Methodological Framework for Life Cycle Assessment of Hydrogen Production Technology via Non-Thermal-Plasma Methane Cracking

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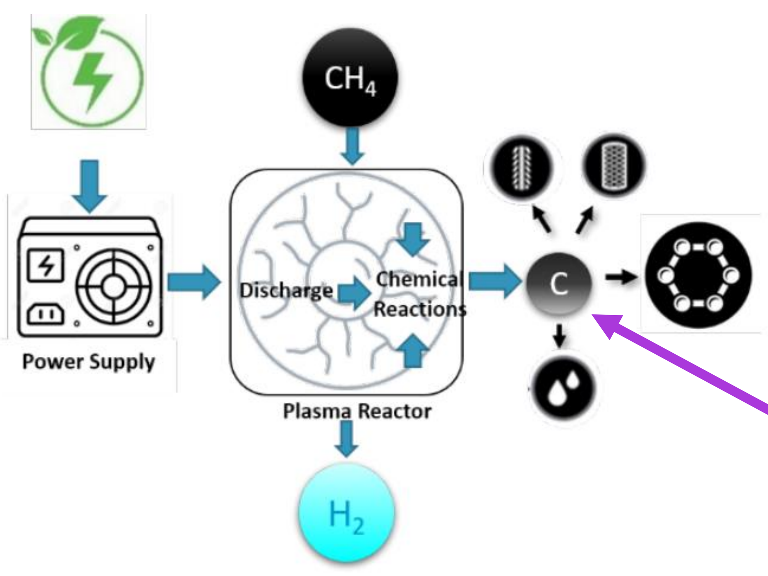
The Non-Thermal-Plasma (NTP) methane cracking technology, developed in the frame of the ColdSpark® European project, is an innovative solution to produce H_2 and elemental carbon with no direct CO_2 emission. Operable at low temperatures and ambient pressure, it obviates the need for catalysts, presenting a promising avenue in the realm of energy transition. The elaboration of a consistent methodological approach to evaluate the process environmental sustainability is essential for the technology development. In this frame, our study is focused on the preliminary analysis of the H_2 life cycle assessment (LCA) methodological framework defining the methodological aspects, methods and parameters for constructing the NTP methane cracking LCA model.

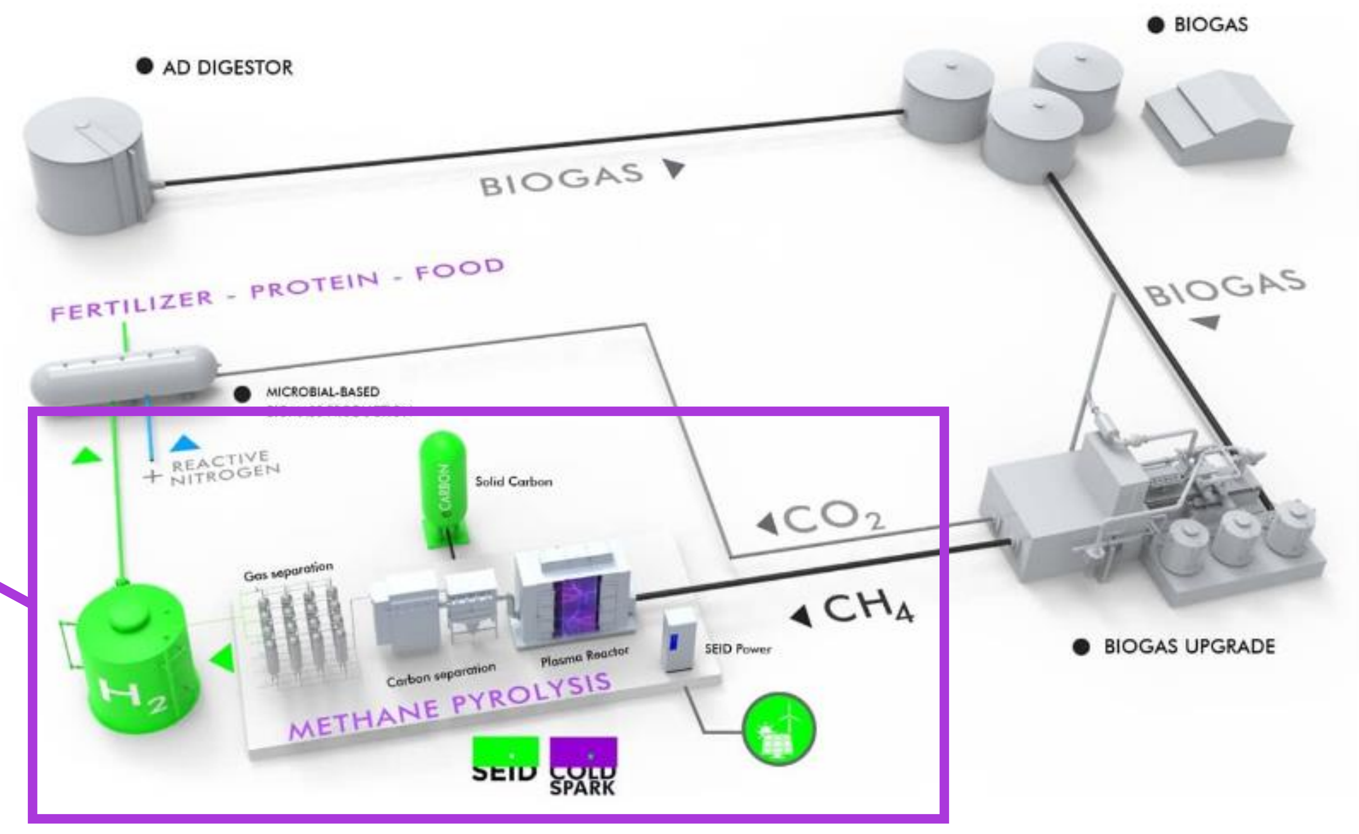
Non-Thermal-Plasma Methane cracking process

The methane cacking technology involves the direct cracking of the methane molecule into hydrogen and elemental carbon:

$$CH_{4(g)} \rightarrow C_{(s)} + H_{2(g)}$$

In the NTP technology the hydrogen and added value carbon is produced with no CO_2 direct emissions, no water consumption and lower energy consumption than water electrolysis (<15 kWh/kg H_2),





Hydrogen Life Cycle Assessment (LCA) Guidelines

The LCA methodology, supported by the ISO 14040/44:2006, involves a comprehensive evaluation of the potential environmental impacts of product systems through the life cycle stages. Its development in the European context is represented by the ILCD handbook (JRC 2010a) and by the definition of the European Environmental Footprint method (EF). In the Hydrogen context there are specific methodologies. These guidelines were revised to unify the methodological framework as showed in tables below.

Methodology	Organization	Scope
Guidance Document for Performing LCA on Hydrogen Production Systems	Fuel cell and Hydrogen – Joint Undertaking	Hydrogen LCA Guideline in EU context
Methodology for Determining the Greenhouse Gas Emissions Associated with the Production of Hydrogen	International Partnership for Hydrogen and Fuel Cells in the Economy	Hydrogen Carbon Footprint guideline
Harmonised Carbon and Energy Footprints of Fossil Hydrogen."	Valente, Iribarren, and Dufour IMDEA Energy, Juan Carlos University	Global warming potential (GWP) and Cumulative non-renewable energy demand (CED) impact indicators harmonization
Harmonising Methodological Choices in Life Cycle Assessment of Hydrogen."	Valente, Iribarren, and Dufour IMDEA Energy, Juan Carlos University	Acidification potential (AP) impact indicators harmonization
Directive (EU) 2018/2001 of 11 December 2018 on the promotion of the use of energy from renewable sources and Commission Delegated Regulation (EU) 2023/1185	European Parliament and of the Council	Sustainability certification of fuel of biomass origin • Sustainability requirements • greenhouse gas emissions savings (gCO2/MJ)

Topic	Methodological parameters
Product system information	○ State hydrogen pressure, temperature, and purity. ○ State hydrogen production capacity
Goal and Scope definition	○ Unambiguously define the goal of the study. ○ The system boundary (cradle to gate or cradle to grave) shall be consistent with the goal of the study. ○ Use "production of a certain amount of hydrogen" as the functional unit (FU). ○ Use the ISO hierarchy for solving multifunctional processes*. ○ In comparative studies, methodological and data assumptions shall be analogous. ○ Allocation for recycling using the End-of-Life (EoL) approach 50-50. *LHV Allocation method is recommended in the GHG calculation for renewable H_2 with biological origin
Life cycle analysis	○ Define foreground and background processes considered to fill data gaps with secondary data. Foreground data should be asked of the developers of the technology.
Life Cycle Impact Assessment (LCIA)	○ Use midpoint indicator for studies on hydrogen production: Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP), and renewable/non-renewable Primary Energy Demand (PED).
Life cycle interpretation	○ Identify and evaluate opportunities to reduce environmental impacts at each life cycle stage. ○ Evaluate the sensitivity of results to assumptions and data limitations. ○ Make recommendations to improve the environmental profile of the technology.
Enhancing of the LCA model	○ Update the LCA periodically as the system evolves and new data becomes available

Life Cycle Assessment Methodology for Non-thermal-Plasma Methane cracking

Goal and scope: Evaluate the environmental impact of the NTP Methane cracking Hydrogen Production.

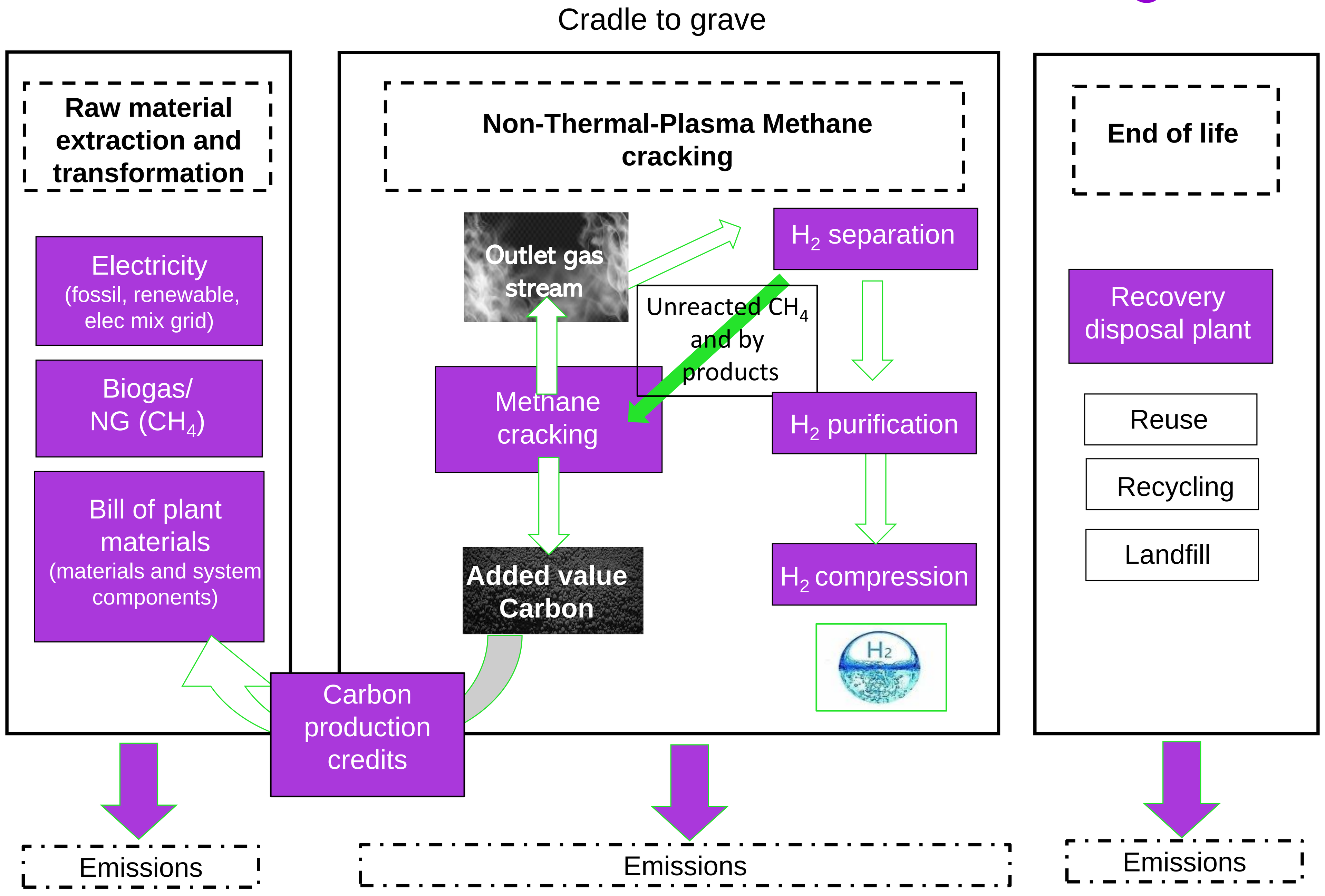
Functional Unit: 1 kg H_2

System boundaries: Cradle to grave (from raw material extraction, methane cracking reaction, H_2 separation, purification, compression and plant end of life).

Multifunctional approach: System expansion with negative carbon credits from elemental carbon production.

Environmental Impact Categories: Impact Indicators following the European Environmental Footprint Method.

kg CO_2 eq | CTUh | kg Sb eq | MJ



Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Climate, Infrastructure and Environment Executive Agency (CINEA). Neither the European Union nor the granting authority can be held responsible for them.

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