Production d'Hydrogène Turquoise par Pyrolyse du Méthane

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H_2 aujourd'hui

- ~ 100 Mt / an
- 95 % = SMR
- $CH_4 + 2\ H_2O \rightarrow CO_2 + 4\ H_2$
- Réaction fortement endothermique

  + 252 $kJ.mole^{-1}$

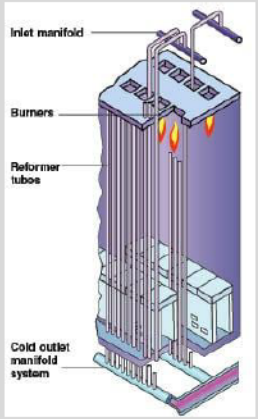
~ 10 kg CO_2 / kg H_2

- **Hydrogène *gris***

Les couleurs de l'hydrogène

Grey

Steam Methane Reforming (SMR)

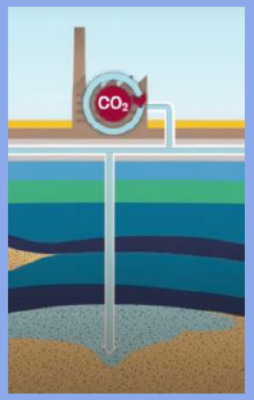


$CH_4 + 2\ H_2O \rightarrow CO_2 + 4\ H_2$

10 CO_2/H_2

Blue

SMR+CCUS

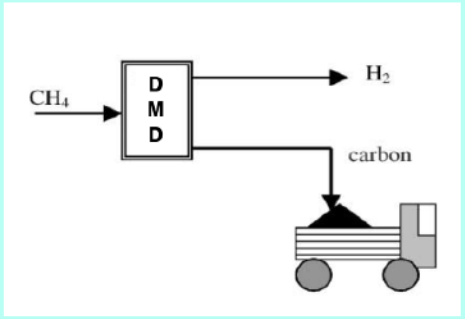


$CH_4 + 2\ H_2O \rightarrow CO_2 + 4\ H_2$

3.0 CO_2 / H_2

Turquoise

Pyrolysis

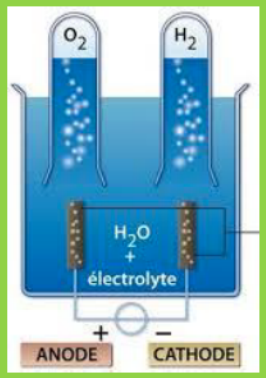


$CH_4 \rightarrow C + 2H_2$

?

Green

Electrolysis



$H_2O_{(l)} \rightarrow H_2 + ½\ O_2$

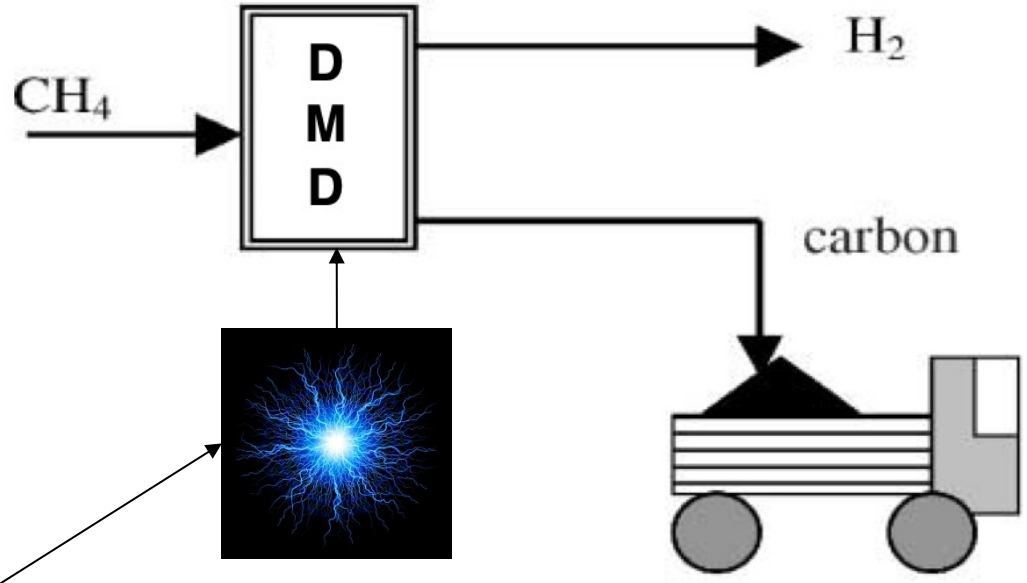
285 kJ/mole

0 CO_2 / H_2

(Renewable Electricity)

Pyrolyse du Méthane

$$CH_4 \rightarrow C + 2\,H_2$$



Electricité décarbonée

Intensité Energétique

	Turquoise	Vert
Thermodynamique : ΔH	75 kJ/mole$_{CH4}$	285 kJ/mole$_{H2O}$
Limite Thermodynamique kWh / kg H_2	5.2	40
Best Available Technology kWh / kg H_2	10-25	50-60

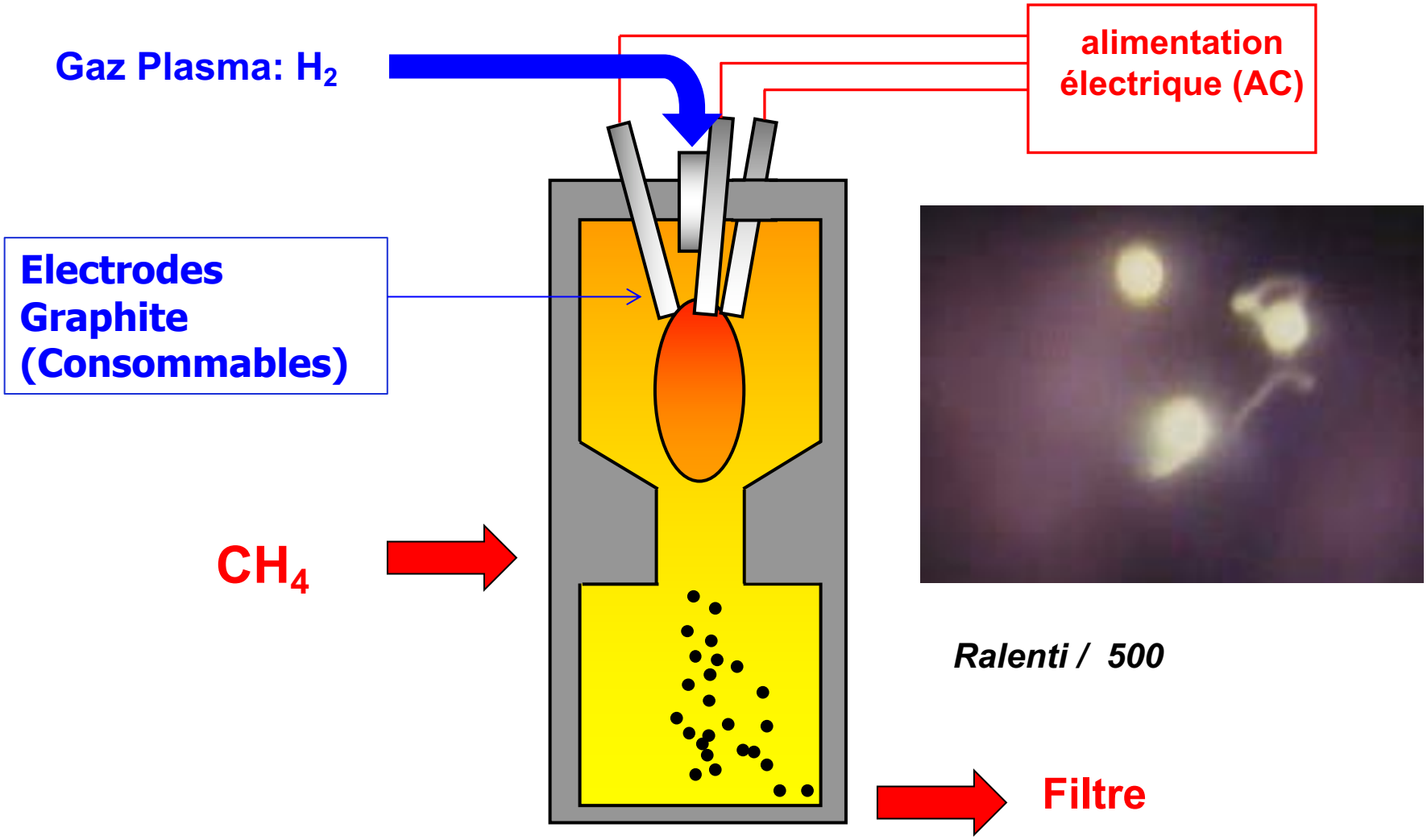
Options pour la Pyrolyse du Méthane

Métal liquide	Décomposition Thermo Catalytique	Plasma
• **Hazer (Australia)** • **Czero (CA, USA)** • Ember-TNO (The Netherlands) • KIT (Karlsruhe) • IASS (Posdam) • TNO (The Netherlands) • BNL (USA) • TRL = 5	• **BASF** • Linde Group • ThyssenKrupp • TUD (Dortmund) • TU Bergakademie (Freiberg) • RUB (Bochum) • TRL = 6	• MONOLITH Materials (US) • MPT (FR) **LEADERSHIP POSITION** **TRL = 8-9**

Plasma ?

- Source d'enthalpie contrôlable
- Zéro direct CO_2
- Particulièrement intéressant pour les procédés endothermiques ET nécessitant de hautes températures
- Une des seules alternatives à la combustion

30 ans R&D à MPT



Pilote *Seaport* (CA): 2012-2018

OC1: démarrage construction 2019 – réception complète 2023

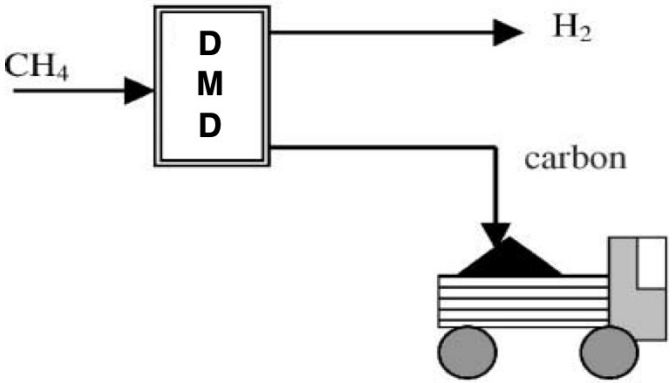
OC1 : Nov 2021

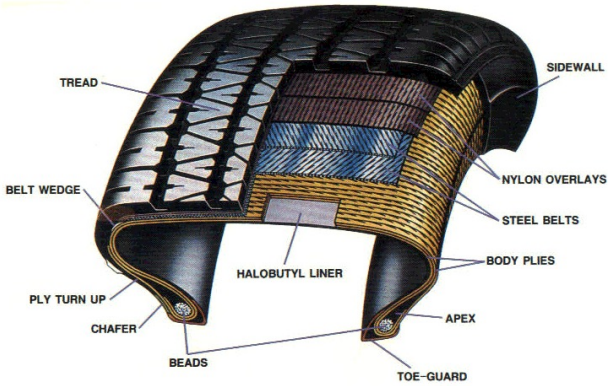
Le marché de l'hydrogène nécessite un important marché de carbone solide

- 1 tonne CH4 produit 250 kg H2 …et 750 kg de carbone solide

- **Applications du carbone solide ?**

GEN 1: Carbon Black





- 12 M tonnes / an
- 15 Milliards € / an (marché)
- **Valeur Premium du Carbone solide**

➔ ***Profitable business right from the start***

GEN 2 : focus sur H_2

➔**Nouvelles applications (massives) de carbone solide**

✓ Routes, matériaux de construction, bétons…

✓ Amendement des sols, agriculture

➔ **Biogaz (RNG)**

✓ Empreinte carbone négative

✓ Puits de carbone

LCA

ARTICLE IN PRESS

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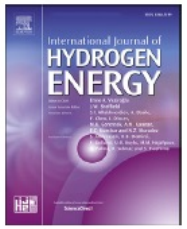

Why turquoise hydrogen will Be a game changer for the energy transition

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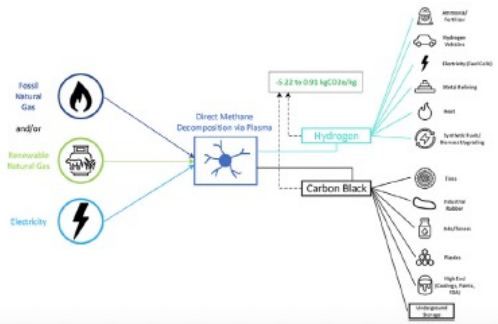
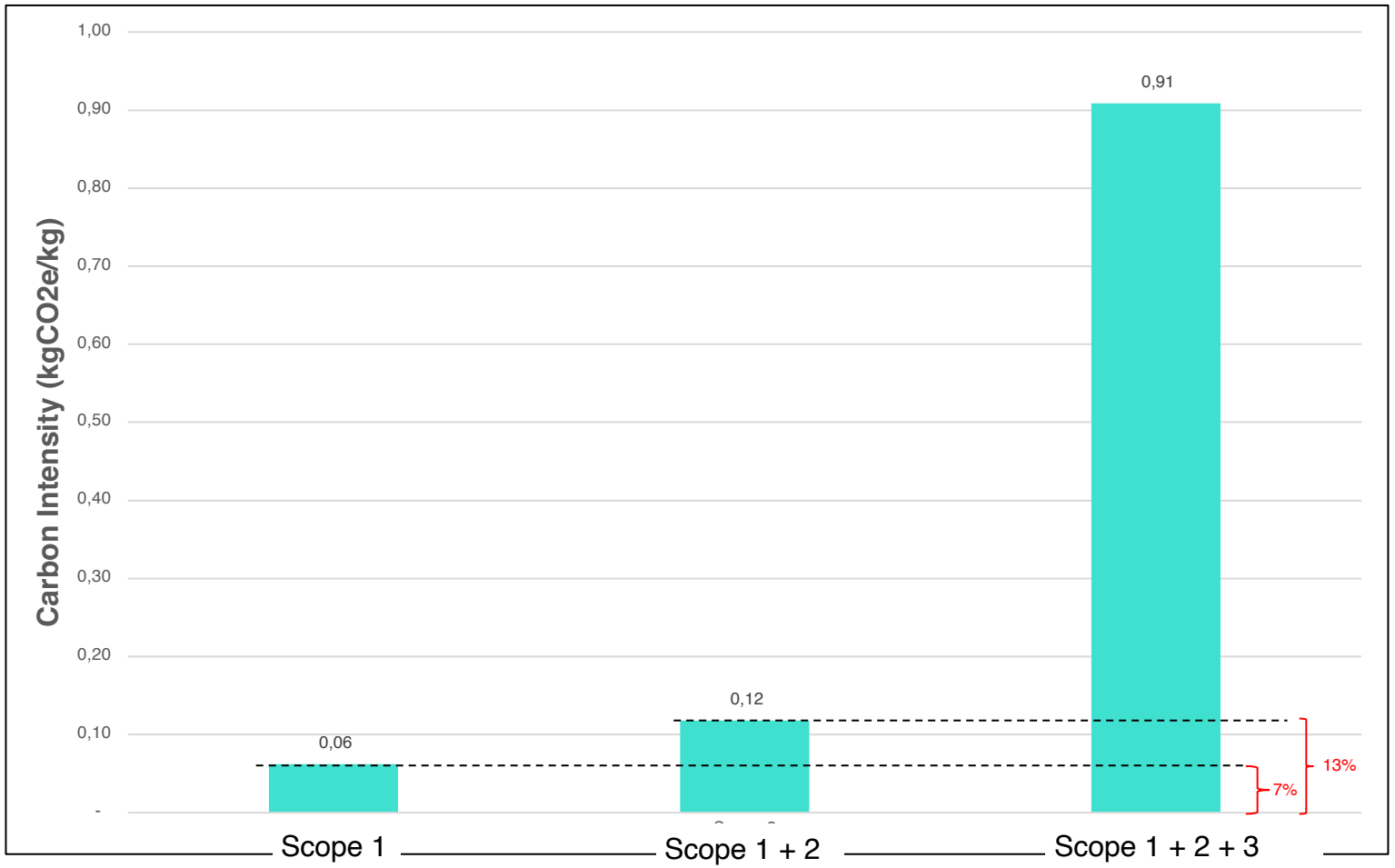
HIGHLIGHTS

- Hydrogen produced by methane pyrolysis via thermal plasma has a very low carbon intensity of 0.91 kgCO2e/kg.
- Sourcing of natural gas is the main factor impacting the carbon intensity.
- Improving natural gas sourcing up to grade A (MiQ) reduces the carbon intensity of hydrogen to 0.45 kgCO2e/kg.
- Replacing the natural gas feed-

GRAPHICAL ABSTRACT

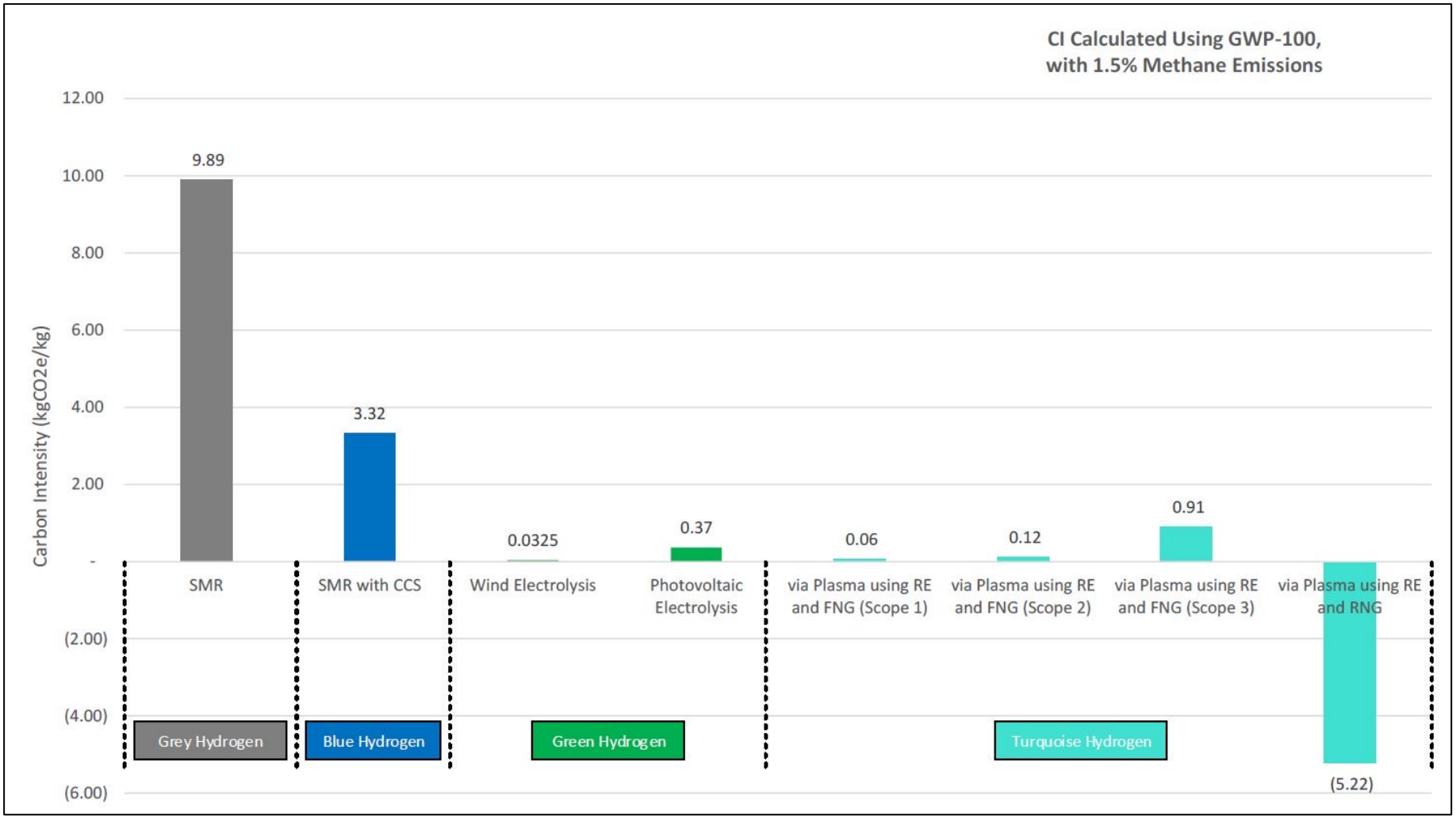


Résultats (1)



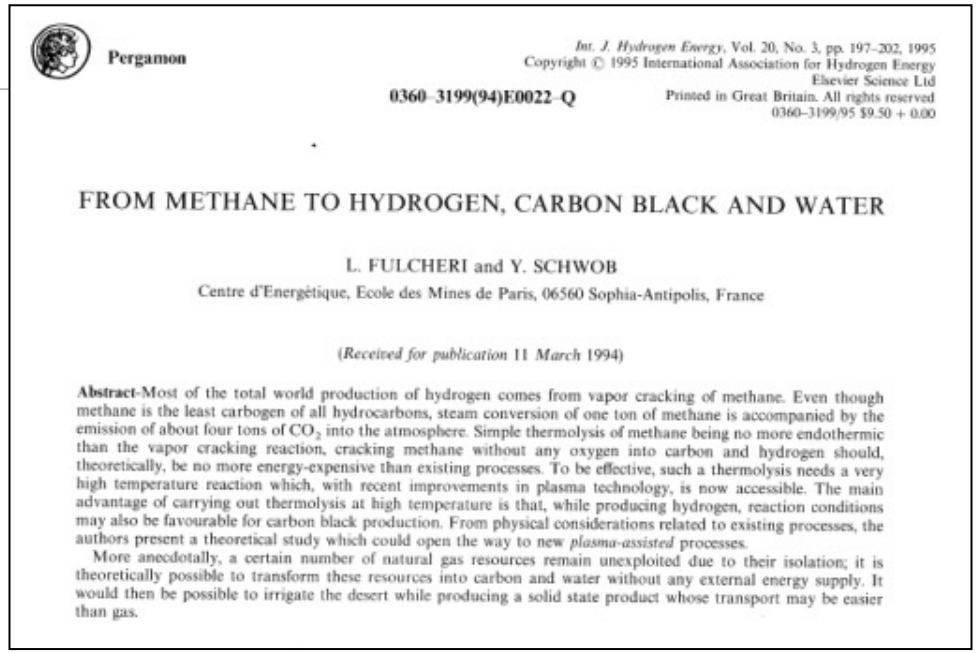
Carbon Intensity of Hydrogen, Carbon-Black, and Coke, for Methane Pyrolysis via Thermal Plasma and for Conventional Processes Using the Mass Allocation Method for Scopes 1, 2 and 3

Résultats (2)


CI Calculated Using GWP-100,
with 1.5% Methane Emissions
Carbon Intensity (kgCO2e/kg)
12.00
10.00
8.00
6.00
4.00
2.00
-
(2.00)
(4.00)
(6.00)
9.89
3.32
0.0325
0.37
0.06
0.12
0.91
(5.22)
SMR
SMR with CCS
Wind Electrolysis
Photovoltaic Electrolysis
via Plasma using RE and FNG (Scope 1)
via Plasma using RE and FNG (Scope 2)
via Plasma using RE and FNG (Scope 3)
via Plasma using RE and RNG
Grey Hydrogen
Blue Hydrogen
Green Hydrogen
Turquoise Hydrogen

Synthèse

Synthèse



Pergamon

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FROM METHANE TO HYDROGEN, CARBON BLACK AND WATER

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(*Received for publication* 11 *March* 1994)

Abstract-Most of the total world production of hydrogen comes from vapor cracking of methane. Even though methane is the least carbogen of all hydrocarbons, steam conversion of one ton of methane is accompanied by the emission of about four tons of CO_2 into the atmosphere. Simple thermolysis of methane being no more endothermic than the vapor cracking reaction, cracking methane without any oxygen into carbon and hydrogen should, theoretically, be no more energy-expensive than existing processes. To be effective, such a thermolysis needs a very high temperature reaction which, with recent improvements in plasma technology, is now accessible. The main advantage of carrying out thermolysis at high temperature is that, while producing hydrogen, reaction conditions may also be favourable for carbon black production. From physical considerations related to existing processes, the authors present a theoretical study which could open the way to new *plasma-assisted* processes.

More anecdotally, a certain number of natural gas resources remain unexploited due to their isolation; it is theoretically possible to transform these resources into carbon and water without any external energy supply. It would then be possible to irrigate the desert while producing a solid state product whose transport may be easier than gas.

- 30 ans R&D
- La pyrolyse du méthane nécessite **10 à 25 kWh par kg H2** (50 kWh pour l'électrolyse de l'eau)
- Technologie mature
- 2019 : 1ere citation dans le rapport de l'AIE « L'avenir de l'hydrogène »
- **Potentiel *game changer* pour la transition énergétique...**

Perspectives

- **US: fort développement attendu**
  - ressources gaz (shale)
  - IRA
- **Europe: peu favorable à court terme**
  - Guerre Russie – Ukraine
  - Biogaz ?
  - UK, Norvège ?


Temperature (K)
20000
10000
5000
2500
1250
600
300
The end
Time = 2.000e-005 s
X
Y
Z