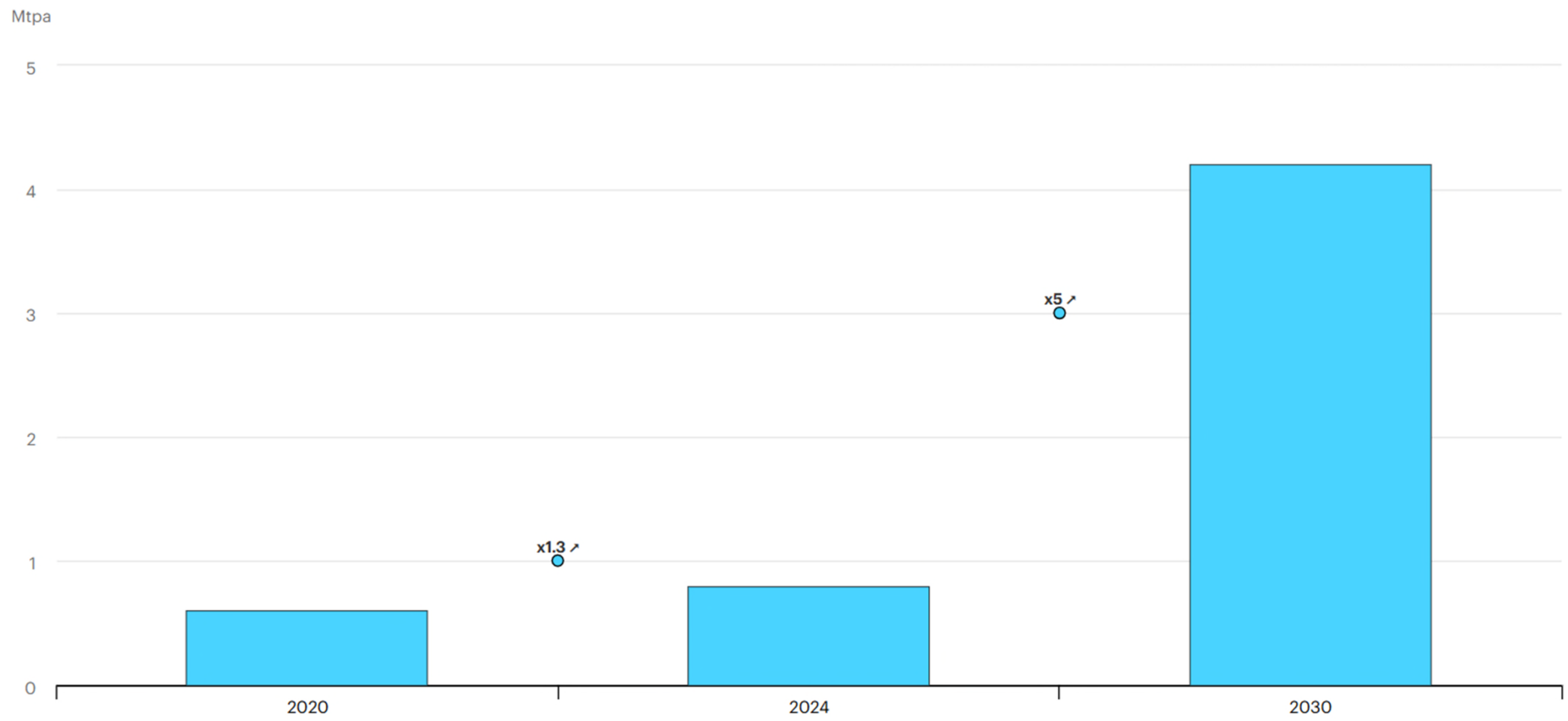
World hydrogen production methods



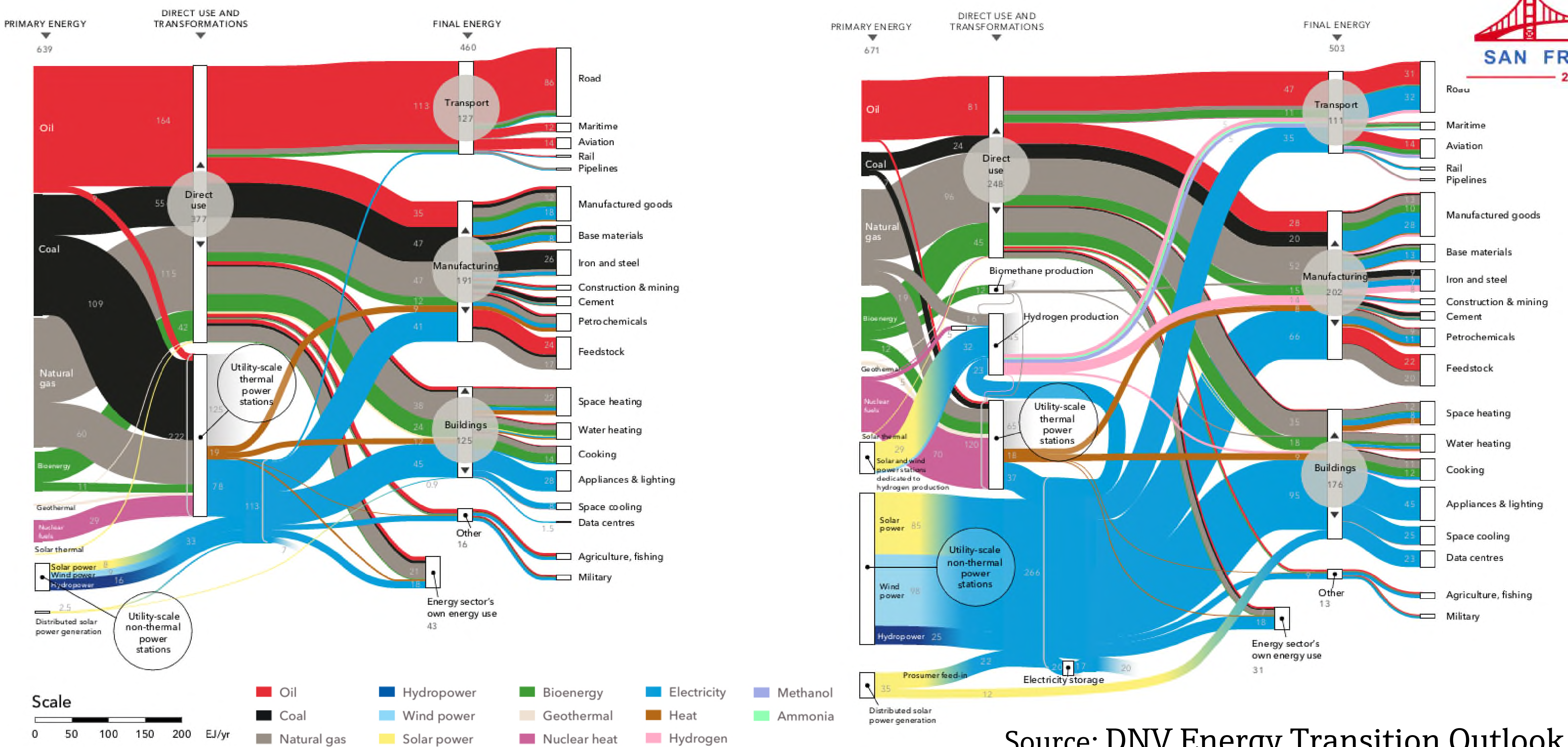
Source: DNV Energy Transition Outlook 2023

World demand for hydrogen and its derivatives as an energy carrier

Source: Hydrogen - IEA

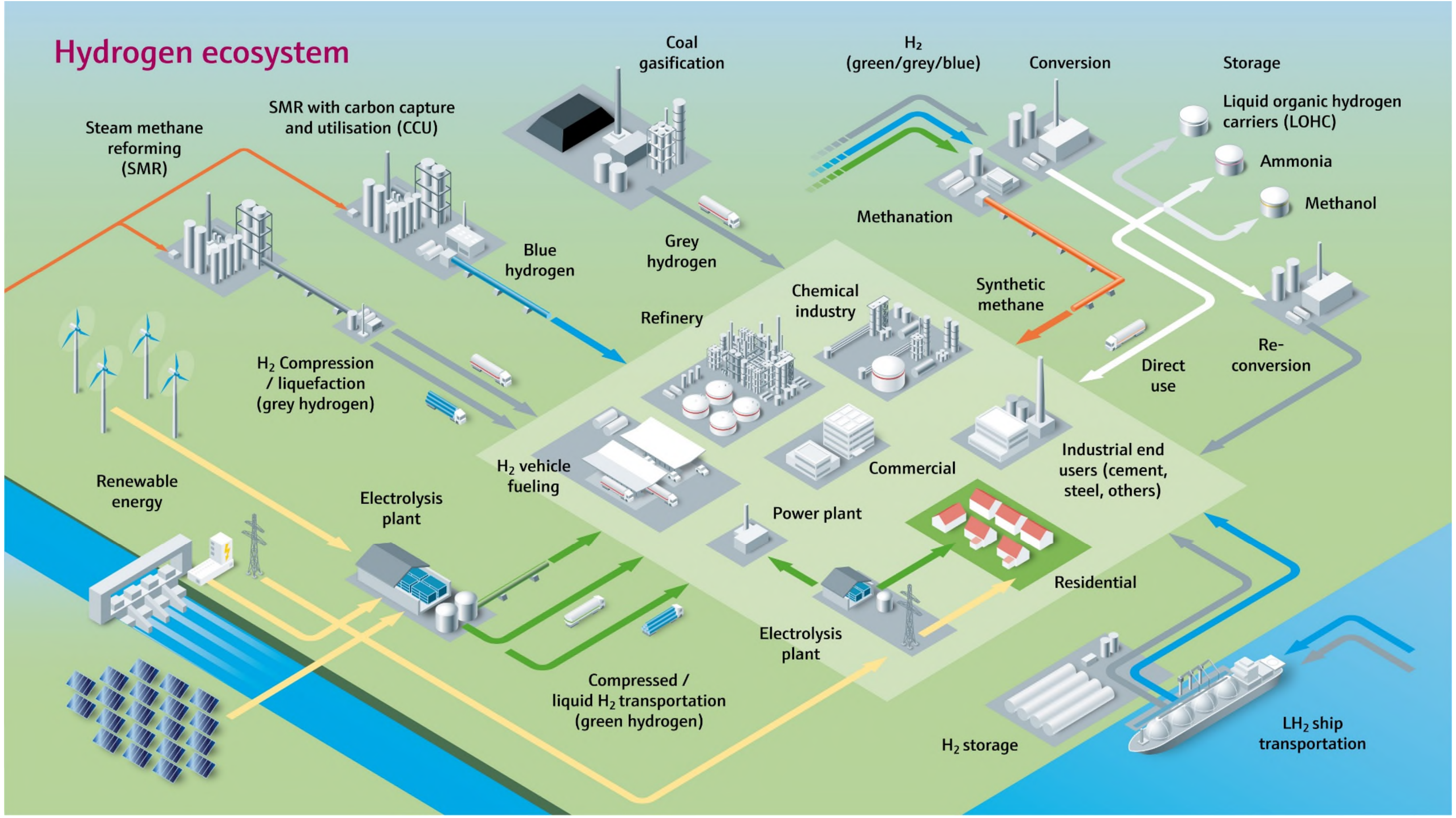


Comparison of world energy flows 2024 (left) v. 2060 (right)



Source: DNV Energy Transition Outlook 2025

Hydrogen Ecosystem

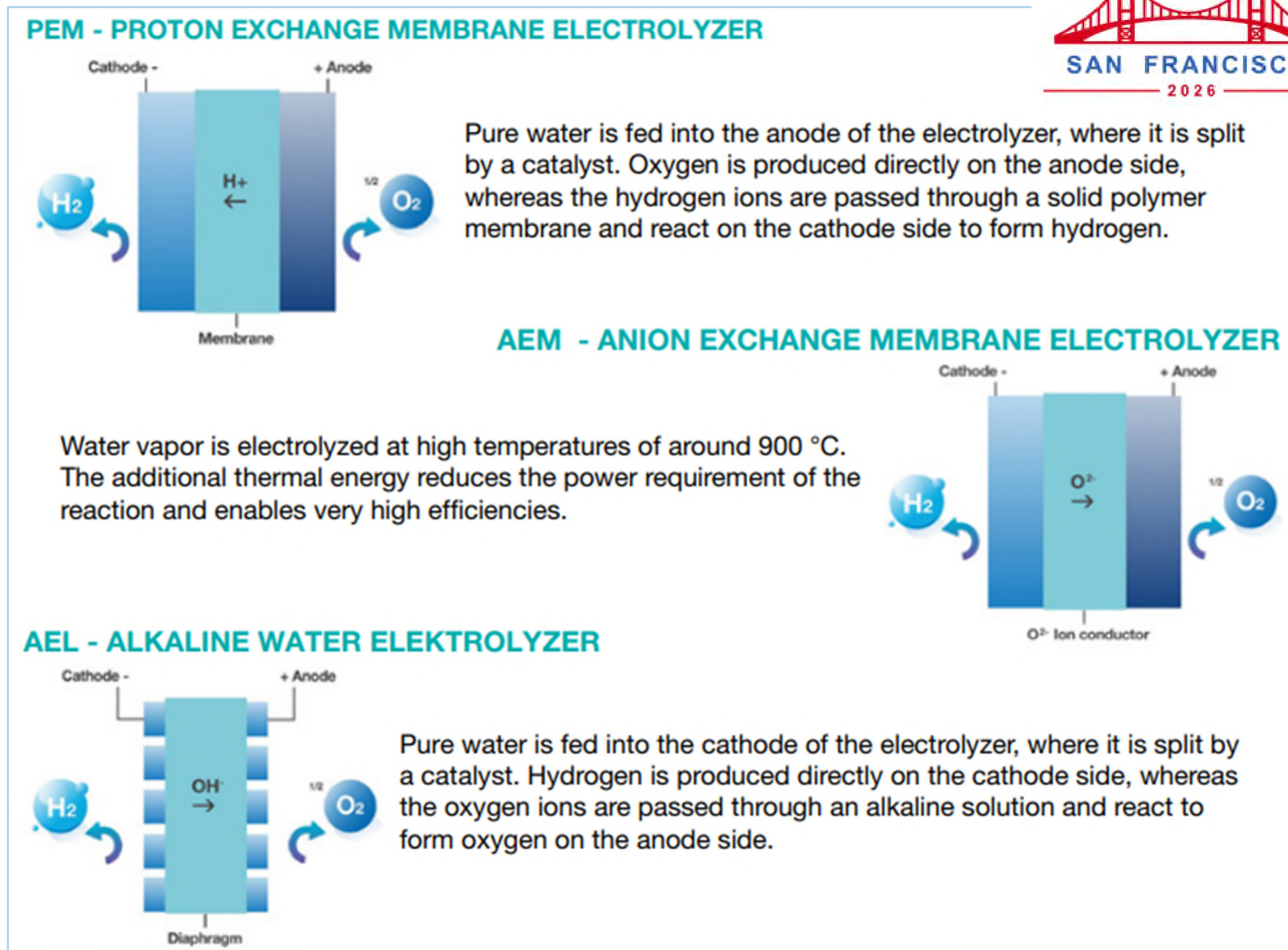


Hydrogen Electrolysis - Applications

Green hydrogen: Electrolyzer design

What to know about electrolyzers?

- 3 main technologies
- Alkaline and PEM technology dominate
- **Alkaline** (est 70 to 90% of market):
  - Older technology
  - Low cost
  - Lower purity H_2
- **PEM**:
  - Very rapid adoption (especially in Europe)
  - Costly (catalyst uses platinum)
  - Very high purity H_2
- AEM:
  - Still mostly in development



https://www.horiba-fuelcon.com/

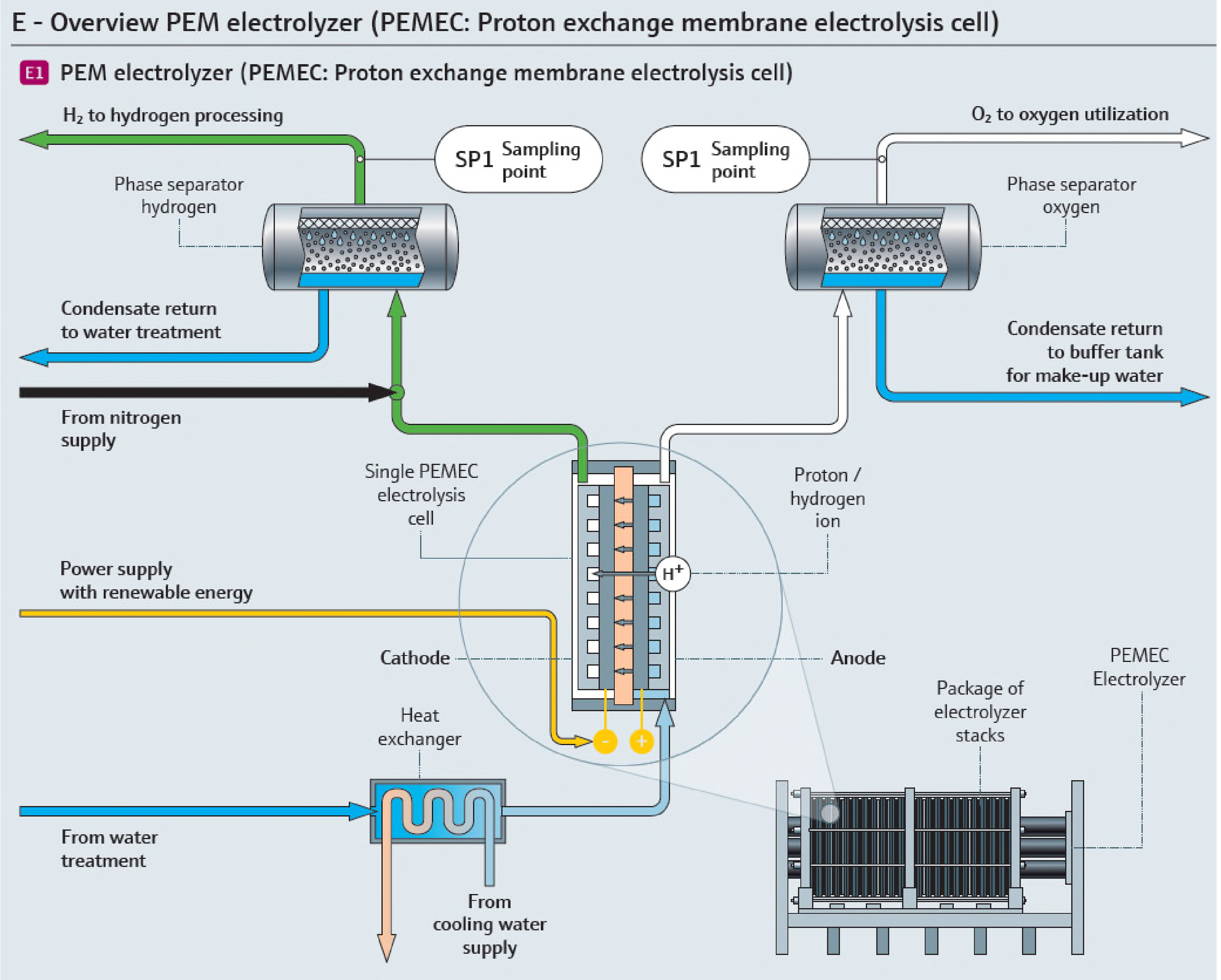
Impurities in green hydrogen

At the electrolyzer

- Purified H_2O feedstock
- Power from renewable energy
- Ion exchange membrane allows H_2 pass but blocks O_2
- Resulting "wet" gases pass out of electrolyzer for additional treatment

SP1 gas analysis

- H_2 is saturated with moisture
- O_2 in H_2 to look for membrane breakthrough



WGMSC western gas measurement short course SAN FRANCISCO 2026

Impurities in green hydrogen

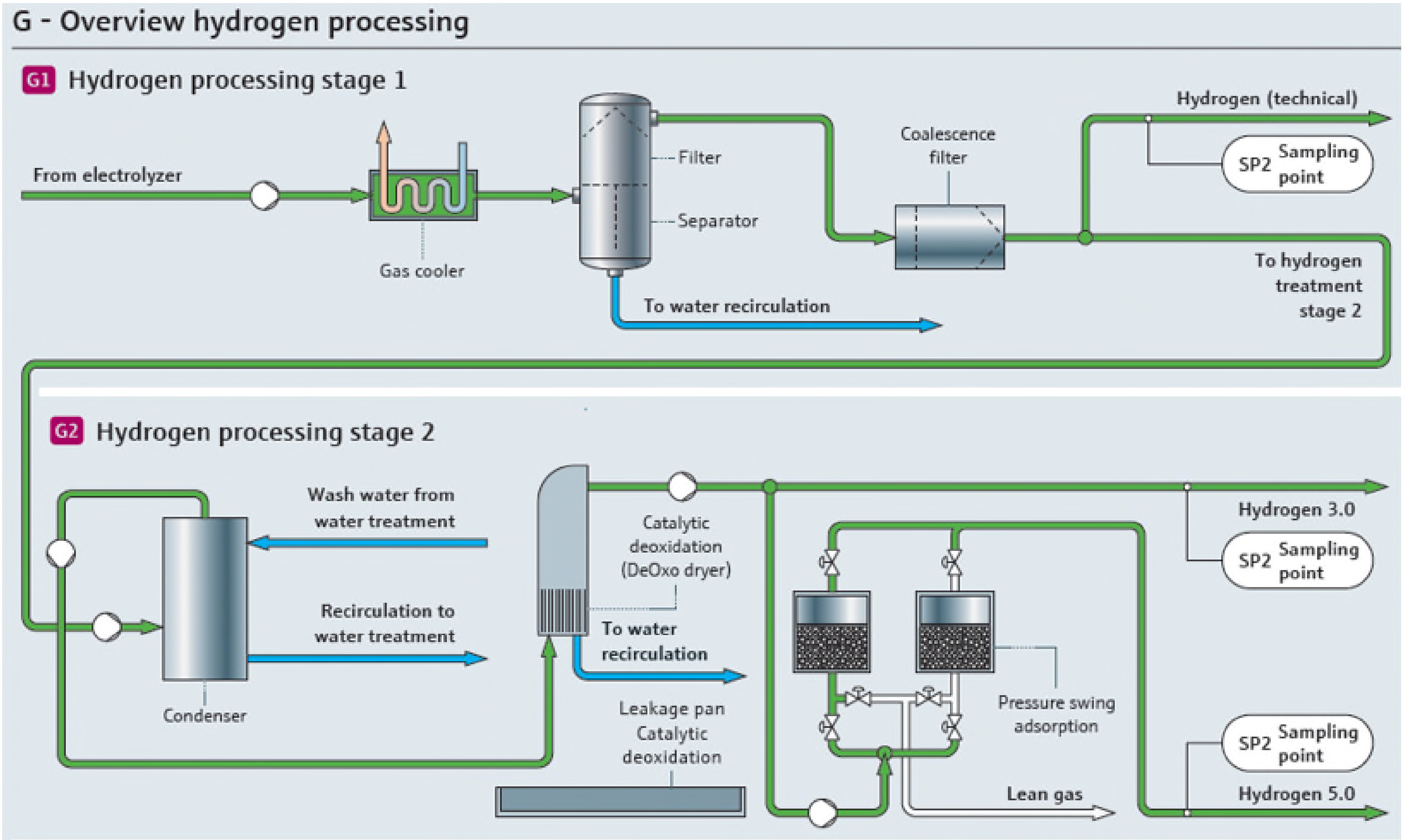
Purification stages

- Aerosol H_2O removal through coalescing filter
- Condenser uses temperature for added H_2O removal
- Catalytic deoxidization removes O_2
- Pressure Swing Adsorption traps residual H_2O and N_2

SP2 gas analysis

- Hydrogen 3.0 = 0-1000 ppmv H_2O
- Hydrogen 5.0 = 0-10 ppmv H_2O

Grade	Purity (%)	Common Applications
3.0	99.9%	General industrial use, welding
4.0	99.99%	Chemical synthesis, metallurgy
5.0	99.999%	Fuel cells, electronics, laboratory use
6.0	99.9999%	Semiconductor manufacturing
7.0	99.99999%	Specialty applications w/ extreme purity



Impurities in green hydrogen

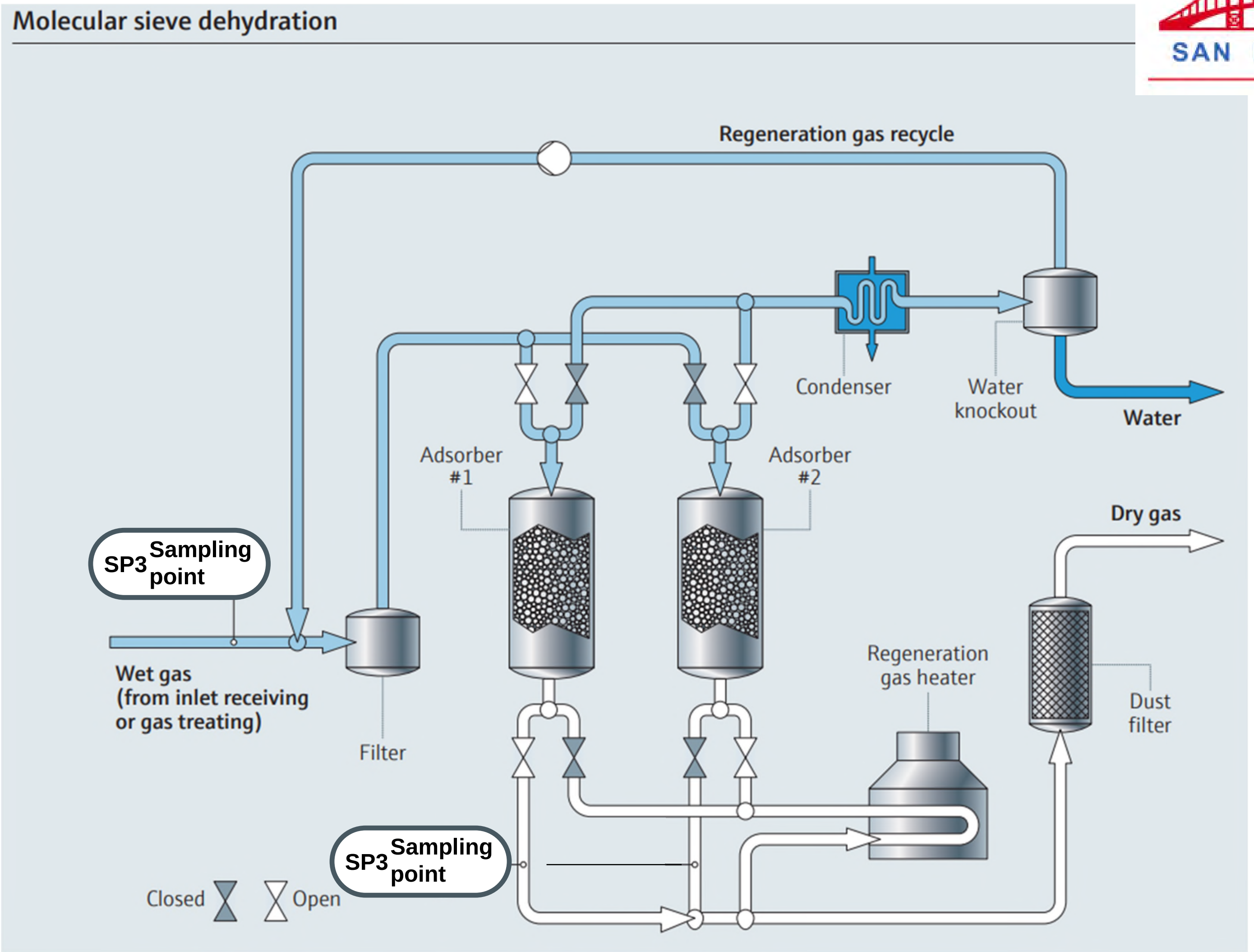
Hydrogen 5.0 and beyond

- < 5 ppmv H_2O is needed for ISO / EN / SAE standards
- requires a molecular sieve desiccant dryer

SP3 gas analysis

- Hydrogen 5.0 = 0-10 ppmv H_2O
- Hydrogen > 5.0 = 1 ppmv H_2O or better

Grade	Purity (%)	Common Applications
3.0	99.9%	General industrial use, welding
4.0	99.99%	Chemical synthesis, metallurgy
5.0	99.999%	Fuel cells, electronics, laboratory use
6.0	99.9999%	Semiconductor manufacturing
7.0	99.99999%	Specialty applications w/ extreme purity



Why is moisture measurement so important?

Corrosion: Condensing moisture can eventually lead to corrosion in piping and valves

Yield: For every 1% of purity below 99% the resulting hydrogen gas is 47% more dense.

Compliance: Hydrogen produced for custody transfer must meet quality standards to be sold.

Efficiency: Technologies such as molecular sieve dryers can be costly to regenerate. Precision measurements help determine when breakthrough occurs or when regeneration is complete.

Liquefaction: Excess moisture leads to ice formation that can block piping during this process.

Grading terminology for hydrogen purity

Grade	Purity (%)	Common Applications
3.0	99.9%	General industrial use, welding
4.0	99.99%	Chemical synthesis, metallurgy
5.0	99.999%	Fuel cells, electronics, laboratory use
6.0	99.9999%	Semiconductor manufacturing, ultra-sensitive analytical instruments
7.0	99.99999%	Specialty applications requiring extreme purity (e.g., space, quantum research)

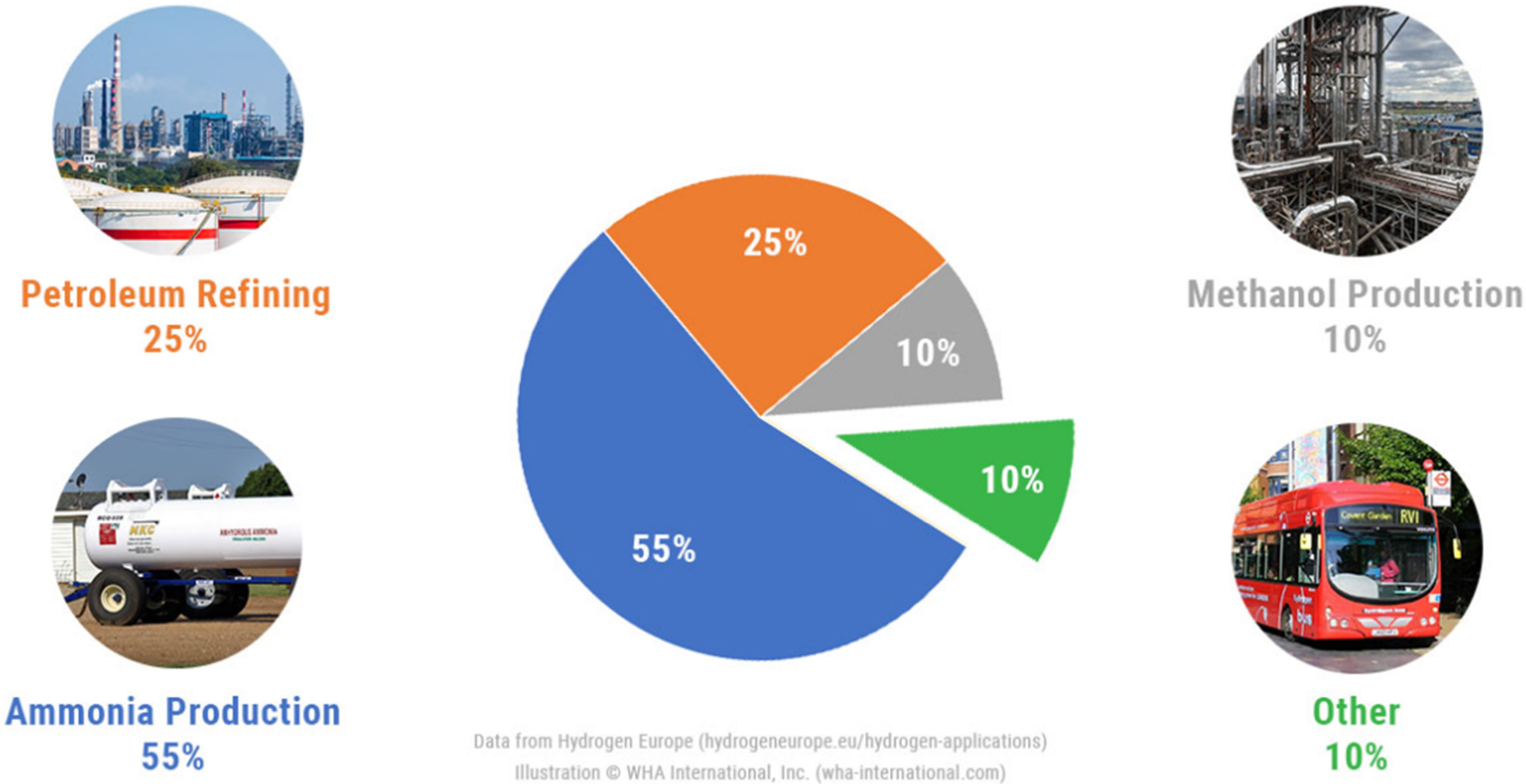
Standard	Grade	Purity	Applications
ISO 14687:2025	Grade A (PEM Fuel Cell - Vehicular)	≥99.97%	Fuel cell vehicles
ISO 14687:2025	Grade B (PEM Fuel Cell - Stationary)	≥99.97%	Stationary PEM fuel cells
ISO 14687:2025	Grade C (Non-PEM)	≥99.5%	Industrial, combustion, etc.
SAE J2719:2020	Fuel Cell Grade	≥99.97%	PEM fuel cell vehicles
CGA G-5.3:2017	Type I - B	99.95%	General industrial
CGA G-5.3:2017	Type I - D	99.99%	Hydrogenation, water chemistry
CGA G-5.3:2017	Type I - F	99.995%	Analytical, propellants
CGA G-5.3:2017	Type I - L	99.999%	Semiconductor manufacturing
JIS K0512:1995	Type 1	≥99.9999%	Semiconductor, analytical
JIS K0512:1995	Type 2	≥99.999%	High-tech applications
JIS K0512:1995	Type 3	≥99.99%	Industrial uses
JIS K0512:1995	Type 4	≥99.9%	Combustion, metallurgy

Common hydrogen contaminants?

Impurity	Maximum Concentration ISO 19880-8:2024	Maximum Concentration EN 17124	Maximum Concentration ISO 14687:2025
Water vapor (H_2O)	5 µmol/mol	5 µmol/mol	5 µmol/mol
Oxygen (O_2)	5 µmol/mol	5 µmol/mol	5 µmol/mol
Nitrogen (N_2)	100 µmol/mol	100 µmol/mol	100 µmol/mol
Argon (Ar)	100 µmol/mol	100 µmol/mol	100 µmol/mol
Helium (He)	100 µmol/mol	300 µmol/mol	100 µmol/mol
Carbon dioxide (CO_2)	2 µmol/mol	2 µmol/mol	2 µmol/mol
Carbon monoxide (CO)	0.2 µmol/mol	0.2 µmol/mol	0.2 µmol/mol
Total hydrocarbons (C_1–C_4)	2 µmol/mol	2 µmol/mol (including CH_4)	2 µmol/mol
Formaldehyde (HCHO)	0.01 µmol/mol	0.01 µmol/mol	0.01 µmol/mol
Ammonia (NH_3)	0.1 µmol/mol	0.1 µmol/mol	0.1 µmol/mol
Formic acid (HCOOH)	0.2 µmol/mol	0.2 µmol/mol	0.2 µmol/mol
Particulates	≤ 1 mg/kg		≤ 1 mg/kg
Total sulfur compounds	0.004 µmol/mol	0.004 µmol/mol	0.004 µmol/mol
Hydrogen sulfide (H_2S)	0.004 µmol/mol		0.004 µmol/mol
Halogenated compounds		0.05 µmol/mol	
Total non-hydrogen gases		300 µmol/mol	

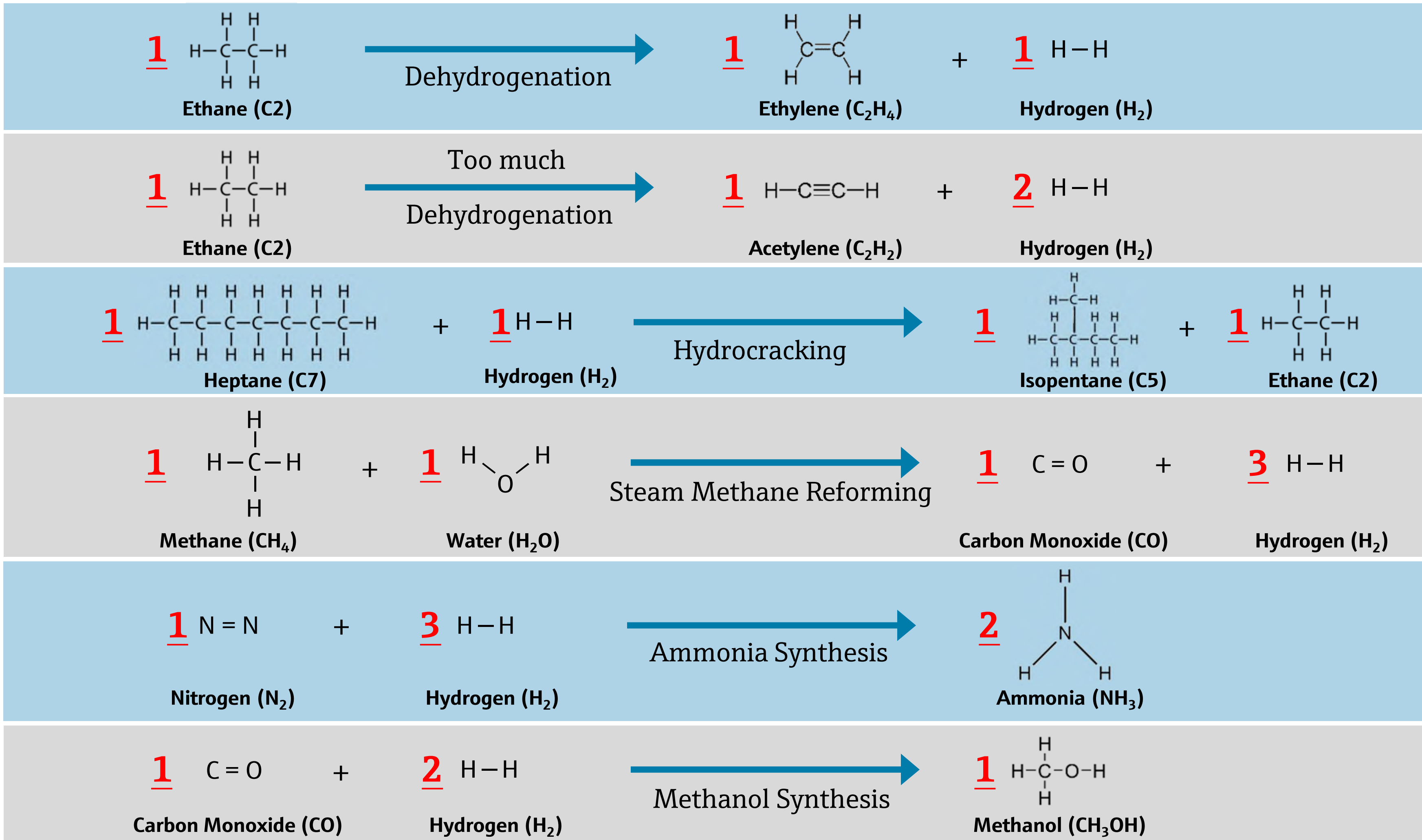
Hydrogen production with SMR

Global hydrogen consumption by industry



About 55% of the hydrogen around the world goes to ammonia production; 25% is used in refining and about 10% is used to produce methanol. Other applications like renewable energy only account for about 10%.

The equations of H_2 Chemistry

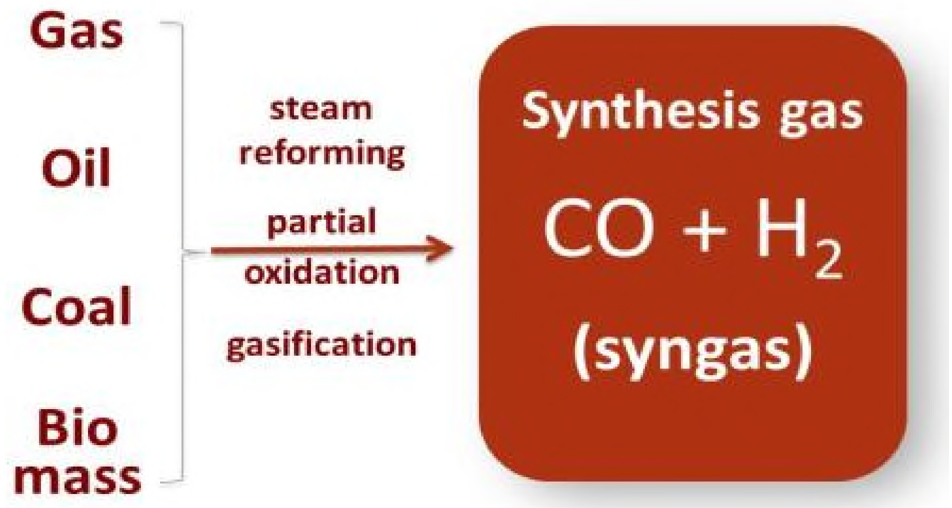


(syngas)

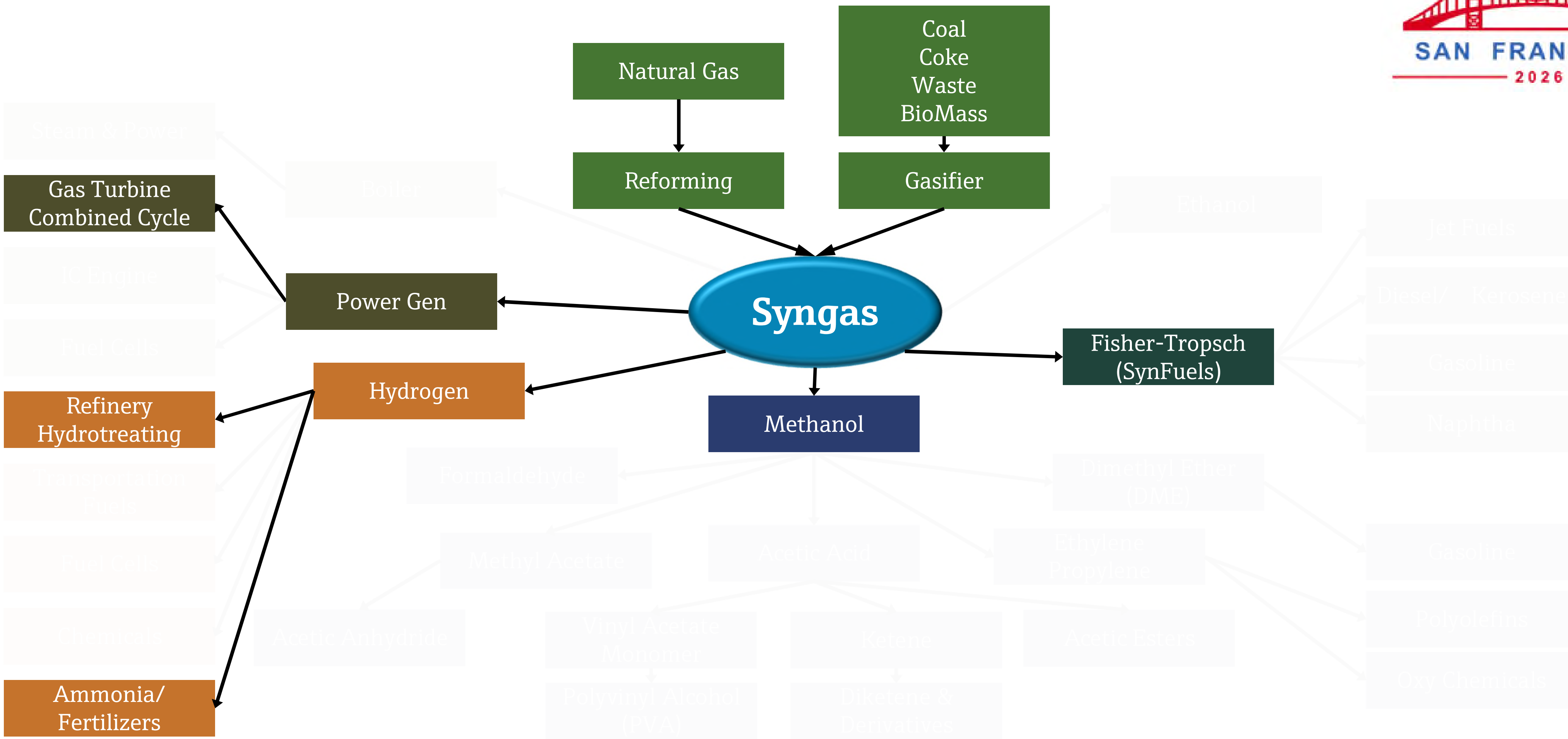
How hydrogen is made (syngas)

- The most common method is via reforming of natural gas
  - **Steam Methane Reforming (SMR), the most common method in use**
  - Partial Oxidation (POX)
  - Autothermal Reforming (ATR)

- Gasification of various feedstocks (common in areas that do not have natural gas and have high coal reserves, such as China)
  - Coal
  - Petcoke
  - Biomass

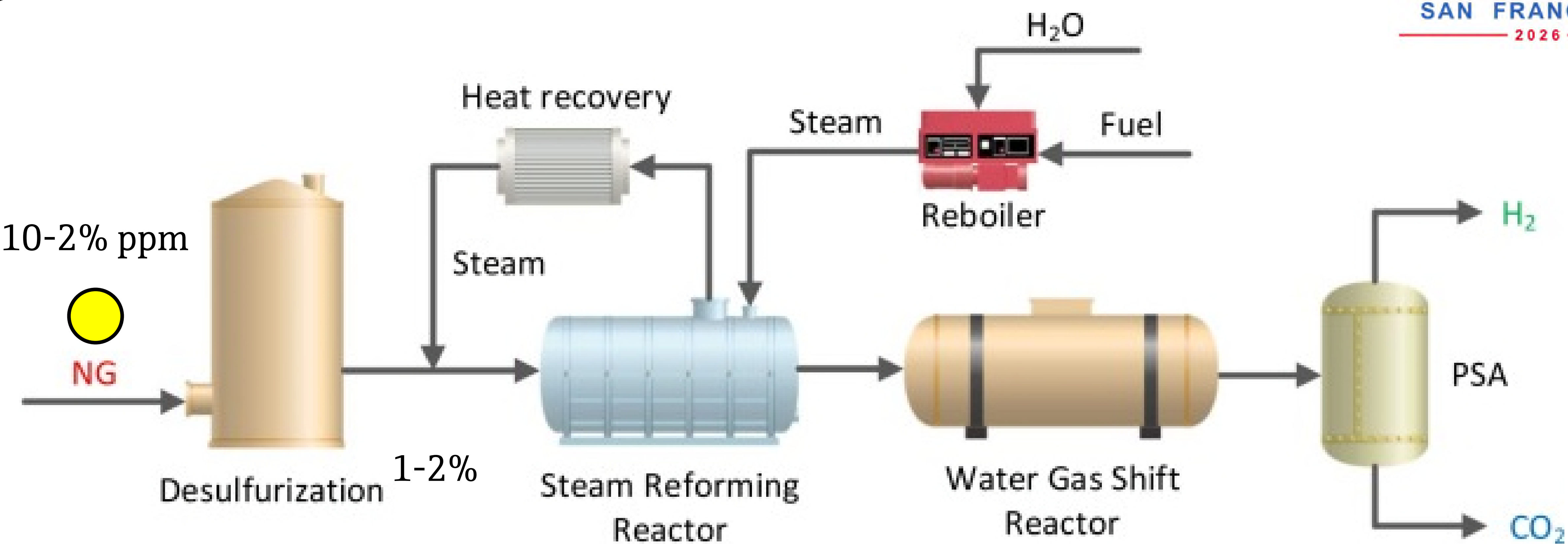


Overview of Syngas Production and Utilization

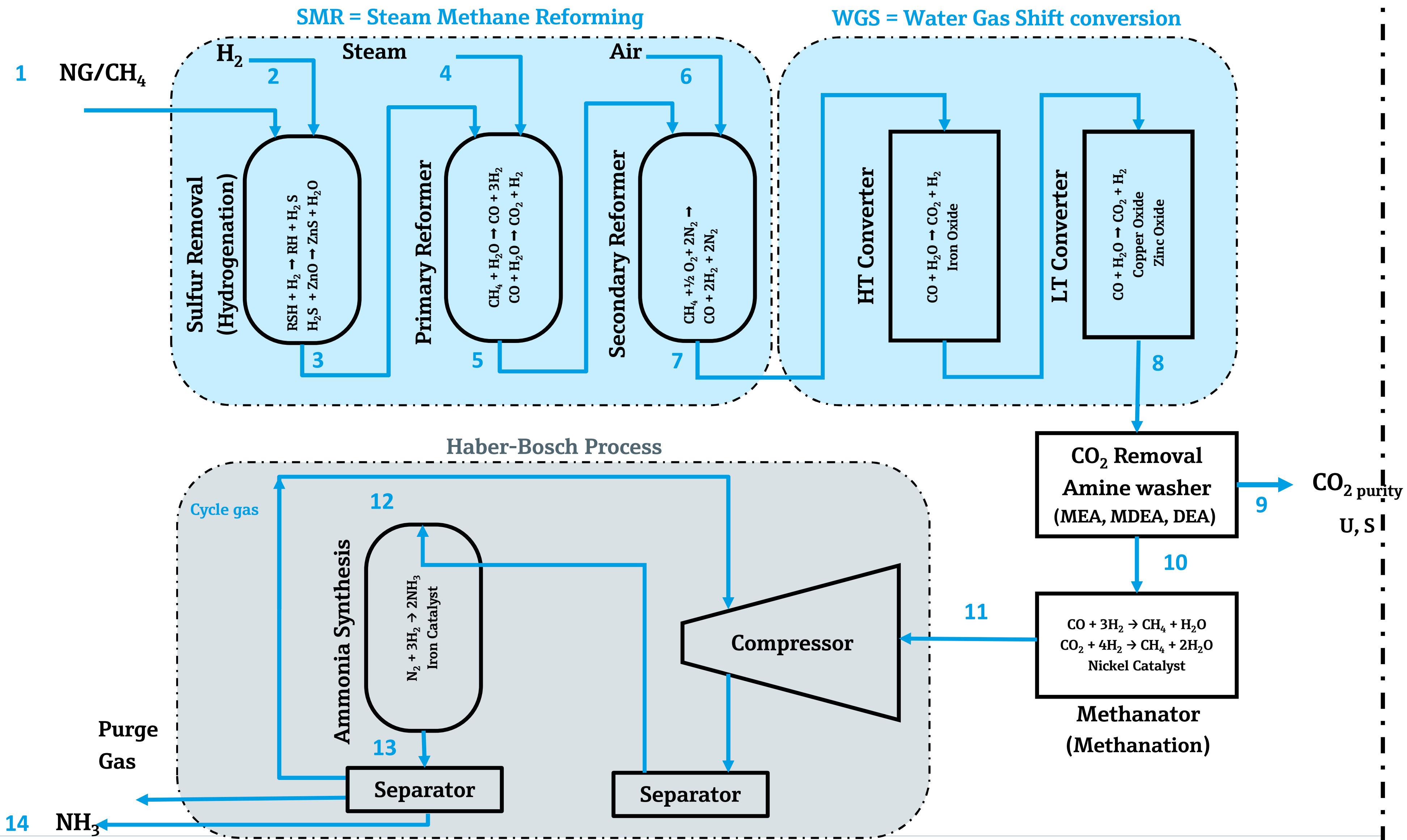


Steam methane reforming to produce H_2

H_2S



H_2, NH_3 production and CO_2



3. Sulfur Removal efficiency
H_2S / Mercaptans
H_2S: 0 – 25 ppm (range tbc)

5. Primary Reformer efficiency
CH_4: 0 - 10 vol% (-50- 60 vol%)

7. Secondary Reformer efficiency

H_2	≈ 56 vol%
CO	≈ 13 vol% (feed shift)
CO_2	≈ 8 vol%
CH_4	≈ 0.3 vol% (efficiency)
N_2+Ar	≈ 23 vol%

8. Shift conversion efficiency

H_2	≈ 61 vol%
CO	≈ 0.3 vol%
CO_2	≈ 18 vol%
CH_4	≈ 0.2 vol%
N_2+Ar	≈ 20.5 vol%

9. CO_2 Purity 95 – 100 vol%
Amine 0 -100 ppmv

10. Carbon Capture efficiency

H_2	≈ 74.6 vol%
CO	≈ 0.4 vol%
CO_2	≈ 0.1 vol%
CH_4	≈ 0.3 vol%
N_2+Ar	≈ 24.6 vol%
Amine slip	≈ 15 ppmv

11. Methanator efficiency control
Protection synthesis reactor
Ammonia feed forward control

H_2	≈ 74.2 vol% (-100 vol%)
CO+CO_2	≈ 5 ppmv (-50 ppmv)
CH_4	≈ 0.8 vol%
N_2+Ar	≈ 24.6 vol%
Amine slip	≈ 15 ppm

12. & 13. NH_3 Synthesis Reactor (In/Out)
H_2: 0 - 80 / 100 vol%
NH_3: 0 – 8 vol%

14. NH_3 Purity

Hydrogen Stream Conditions

	Compressor (1)	Compressor (2)	Start-up (3)
Temperature (˚F)	150-190	178-226	120*
Pressure (psig)	2800	1800	280
H_2	93.00	85.78	93.0
C1	3.69	5.71	3.69
C2	1.10	1.34	1.10
C3	0.31	1.47	0.31
i-C4	0.07	1.85	0.07
n-C4	0.07	0.85	0.07
H_2S	1.60	0.00	1.60
NH_3	0.01	0.00	0.01
C_2H_4	0.00	0.00	0.00
N_2	0.10	1.50	7.00
i-C5	1.10	0.50	0.10
n-C5	0.00	0.10	0.00
C6+	0.30	0.50	0.30

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Measurement technologies

Measurement challenges

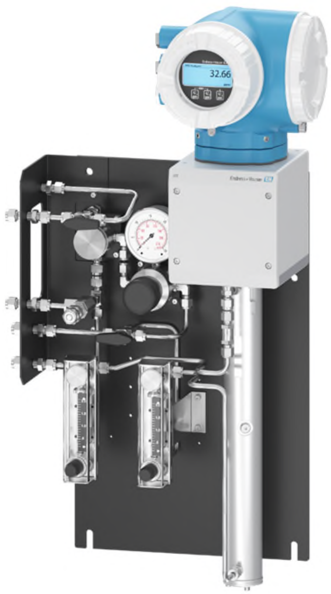
Two moisture measurement ranges

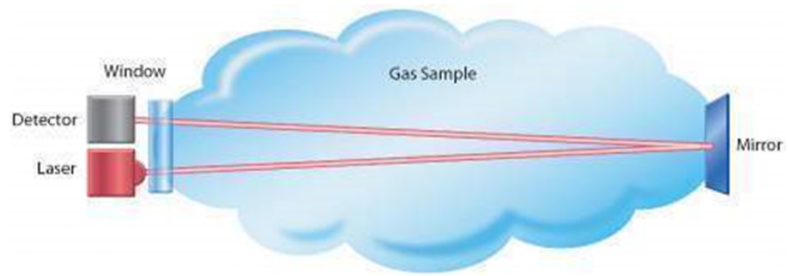
Non-Differential TDLAS

- Suitable for Hydrogen 5.0 (down to 1 ppmv)
- Less cost and complexity
- May require temperature control of gas sample

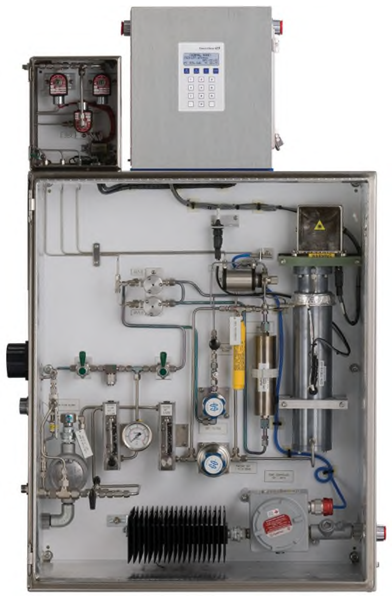
Differential TDLAS

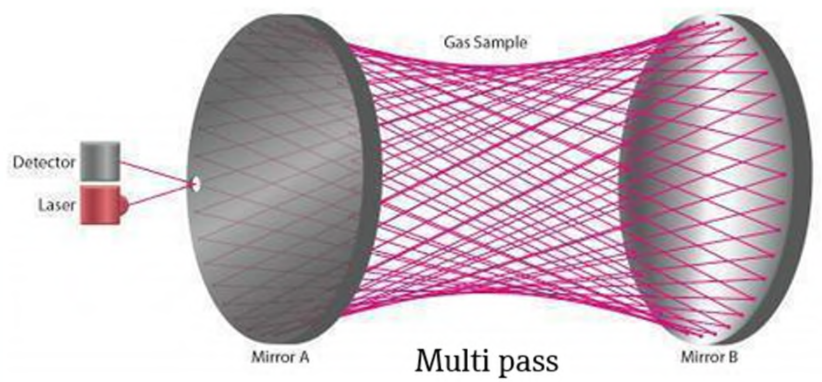
- Suitable for Hydrogen 6.0 (< 1 ppmv)
- Most cost and complexity
- Best design if other impurities could be a concern





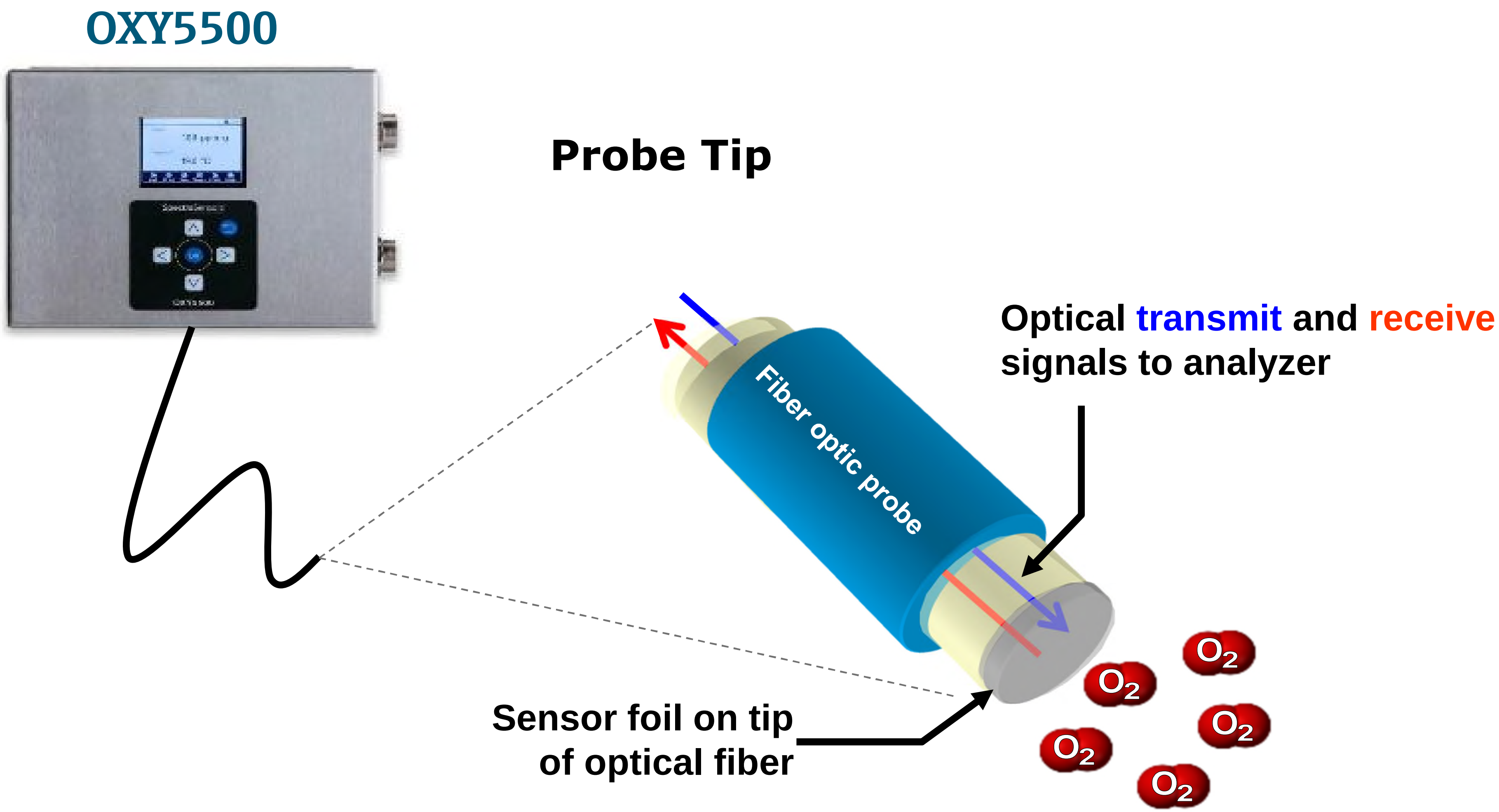
Two pass





Multi pass

Quench Fluorescence for O_2 Measurement in H_2 0-10 ppmv



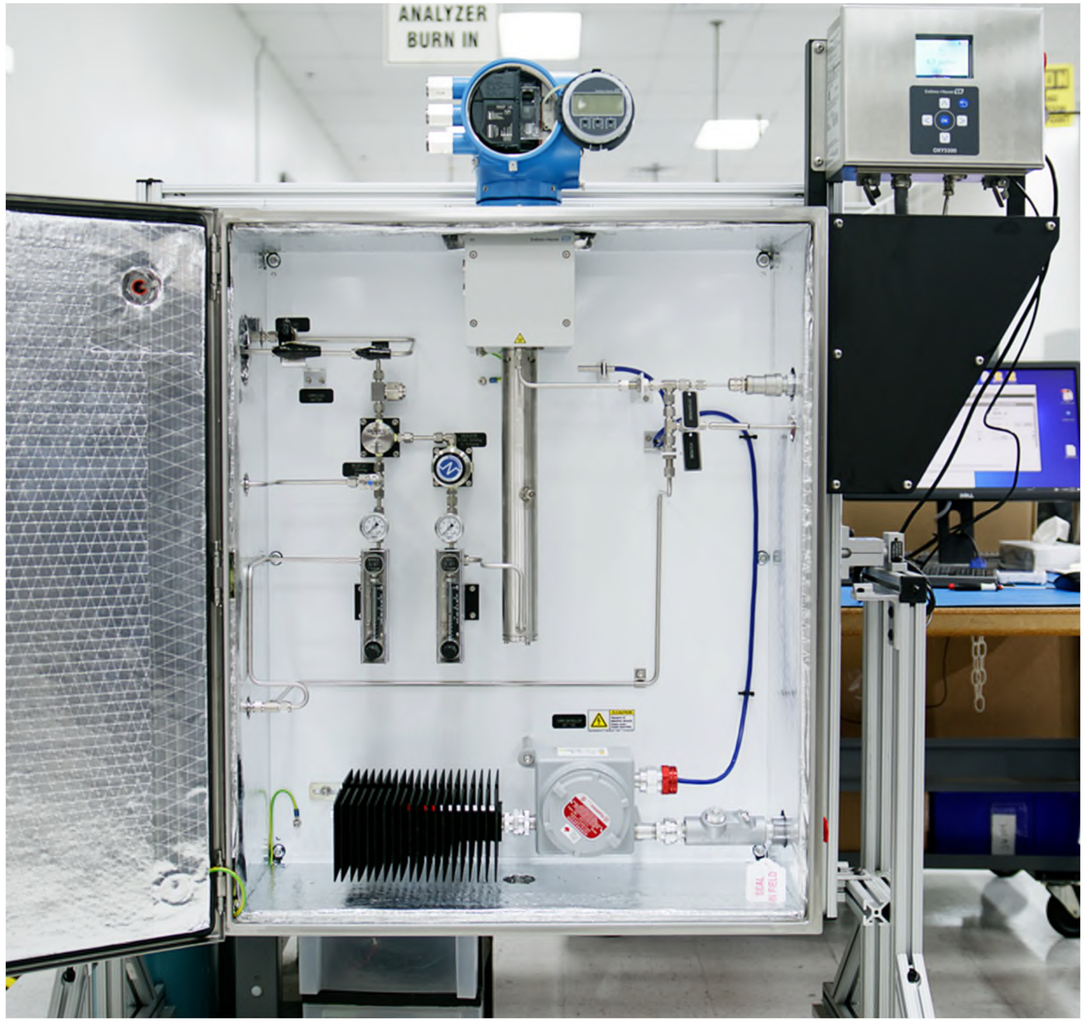
Non-differential H_2O in H_2 measurement

Non-Differential TDLAS at AEM Electrolyzer mfg

- Indoor installation
- Within temp-controlled, insulated enclosure (± 0.2 ˚C)
- Measurement at 0-20 ppmv

H_2O in H_2 measurement

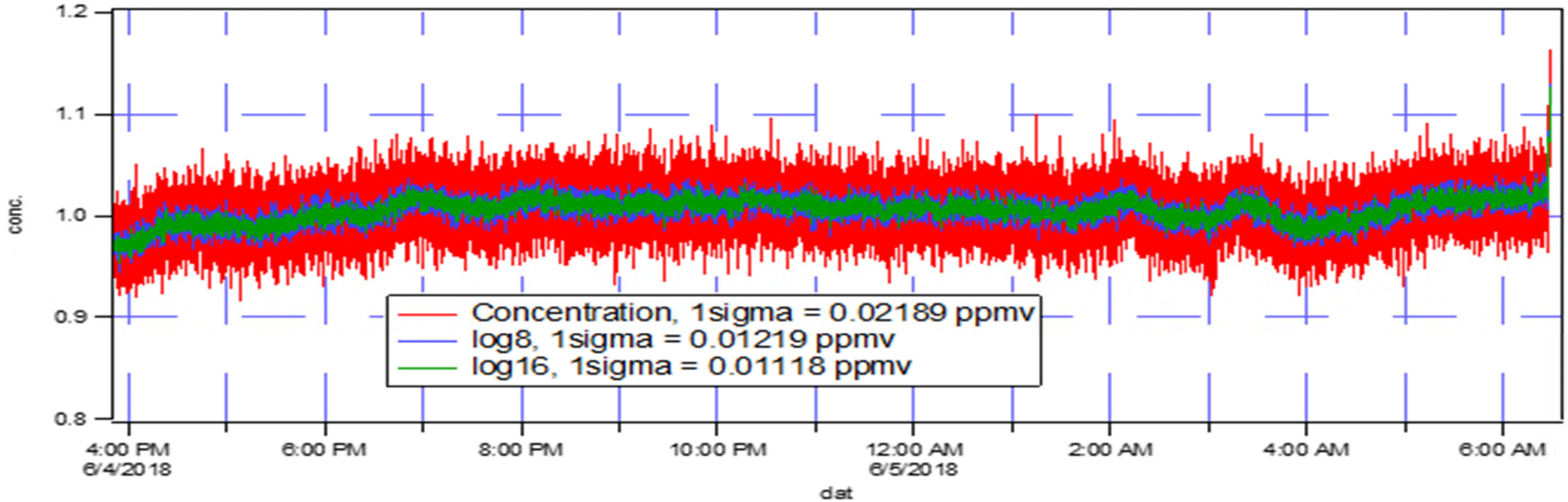
H2O O2



Non-Differential TDLAS at power plant

- PEM electrolyzer creating hydrogen for generator / stator cooling
- Outdoor installation in Midwest USA
- Measurement at 0-10 ppmv

Trace H2O in H_2 Measurement



Other considerations for moisture in hydrogen measurement

Sample System: Avoid excess fittings that could be potential leak points

- Consider N_2 purge during start-up and shut-down
- Armored variable area flow meters often specified
- H_2 can be vented to atmosphere

Validation: Consider the methods available to test analyzer functionality

- Gas validation?
  - May require higher concentrations than your measurement requirement
- Permeation tubes?
  - Typically built into the analyzer
- Reference analyzer?
  - Compare sample vs lab measurement
  - Dew-point vs. concentration conversion

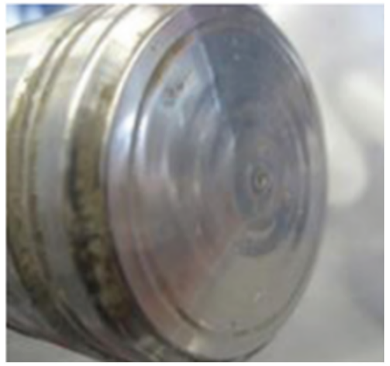
Wetted materials: All wetted materials must be compatible with hydrogen

- Pressure compensation (look for sensor materials compatible with hydrogen)
- Consider Silconert tubing if < 1 ppmv H_2O measurement is required

Safety: Review design for hazardous area approval

- NEC: Class 1 Division 1, Group B (specific for hydrogen)
- IECEx: Zone 1, Group IIC (specific for acetylene & hydrogen)

Armored (left) vs Glass tube (right) flow meters



Pressure sensor diaphragm deformed due to H_2 ingress

Detection Techniques for Hydrogen – Raman spectroscopy

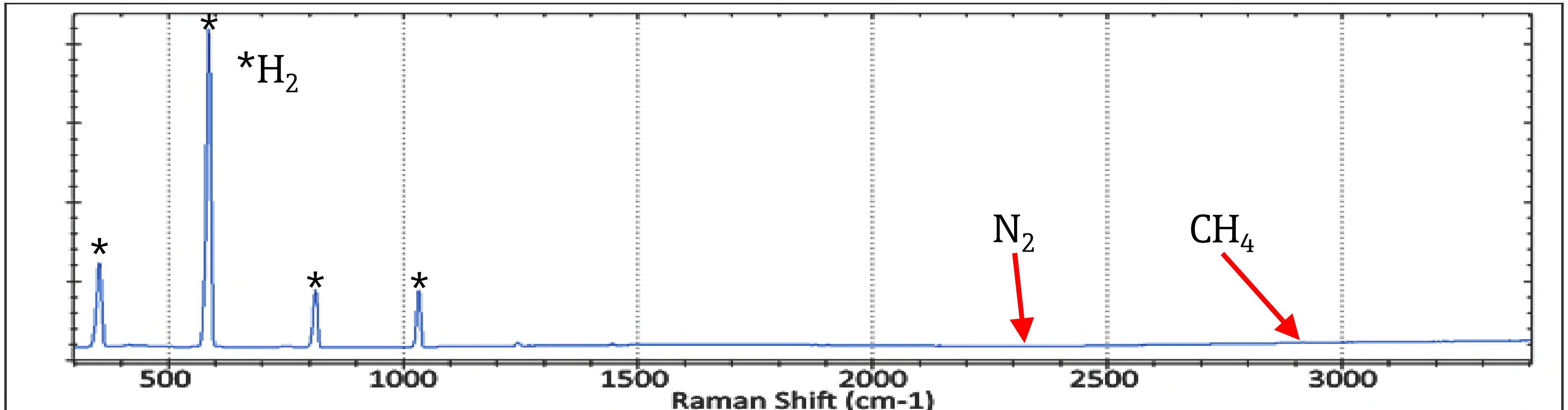
Detection Techniques for Hydrogen – Raman spectroscopy

'High Purity' Composition

99.941% **H_2**

0.033% **CH_4**

0.026% **N_2**

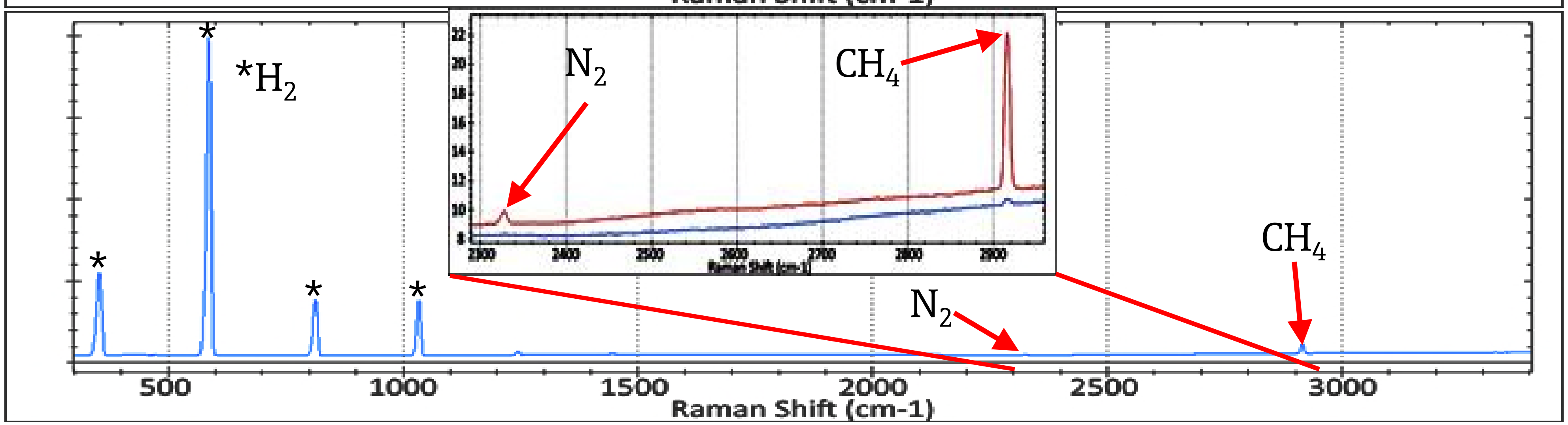


'Low Purity' Composition

99.025% **H_2**

0.532% **CH_4**

0.443% **N_2**



Endress+Hauser

Hydrogen Analysis Technology - Thermal Conductivity

- Thermal conductivity uses thermally sensitive metals such as tungsten and platinum
- When Hydrogen is present it absorbs some of the heat from the active bead
- The amount of heat loss is proportional to the concentration

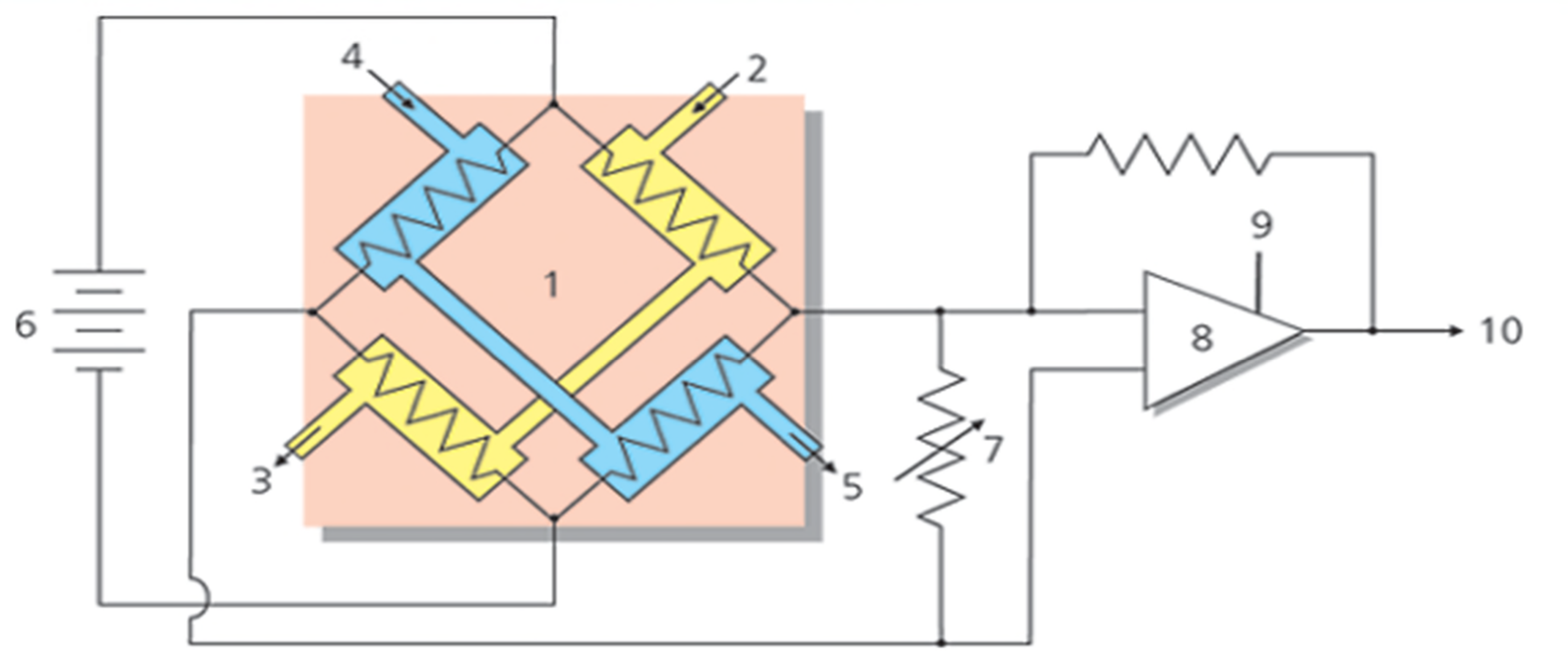
- **Applications**: Hydrogen Purity or a binary Gas mixture

- **Advantages:** No Consumables, sensitive with fast response time

- **Disadvantages:** If more than one other gas is present in a Hydrogen stream other analyzers are required to speciate and compensate for heat loss due to other gases present. This increases the cost and complexity of the system

Hydrogen Analysis Technology

Figure 2: Schematic diagram of thermal conductivity detector block and electronics. 1 = TCD block, 2 = sample gas inlet from column, 3 = sample gas outlet, 4 = reference gas inlet, 5 = reference gas outlet, 6 = power supply for filaments, 7 = bridge balance adjustment, 8 = amplifier, 9 = amplifier offset adjustment, 10 = output to A/D converter and signal processing.



Hydrogen Analysis - Thermal Conductivity

Hydrogen analyzers

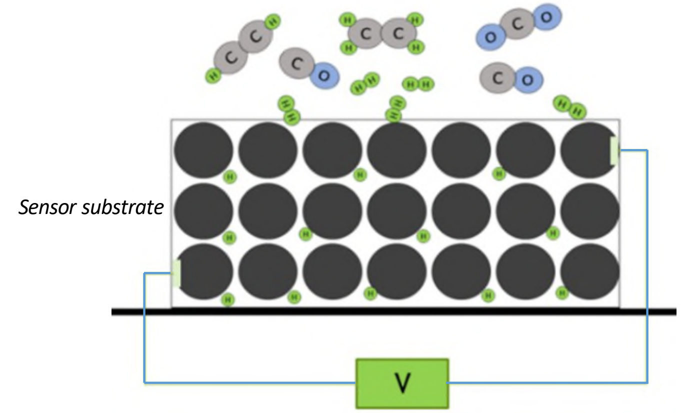
Gas chromatograph

Hydrogen Analysis Technology

MOS Solid State Sensor

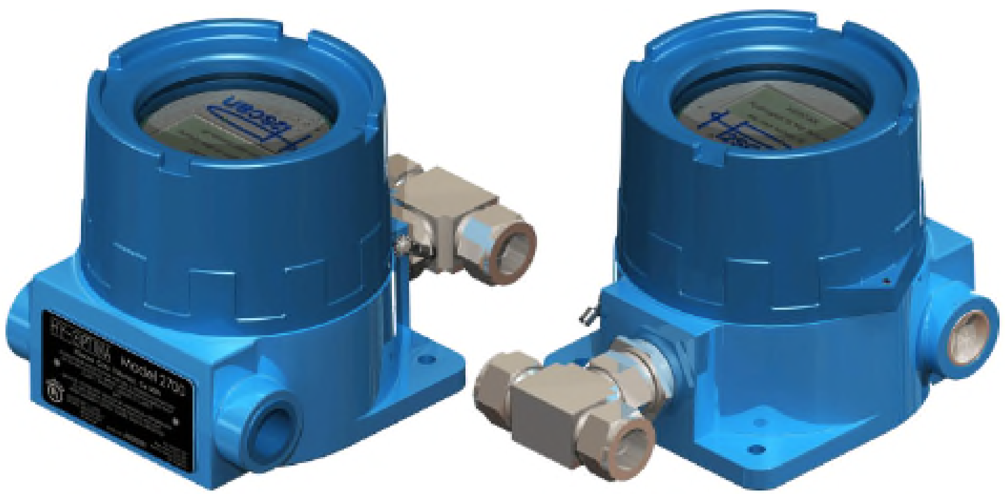
- Continuous, **real-time** measurement
- **Hydrogen specific MEMS sensor**: only affected by hydrogen
- Measures the **partial pressure** of hydrogen at the analyzer
- **Not consumed** and does not wear out
- Easily handles **complex**, **varying** gas streams
- **No preventive maintenance** or reference gases required
- Autocalibration to normalize drift and maintain accuracy

HOW IT WORKS



Sensor bulk thin film resistance changes linearly as a function of H2 concentration as it is continuously adsorbed and desorbed from the proprietary solid-state substrate

Metal Oxide Semiconductor (MOS) Solid State Sensor



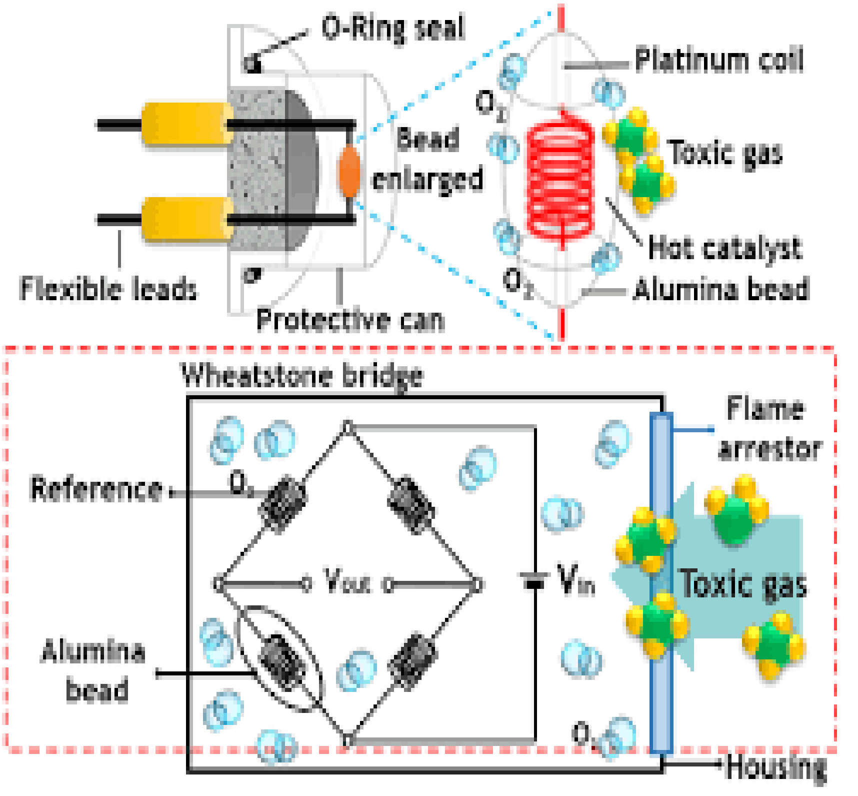
Catalytic Combustion Sensor

- Catalytic combustion sensors operate at 450 degrees Centigrade. One bead is passivated (no catalyst applied) so it does not react when it comes into contact with H2 molecules. This bead acts a background reference.
- The other bead is coated with a catalyst, so it reacts to gas. The bead is placed on a separate leg of wheat stone bridge electrical circuit.
- When H2 is present the active bead's resistance increases while the passivated bead remains unchanged. This alters the balance of the bridge and changes the output voltage.

- **Applications**: Area safety monitoring LEL Detection, Fugitive emissions
- **Advantages:** Fast response, no sample system
- **Disadvantages**: Elevated sensor temperature and higher power consumption

Hydrogen Analysis

- Catalytic Combustion Sensor



Electrochemical Sensor

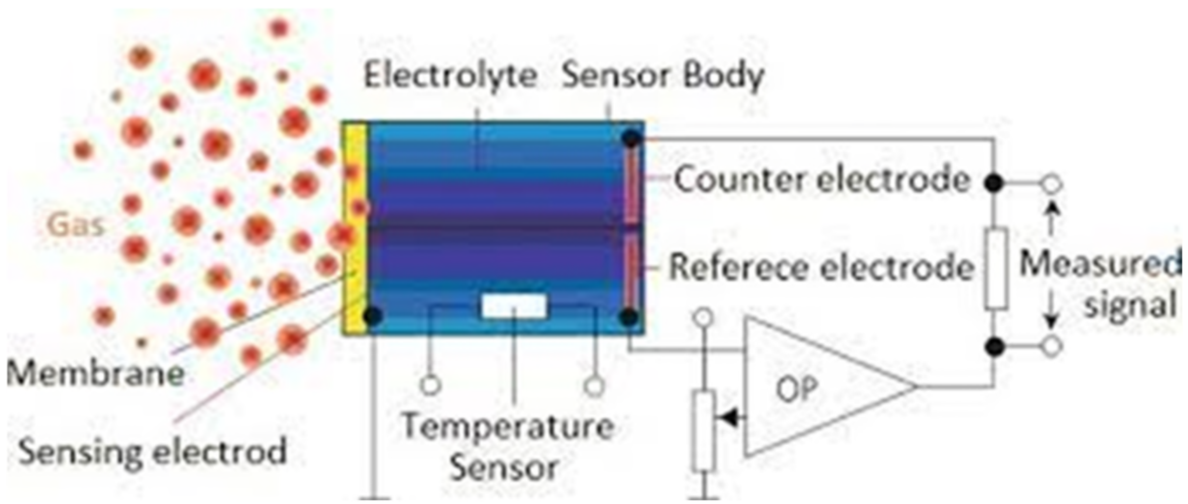
- Electrochemical hydrogen sensors work on the same principle as fuel cells. They have and anode and cathode separated by thin layer of electrolyte. When hydrogen passes through the electrolyte a reversible chemical reaction takes place that produces and electric current proportional to the concentration hydrogen.

- *Advantages:* Relatively low initial cost and power consumption. Sensitive and selective to hydrogen concentration

- *Disadvantages:* Sensor is consumable and requires either replacement or refurbishment at 3–6-month intervals. There is no positive indication of performance. The only way to determine if sensor is working is to challenge it with calibration gas

Hydrogen Analysis Technology

- Electrochemical Sensor



Thank you very much for your attention.