Reliability and resilience engineering for green hydrogen production process

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Outline

- Hydrogen: alternative energy carrier
- H_2 production methods & color codes
- Review article
    - Green H_2 production plant
    - Methodology and results
    - Contribution, research gaps and challenges

H_2 : alternative energy carrier

- According to Paris Agreement, the global average temperature increase should be kept below 2^o C.

- EU countries and other nationalities aim to achieve carbon neutrality by 2050.

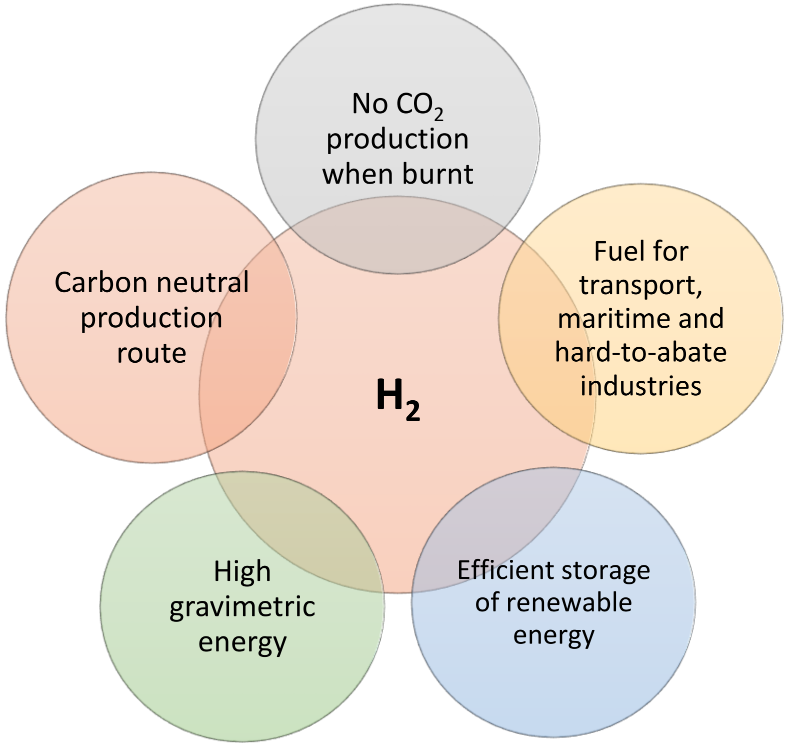
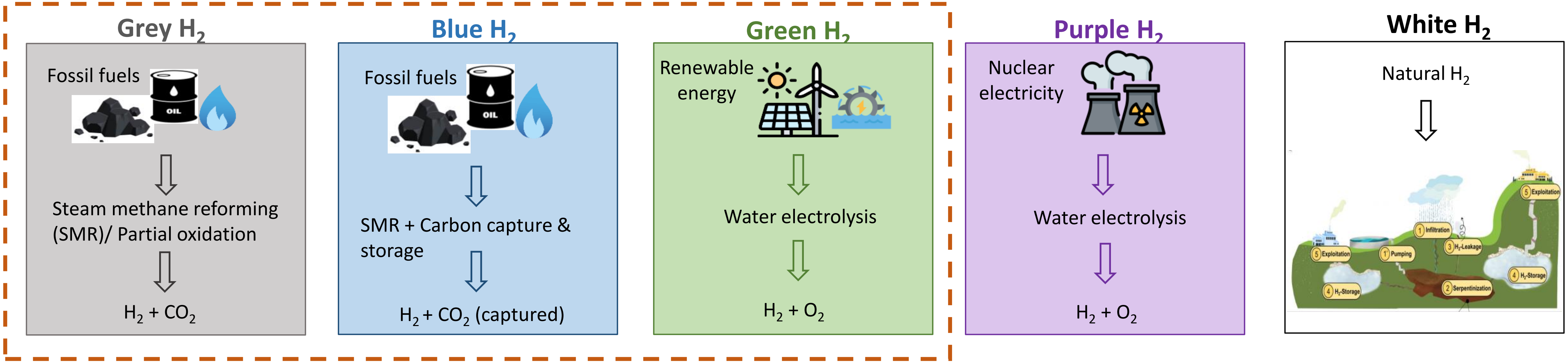


Table 1: Physical properties of hydrogen (IEA, 2019)

Property	Hydrogen	Comparison
Density (gaseous)	0.089 kg/m3 (0°C, 1 bar)	1/10 of natural gas
Density (liquid)	70.79 kg/m3 (-253°C, 1 bar)	1/6 of natural gas
Energy per unit of mass (LHV)	120.1 MJ/kg	3x that of gasoline
Energy density (ambient cond., LHV)	0.01 MJ/L	1/3 of natural gas
Specific energy (liquefied, LHV)	8.5 MJ/L	1/3 of LNG
Flame velocity	346 cm/s	8x methane
Ignition range	4–77% in air by volume	6x wider than methane
Autoignition temperature	585°C	220°C for gasoline
Ignition energy	0.02 MJ	1/10 of methane

H_2 production methods & color codes



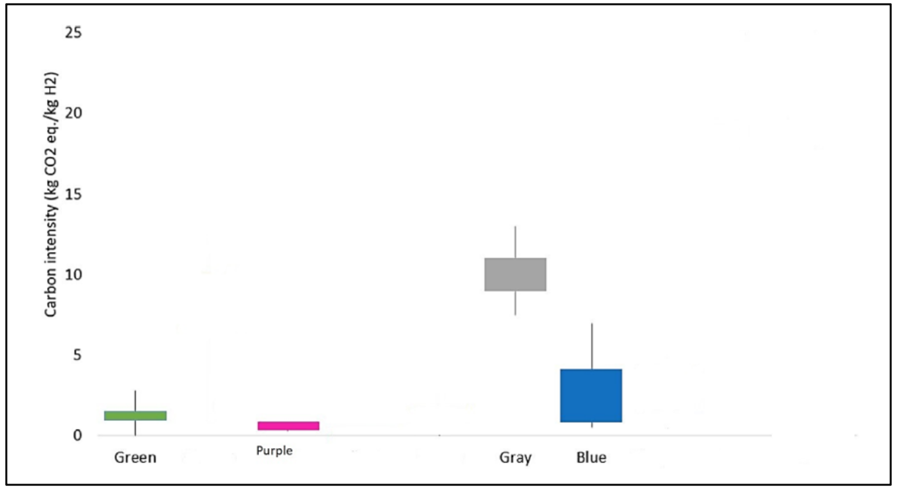


Figure 1: Carbon intensity of the hydrogen colors (Incer-Valverde et al., 2023)

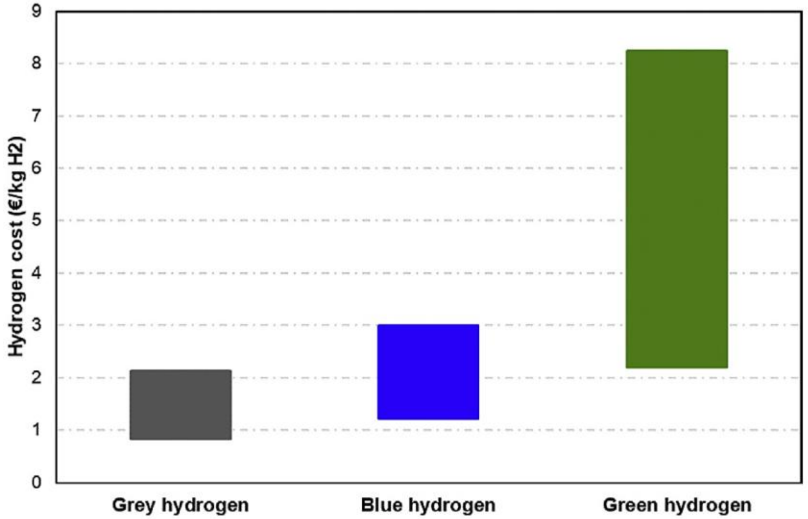


Figure 2: Reported cost of hydrogen production for different production pathways (Ajanovic et al., 2022)

High cost for green H2???

- Premature technologies
- Unexpected production shutdown
- Incidents & accidents
- Associated expenses in maintenance and repairs

Reliability engineering

Reliability engineering refers to the engineering discipline for applying scientific knowledge to a component, plant, or process, generally termed as system, in order **to ensure that it performs its intended function**, for the required time duration in a specified environment.

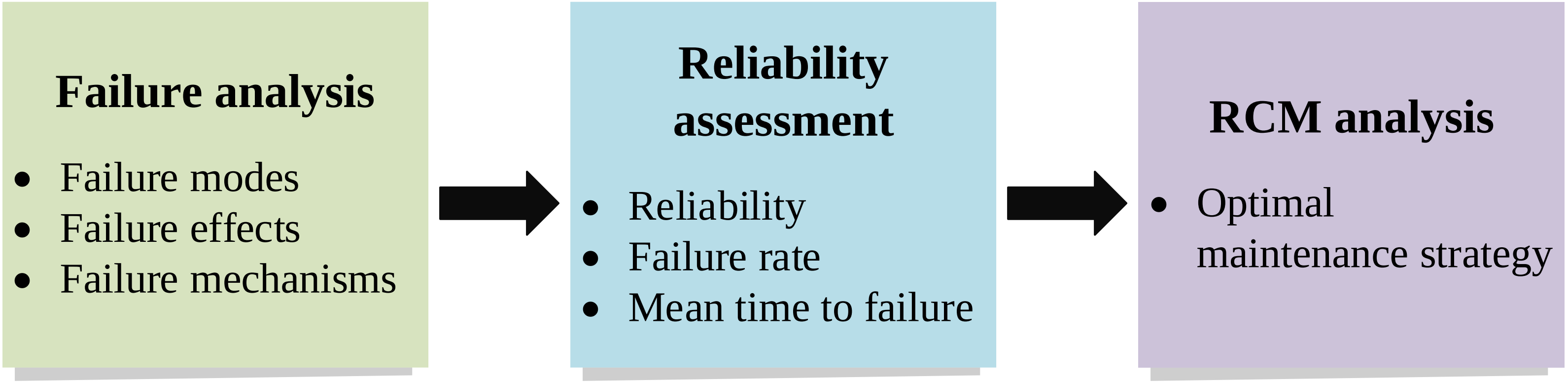


Figure 3: Three steps of reliability engineering and the results obtained from each step

Nuclear Industry — Chemical industry — Oil & gas industry

Applied RE ⇒

- Prevent technical failures
- Enhance operational efficiency
- Reduce unnecessary maintenance costs

= Fail-safe, efficient operation and economic savings

Review article

Tuhi FY, Bucelli M, Liu Y. *Technical failures in green hydrogen production and reliability engineering responses: Insights from database analysis and a literature review.* Int J Hydrog Energy 2024;94:608–25.

The research objectives are:

- **Present the state-of-the-art research** work related to the application of reliability engineering steps in the hydrogen field and industries similar to it;
- **Discuss contribution and potentials** of reliability engineering in green H_2 ;
- **Identify research gaps** in the field of green hydrogen production;
- **Highlight challenges of implementing the reliability engineering** for green hydrogen production plant.

SCAN ME

https://doi.org/10.1016/j.ijhydene.2024.11.129

Green H_2 production plant

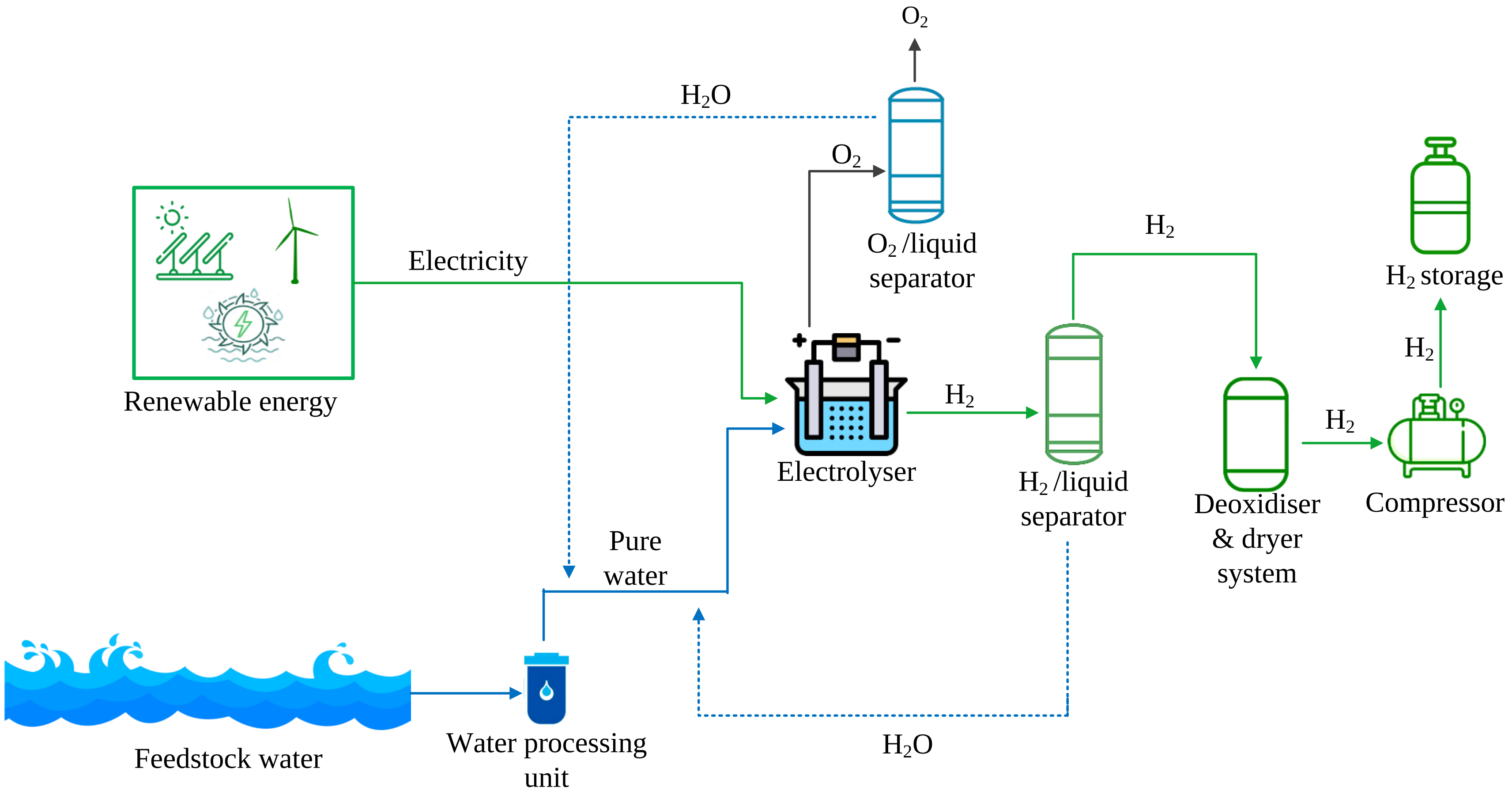


Figure 4: Schematic of a water electrolysis based green hydrogen production plant

Methodology

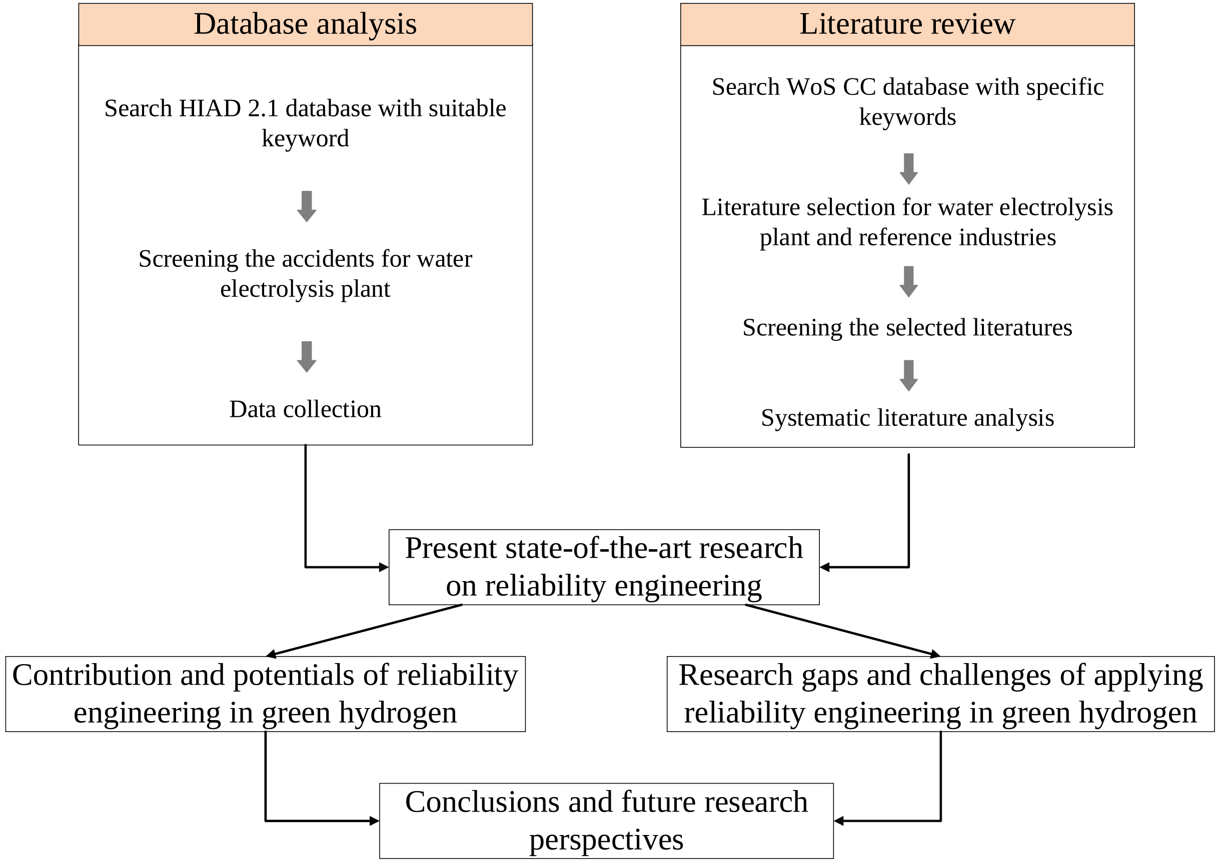


Figure 5: Overall research methodology

Reference industries

- Fuel cell technology
- Chemical industry
- Water treatment industry
- Oil and gas industry

Table 2: Queries and filters selected in Web of Science Core Collection database

Type	Description
Queries	1. "Hydrogen production" AND ("reliability analysis" OR "reliability engineering") 2. "Fuel cell" AND ("reliability analysis" OR "reliability engineering") 3. "Hydrogen" AND ("reliability analysis" OR "reliability engineering") 4. "Chemical industry*" AND ("reliability analysis" OR "reliability engineering") 5. "Oil and gas" AND ("reliability analysis" OR "reliability engineering") 6. "Hydrogen" AND "Reliability centered maintenance" 7. "Chemical industry" AND "Reliability centered maintenance" 8. "Oil and gas industry" AND "Reliability centered maintenance"
Analysis Field	Topic (searches title, abstract and author keywords)
Document Type	Journal articles, review articles, conference proceedings, reports
Language	English
Countries/Regions	Global
Publication Year	Not specified

Results: Database analysis & Literature review

Accidents reviewed

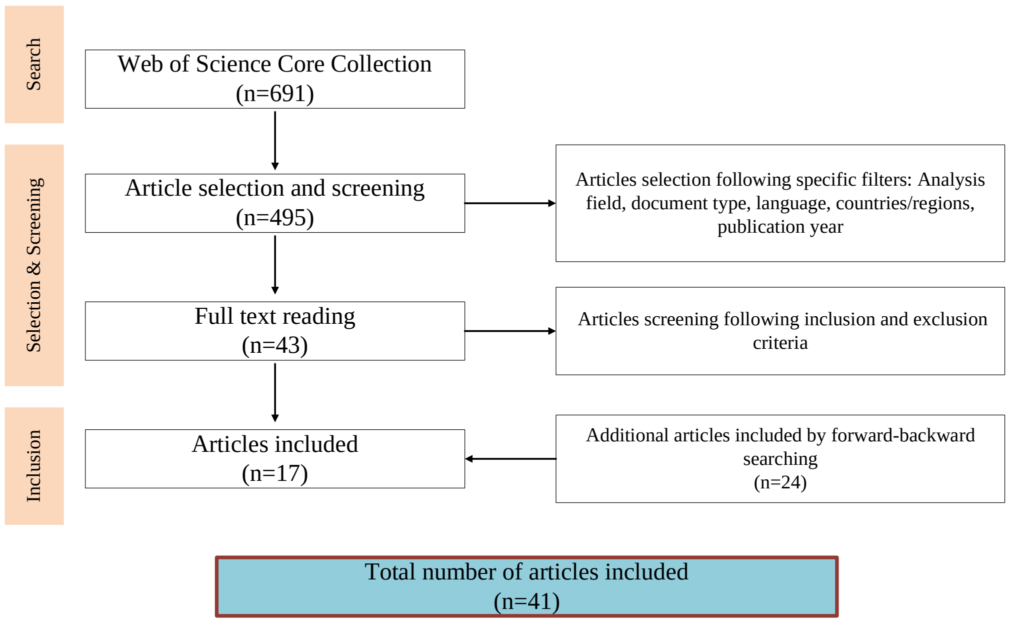
HIAD #778 HIAD #889

HIAD #243 HIAD #1084

HIAD #1002 HIAD #1037

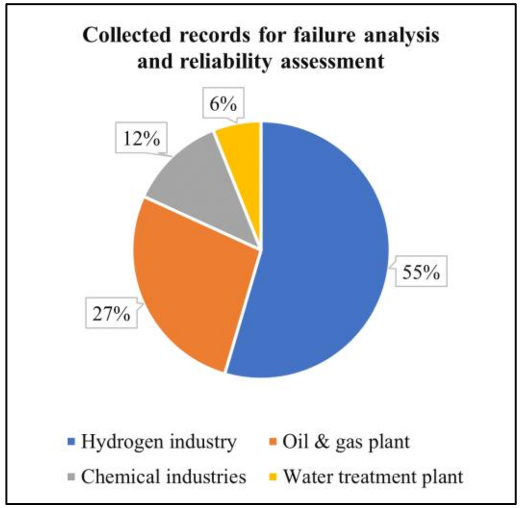
HIAD #970 HIAD #1065

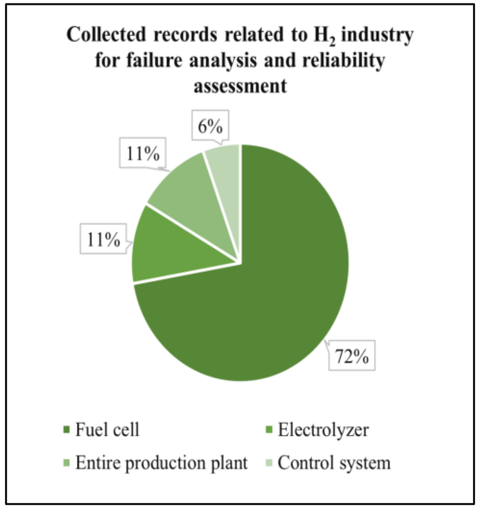
Event description
Failure cause
Consequence
Damage & Fatalities
Lessons learnt

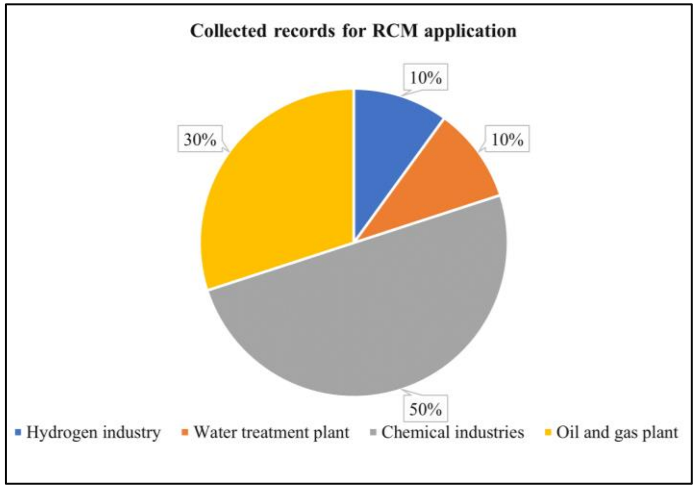


Failure analysis & reliability assessment = 31

Reliability centered maintenance (RCM) = 10







Contribution & potentials of reliability engineering in green H_2

Contributions to understanding & avoiding failures

- Well recorded failure data in database;
- Proven methods for determining failure modes, causes and probabilities;
- Established approaches of identifying critical components.

Contributions to guiding system design & development

- Facilitated procedure for understanding system reliability;
- Guiding system development.

Contributions to system operation assurance

- Well developed theories and framework for planning & managing maintenance;
- Preparedness for system degradation and unexpected event.

Identified research gaps & challenges

Research gaps

- Insufficient failure analysis and degradation modelling of electrolyzers;
- Lack of reliability assessment of auxiliary components;
- Overlook the impacts of human and environmental factors;
- Absence of study on maintenance of water electrolysis plants.

Challenges

- Absence of reliability database specific for hydrogen;
- Particular degradation phenomena and high explosion risk due to hydrogen's inherent properties;
- High complexity due to multi-system coupling and multi-operational states;
- Intermittent issues related to power supply;
- Inexperience in human-machine interplays and human factors issues;
- Needs of multidisciplinary approach.

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Thank you for your attention!

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