# TRANSITION TO HYDROGEN ECONOMY

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# GENERAL PROPERTIES OF HYDROGEN

- Hydrogen is the 3rd abundant substance on earth.
- Not available as free $H_2$.
- Energy is required to free $H_2$ from its compounds.
- Combustion of Hydrogen produces $H_2O$. Nevertheless, its well to wheel LCA suggests only green $H_2$ is environmentally friendly.

# Specific $H_2$ properties compared to other fossil fuels

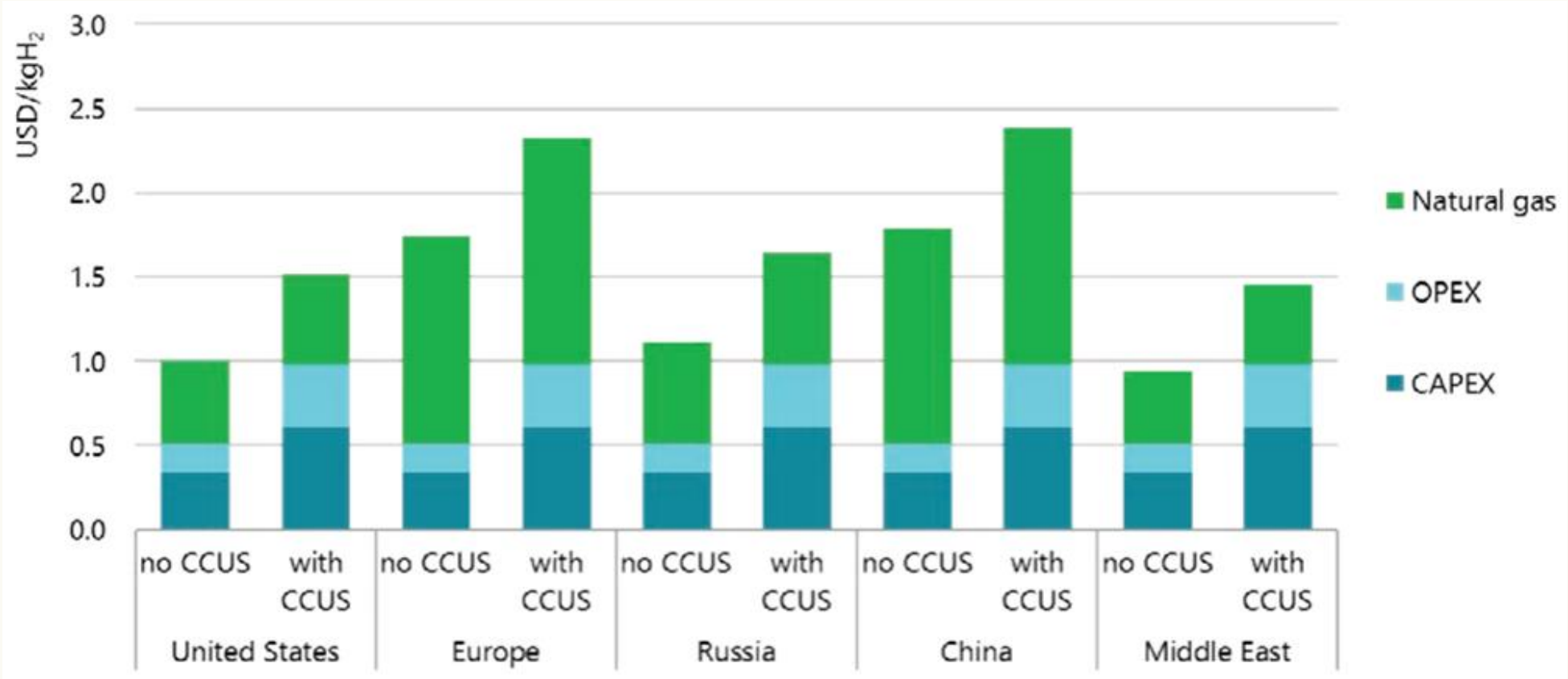
| Property | Hydrogen | CNG | Gasoline | Diesel |
|---|---|---|---|---|
| Carbon content (mass%) | 0 | 75 [e] | 84 | 86 |
| Lower heating value (MJ/kg) | 119.7 | 45.8 | 44.8 | 42.5 |
| Density [a,b] ($kg/m^3$) | 0.089 | 0.72 | 730–780 | 830 |
| Volumetric energy content [a,b] ($MJ/m^3$) | 10.7 | 33.0 | $33 \times 10^3$ | $35 \times 10^3$ |
| Molecular weight | 2.016 | 16.043 [e] | ~110 | ~170 |
| Boiling point [a] (K) | 20 | 111 [e] | 298–488 | 453–633 |
| Auto-ignition temperature (K) | 858 | 813 [e] | ~623 | ~523 |
| Minimum ignition energy in air [a,d] (mJ) | 0.02 | 0.29 | 0.24 | 0.24 |
| Stoichiometric air/fuel mass ratio | 34.5 | 17.2 [e] | 14.7 | 14.5 |
| Stoichiometric volume fraction in air (%) | 29.53 | 9.48 | ~2 [f] | - |
| Quenching distance [a,c,d] (mm) | 0.64 | 2.1 [e] | ~2 | - |
| Laminar flame speed in air [a,c,d] (m/s) | 1.85 | 0.38 | 0.37–0.43 | 0.37–0.43 [g] |
| Diffusion coefficient in air [a,b] ($m^2/s$) | $8.5 \times 10^{-6}$ | $1.9 \times 10^{-6}$ | - | - |
| Flammability limits in air (vol%) | 4–76 | 5.3–15 | 1–7.6 | 0.6–5.5 |
| Adiabatic flame temperature [a,c,d] (K) | 2480 | 2214 | 2580 | ~2300 |

[a] at 1 bar, [b] at 273 K, [c] at 298 K, [d] at stoichiometry, [e] methane, [f] vapor and [g] n-heptane.

# $H_2$ PRODUCTION SMR

- 70 Mt/year is the world production of $H_2$.
- 76% from $CH_4$ steam reforming.
- 23% from coal gasification.
- It consumes 6% of global $CH_4$.
- And 2% of global coal.
- It releases 830 Mt/year of $CO_2$.
- The price is \$1/kg $H_2$ in the middle east without CCUS.

# $H_2$ PRODUCTION COST



# $H_2$ PRODUCTION BY SMR

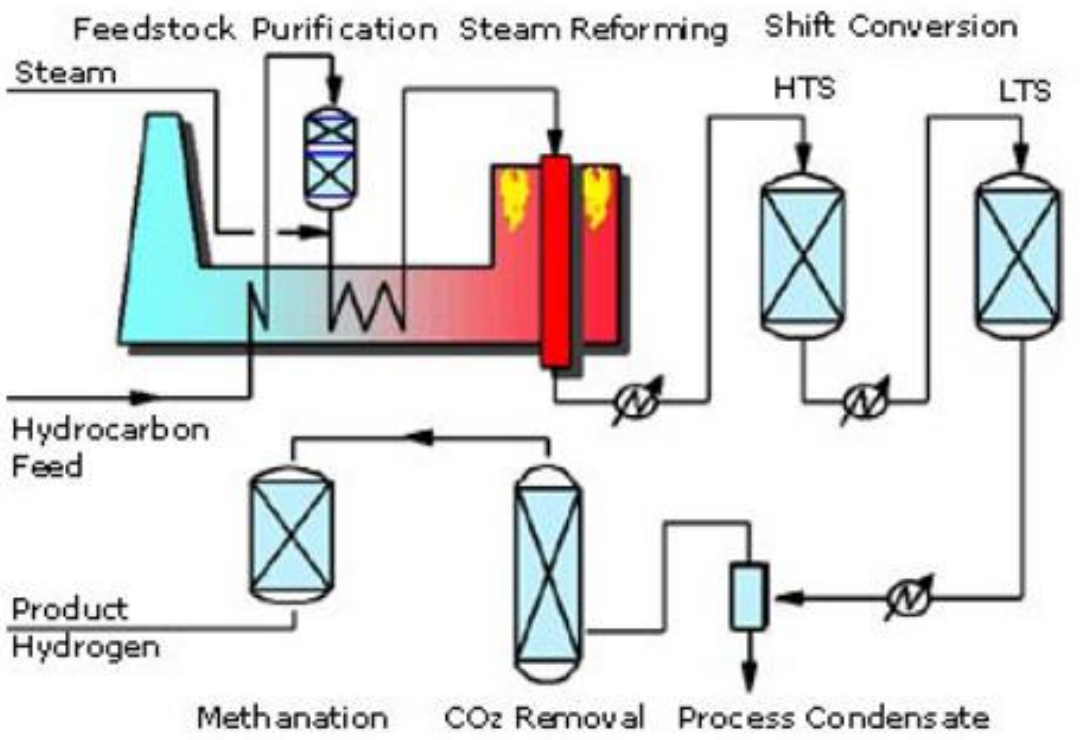
- Feedstock is $CH_4$ and steam.
- Steam works as oxidant and a source of $H_2$.
- 30~40% of $CH_4$ is used as fuel to elevate the temp. to 700~1100°C.
- Pressures as high as 25 bar are required.
- 6.6 $m^3$ of water is required for 1t $H_2$.

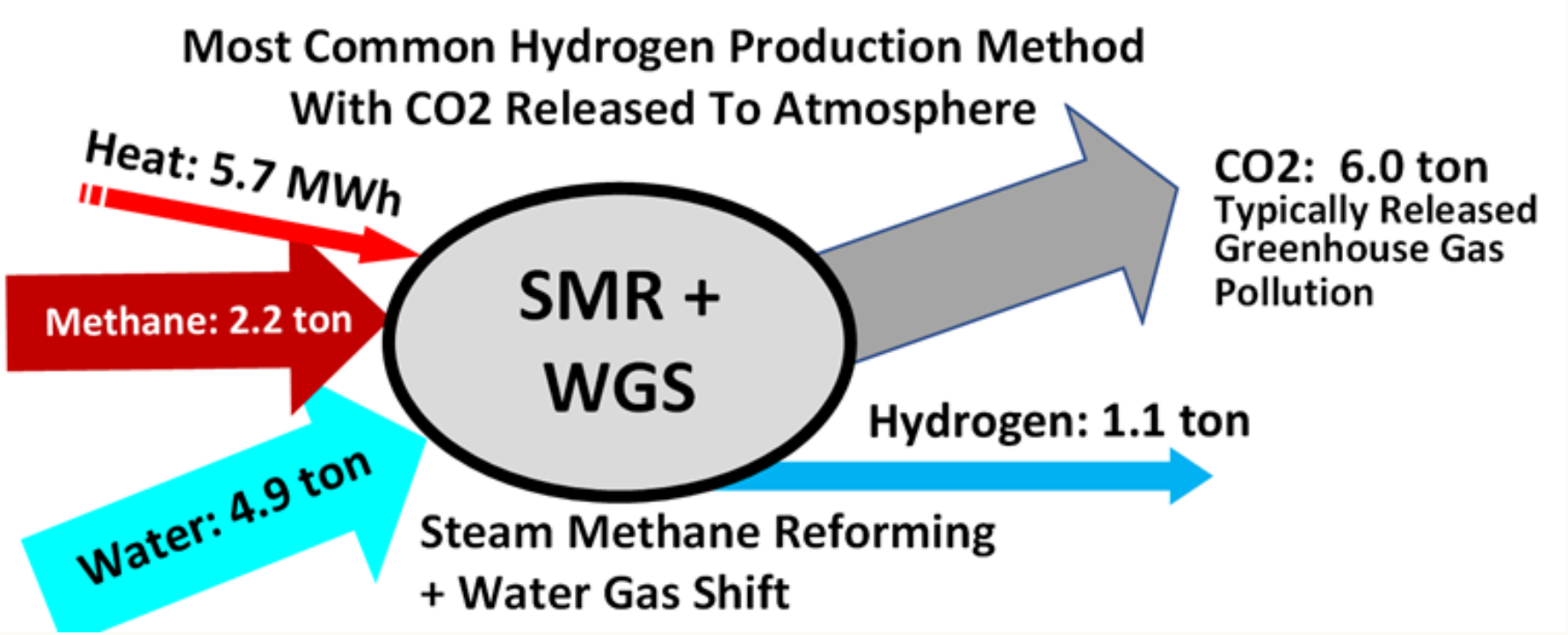
$$CH_{4\,gas} + H_2O + Heat \rightarrow CO_{gas} + 3H_{2\,gas}$$

- Syngas is treated in a water gas shift process.

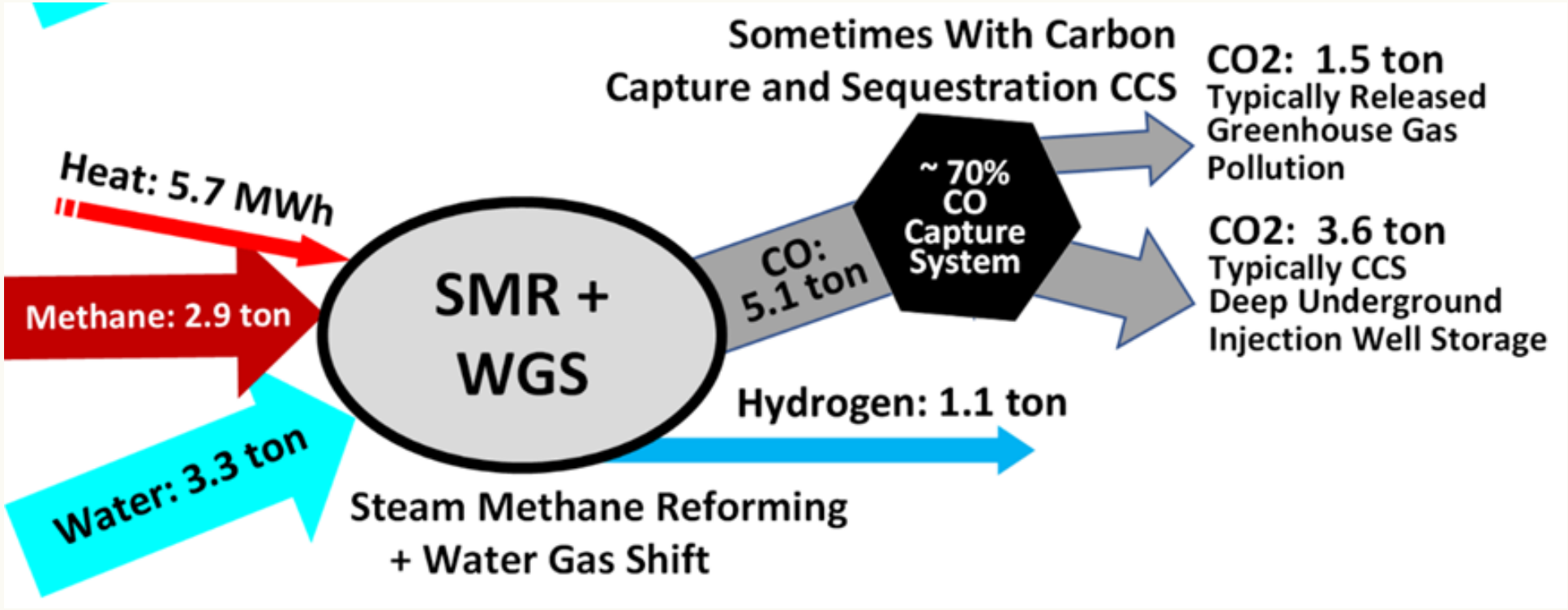
$$CO_{gas} + H_2O_{gas} \rightarrow CO_{2\,gas} + H_{2\,gas} + Heat$$

- CCUS could reduce $CO_2$ by 90% to upgrade the renewability of SMR.



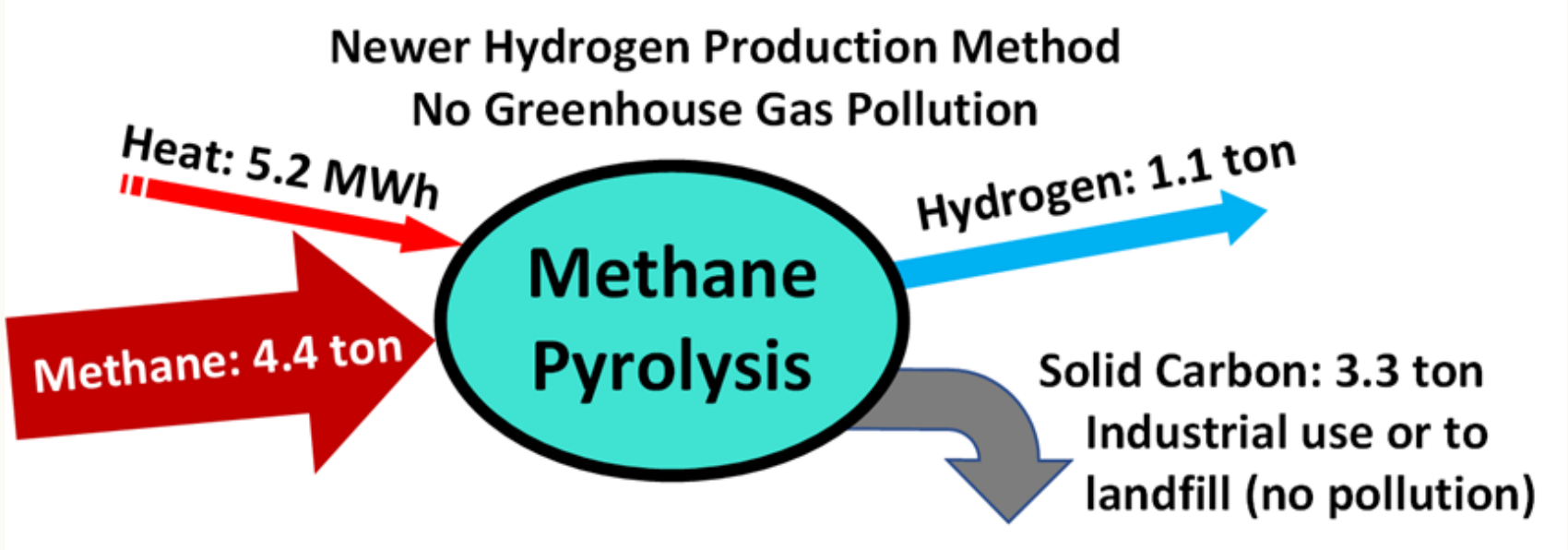



- The cost to produce 1.1 t $H_2$ is \$590.
- Electricity \$217 and \$373 for power gas.




- The cost to produce 1.1t $H_2$ is \$1,091.
- Electricity \$217 , CCUS \$377 and \$497 for power gas.

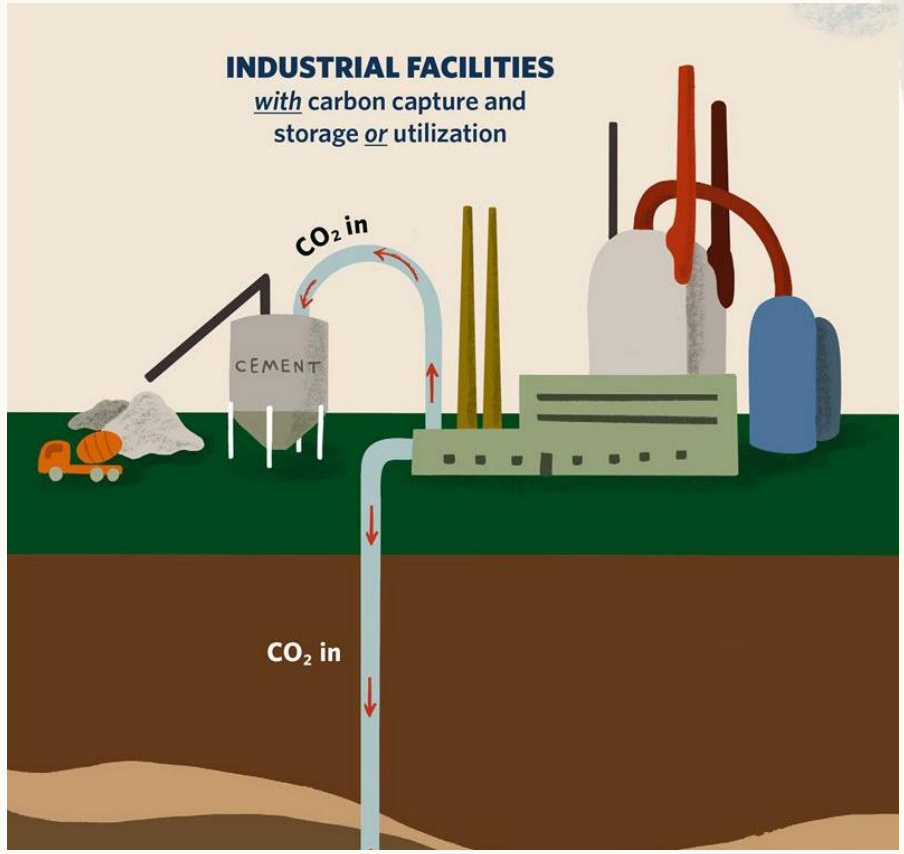
# $H_2$ Production by $CH_4$ Pyrolysis




- It requires more methane gas but less energy.
- No $CO_2$.
- Solid carbon is a by-product for reuse in tyre industry.
- The cost to produce 1.1t$H_2$ is $944.
- The cost is subdivided to $198 electricity and $746 power gas

# CARBON CAPTURE FOR USAGE AND STORAGE

- To upgrade the level of renewability of $H_2$.
- The cost for 60% $CO_2$ removal from syngas is \$ 53/t $CO_2$.
- 90% $CO_2$ removal increases the cost to \$ 80/t $CO_2$.

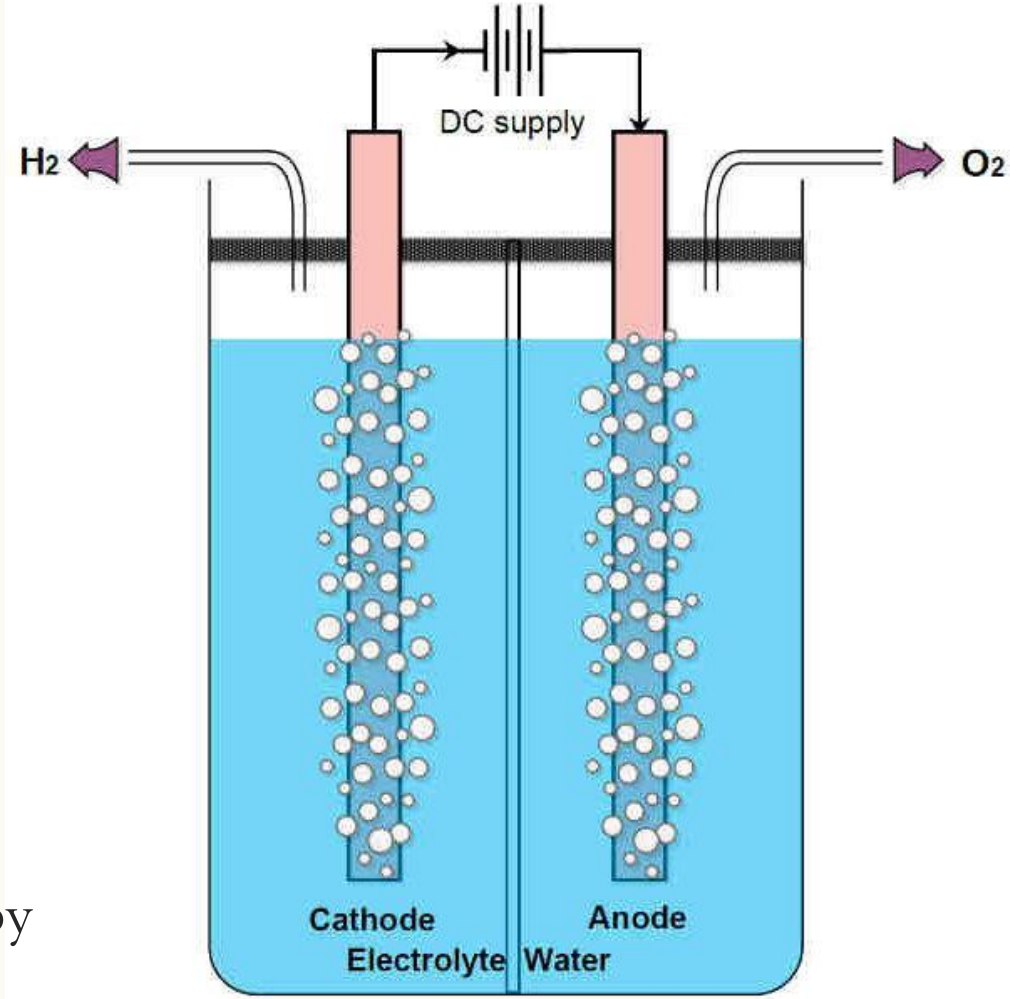


# $H_2$ PRODUCTION BY WATER ELECTROLYSIS

- Provides only 0.1% of dedicated $H_2$.
- Very pure $H_2$, mainly used in electronics industry and polysilicon.

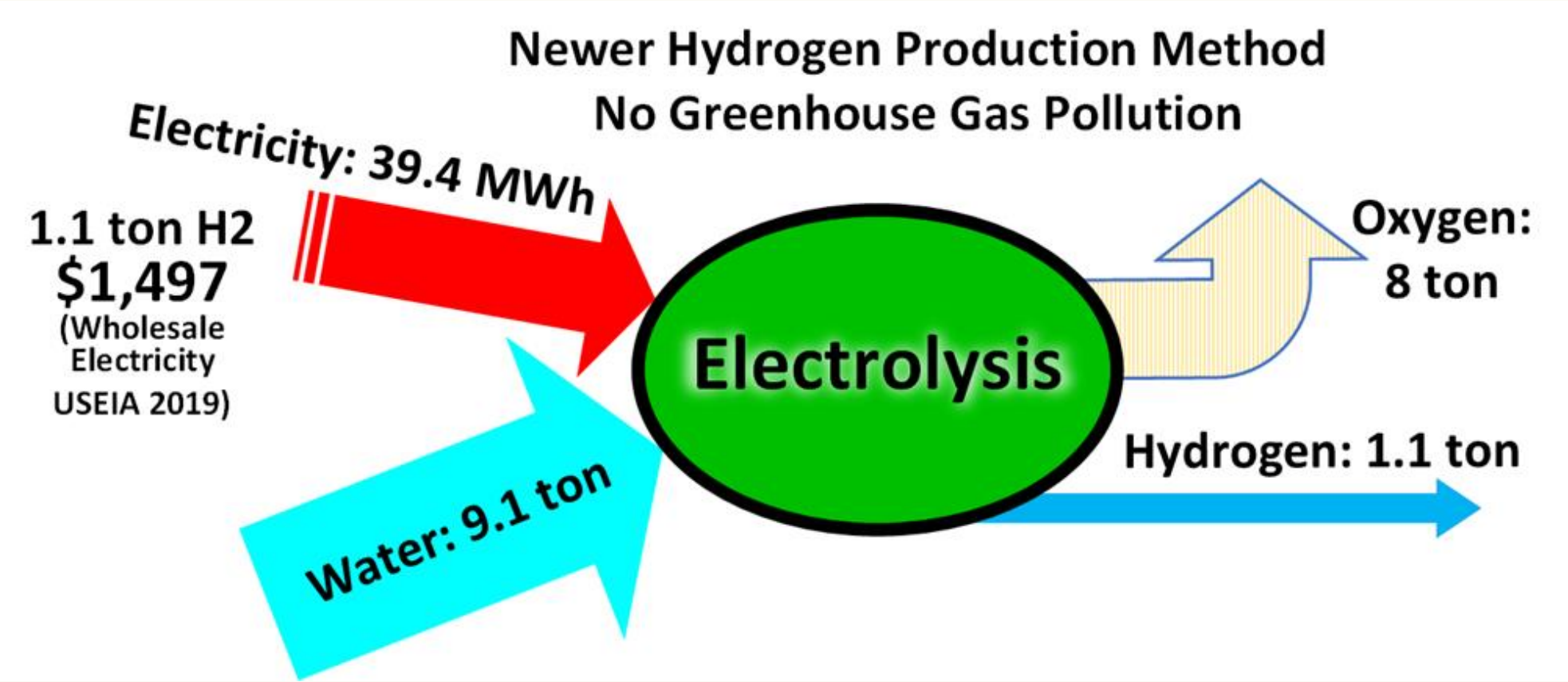
$$2H_2O + electricity \rightarrow 2H_2 + O_2$$

- 1kg $H_2$ is produced from 9kg $H_2O$.
- Low carbon emission.
- Could be upgraded to Net Zero Carbon by green electricity.



# $H_2$ PRODUCTION BY WATER ELECTROLYSIS

- 3,600 TWh electricity is needed to shift to $H_2$ production by water electrolysis.
- This is more than the annual EU electricity generation.
- 617 $Mm^3$ fresh water is needed.
- This is twice the $H_2O$ needed for SMR and 1.3% of $H_2O$ consumption in the energy sector.




- 3~4 kWh is needed to desalinise sea water by reverse osmosis.
- This will add a cost of \$0.7~2.5/$m^3$ of water.
- The cost of $H_2$ production increases by \$0.01~0.02/kg $H_2$.

# Supas


thank you
danke
謝謝
ngiyabonga
teşekkür ederim
gracias
спасибо
bedankt
dziękuję
obrigado
merci
go raibh maith agat
sukriya
kop khun krap
terima kasih
감사합니다
ευχαριστώ
dakujem
arigatô
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