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State-of-the-art and knowledge gaps in gaseous hydrogen pipelines: from the perspective of materials, design, and integrity management

Key words:

Hydrogen pipelines, Hydrogen embrittlement, Standards, Pipeline design, Hydrogen velocity

Summary

This review focused on the current state of hydrogen pipelines in terms of material compatibility with hydrogen, design methods, process operations, safety monitoring, and standards, this paper focuses on the following knowledge gaps in gaseous hydrogen pipelines:

- **Utilization of high-strength materials for hydrogen pipelines,**
- **Design of high-quality hydrogen pipelines,**
- **Determination of hydrogen velocity,**
- **Repurposing of existing natural-gas pipelines.**

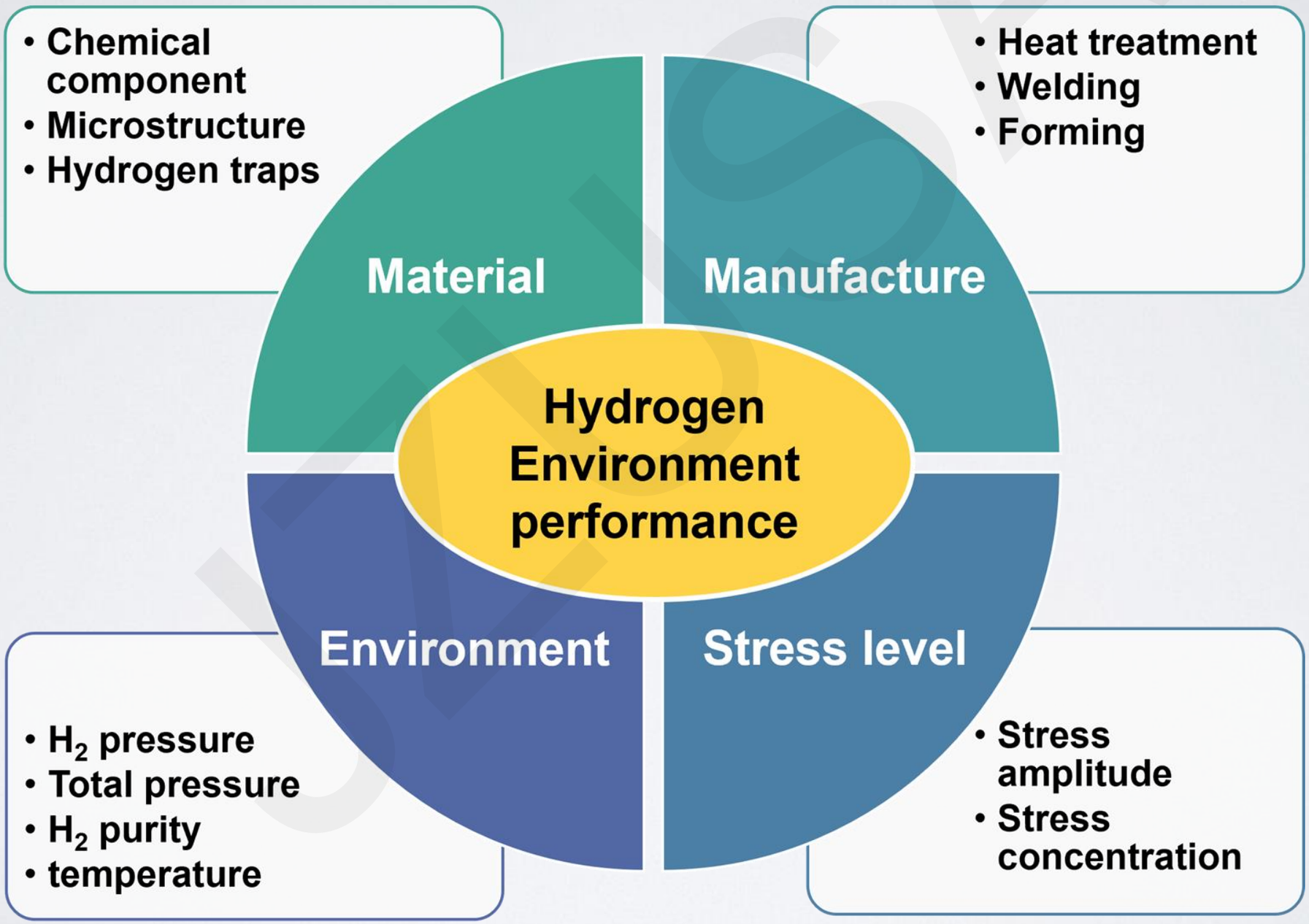
This review aims to identify the challenges in current hydrogen pipelines development and provide valuable suggestions for future research.

Comparison of materials, diameters, and pressures of hydrogen and natural gas pipelines

	Pipeline Name	Material	Thickness (mm)	Pressure (MPa)	Diameter (mm)
Natural gas pipelines	Bovanenkovo-Ukhta	X80	23, 27.7, 33.4	11.8	1420
	West-to-East Gas Transmission Line 1	X70	14.6	10	1016
	West-to-East Gas Transmission Line 2	X80	18.4	12	1219
	Nord Stream pipeline	X70	26.8–41	22–10.6	1220, 1153
	China-Russia Eastern Pipeline	X80	21.6	12	1422
Hydrogen pipeline	Jiyuan-Luoyang	L245 (equals API 5L grade B)	11.1, 11.9	4	508
	Texas Hydrogen Pipeline	X42	/	3–4	273
	SNAM 440 km (planning)	X60	11.1, 15.9	/	660

- A major trend in pipeline technology is to **increase the pressure and diameter.**
- Hydrogen pipelines commonly use **relatively low-strength materials** (such as X42 and X52), resulting in low transport efficiency and high construction costs

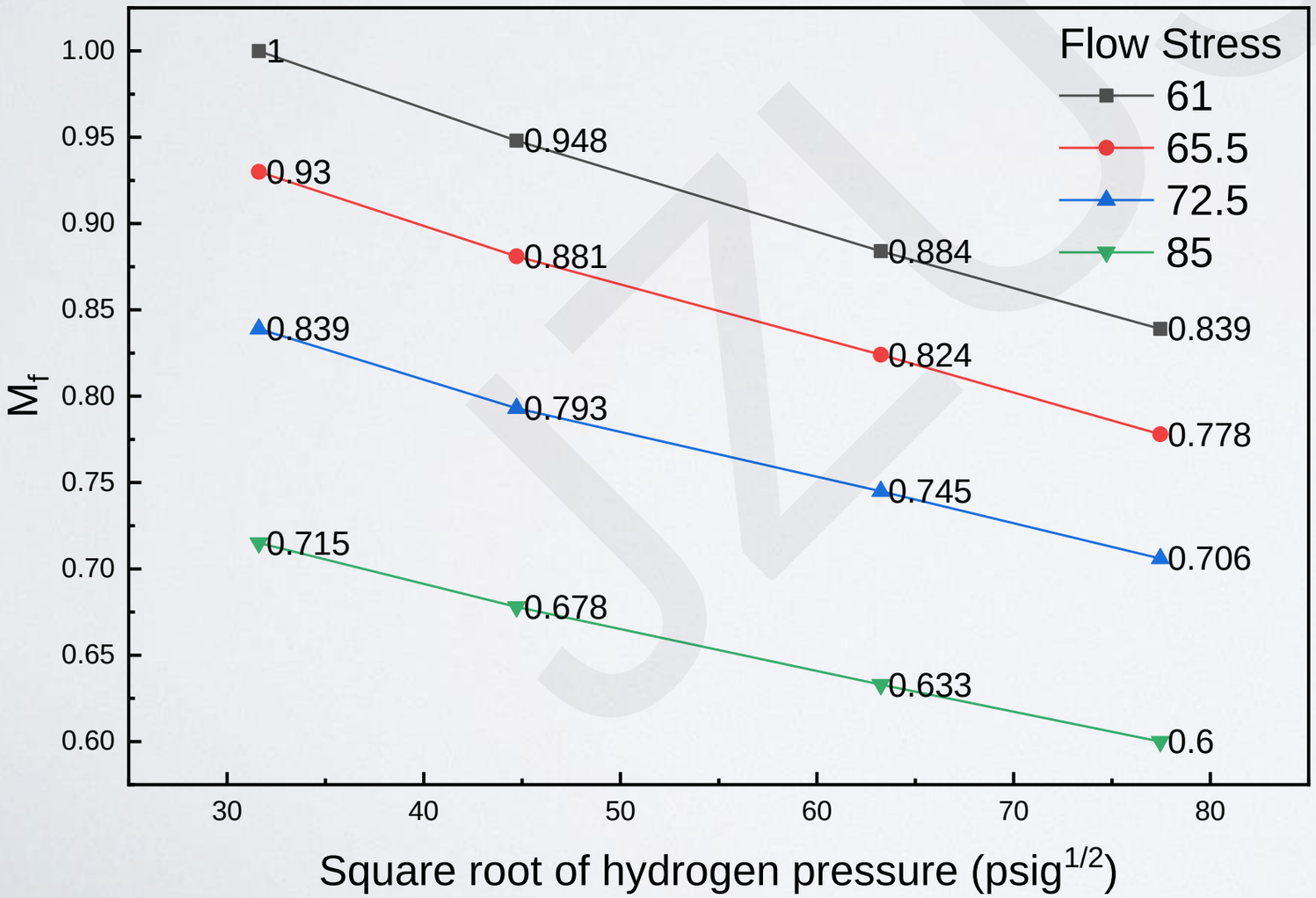
Factors affecting mechanical properties of steel in hydrogen environments



Design method of hydrogen pipelines

The values of the material performance factor in ASME B31.12 adhere to two key assumptions.

- Firstly, the material performance factor exhibits a linear correlation with the **square root of the hydrogen pressure** following Sievert' s law.
- Secondly, the material performance factor displays linearity proportional to the material **flow stress.**

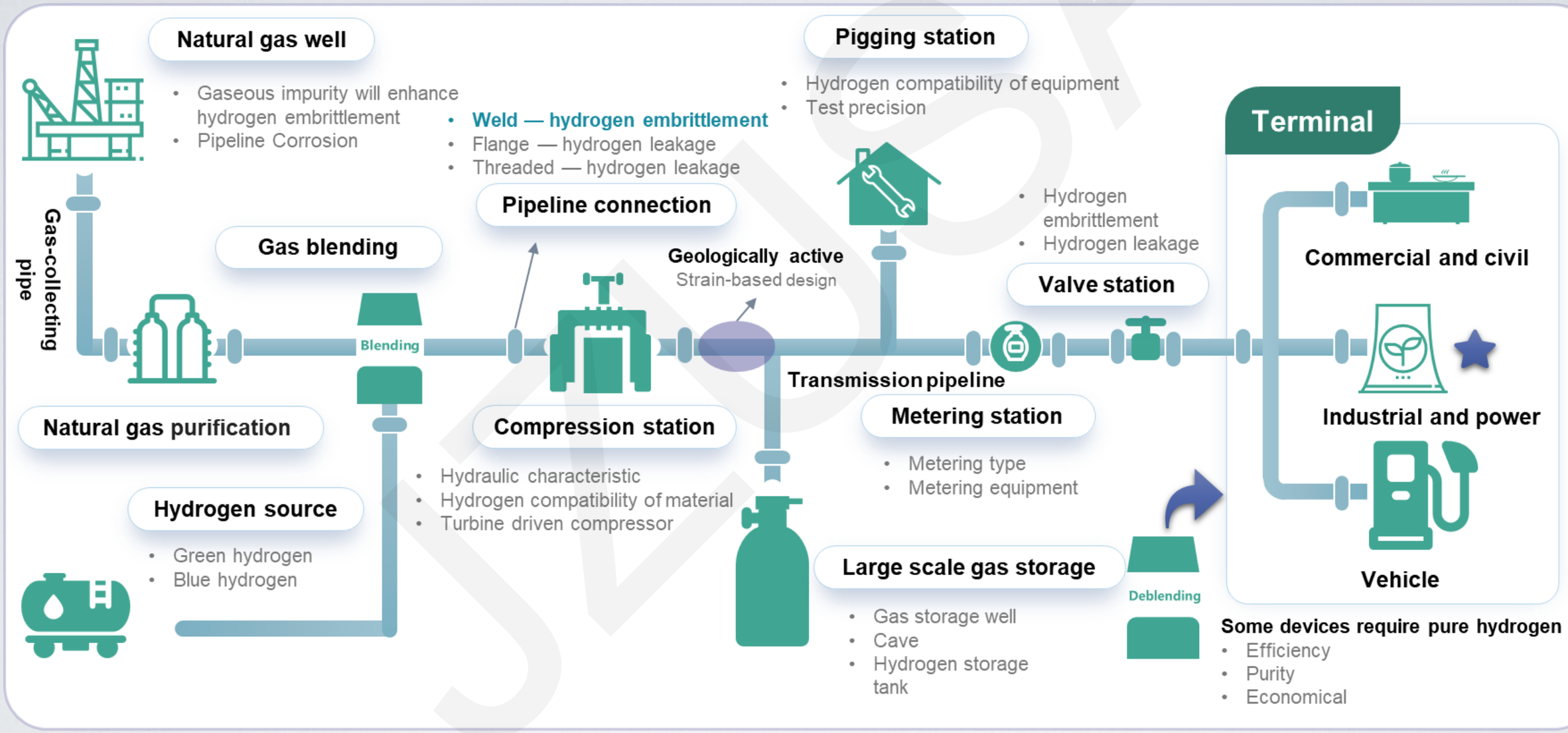


$$P = \frac{2St}{D_o} FE_1TH_f$$

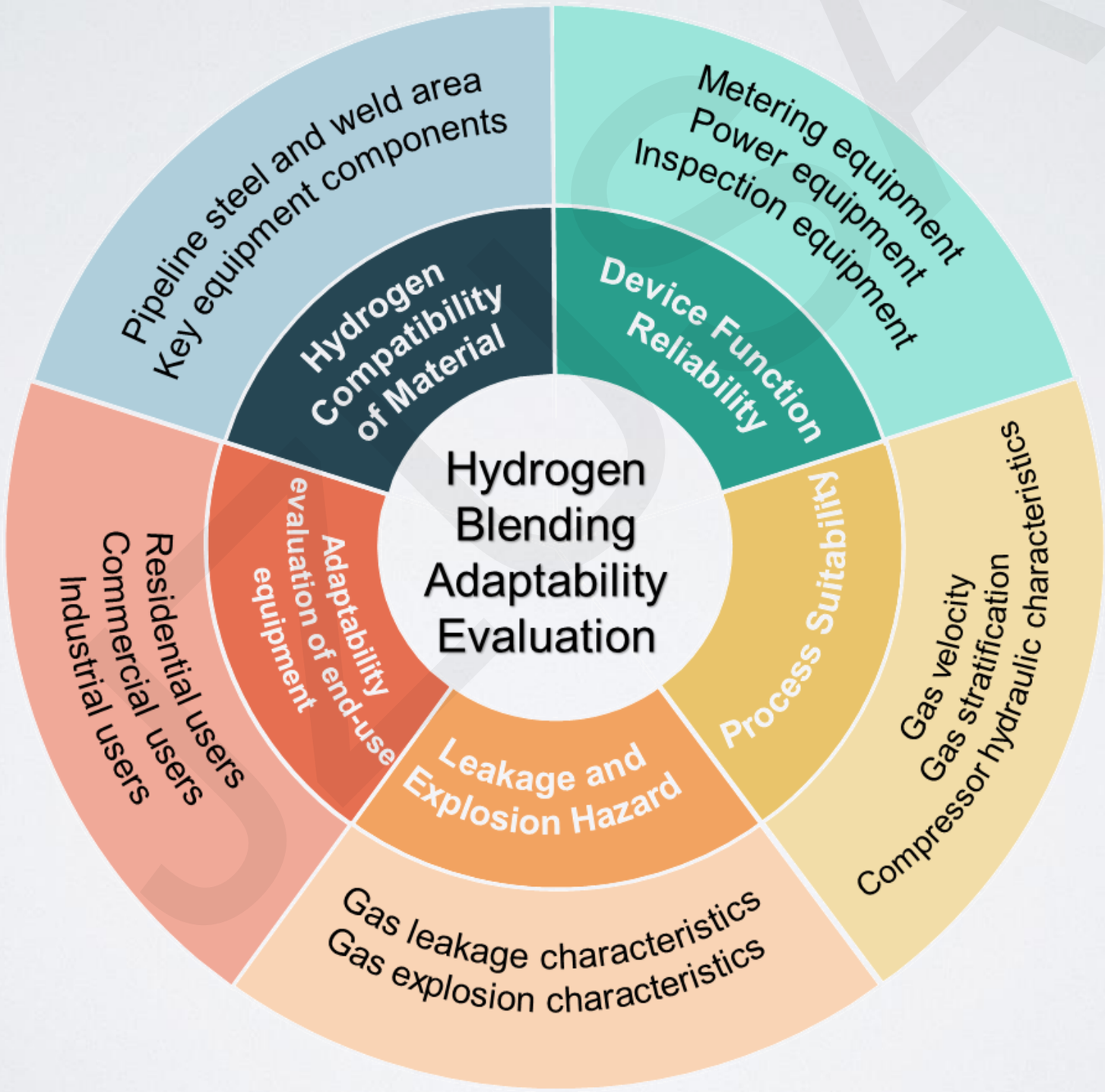
Material performance factor

Flow stress represents the average of the specified maximum ultimate tensile strength and minimum yield strength

The process of blending hydrogen into natural gas pipelines



How to evaluate the adaptability of hydrogen blending in natural gas pipelines



Current codes regarding repurposing of existing natural gas pipelines

Code	Title	Section	Code	Title	Section
ASME B31.12 - 2019	Hydrogen piping and pipelines	Part PL 3.21 - steel pipeline service conversions	ASME B31.12 - 2019	Hydrogen piping and pipelines	Part PL 3.21 - steel pipeline service conversions
IGEM/TD/3 Edition 5 Supplement 1	Repurposing of natural gas pipelines with MOP not exceeding 7 bar for NG/hydrogen blends	/	IGEM/TD/3 Edition 5 Supplement 1	Repurposing of natural gas pipelines with MOP not exceeding 7 bar for NG/hydrogen blends	/
CGA G5.6-R2013	Hydrogen Pipeline Systems	Appendix H - Requalification of existing pipelines for hydrogen service	CGA G5.6-R2013	Hydrogen Pipeline Systems	Appendix H - Requalification of existing pipelines for hydrogen service
AIGA 033-2014	Hydrogen Pipeline Systems	Generally consistent with CGA G5.6	AIGA 033-2014	Hydrogen Pipeline Systems	Generally consistent with CGA G5.6
ISO 13623:2017/DAM1	Complementary requirements for the transportation of fluids containing carbon dioxide or hydrogen	Appendix H.9 Repurposing	ISO 13623:2017/DAM 1	Complementary requirements for the transportation of fluids containing carbon dioxide or hydrogen	Appendix H.9 Repurposing