PPSA – 5th November 2021

WHEN BOTH SHALL MEET: MANAGING INTEGRITY FOR H_2 AND CO_2 CONVERSION

In cooperation with

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presented by

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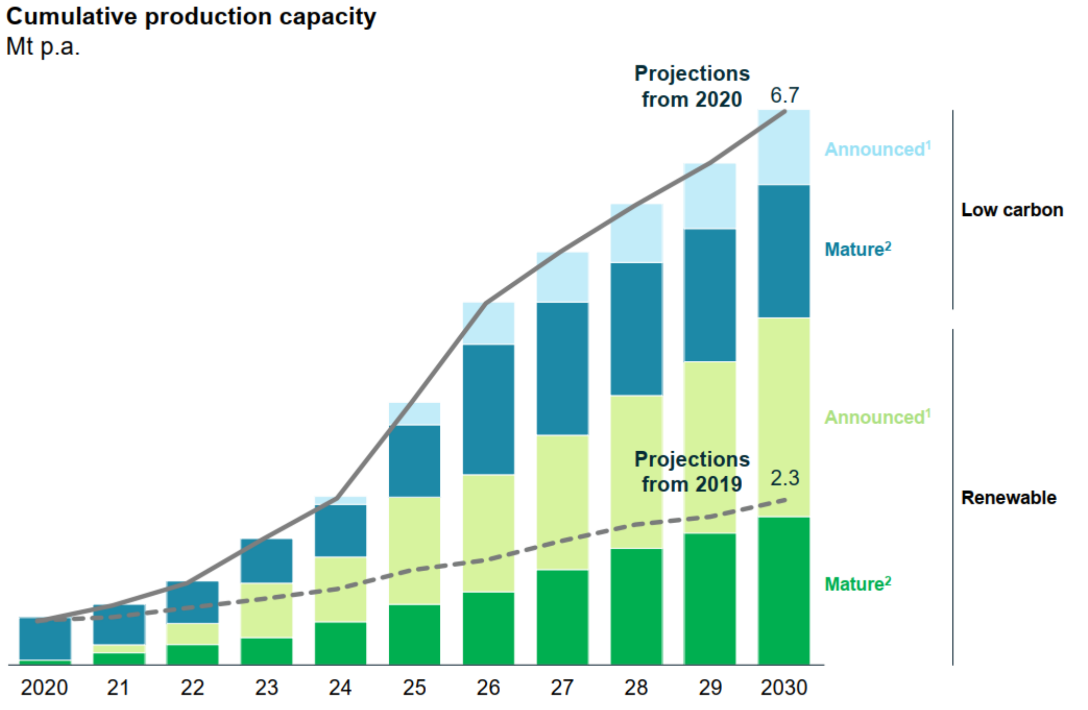
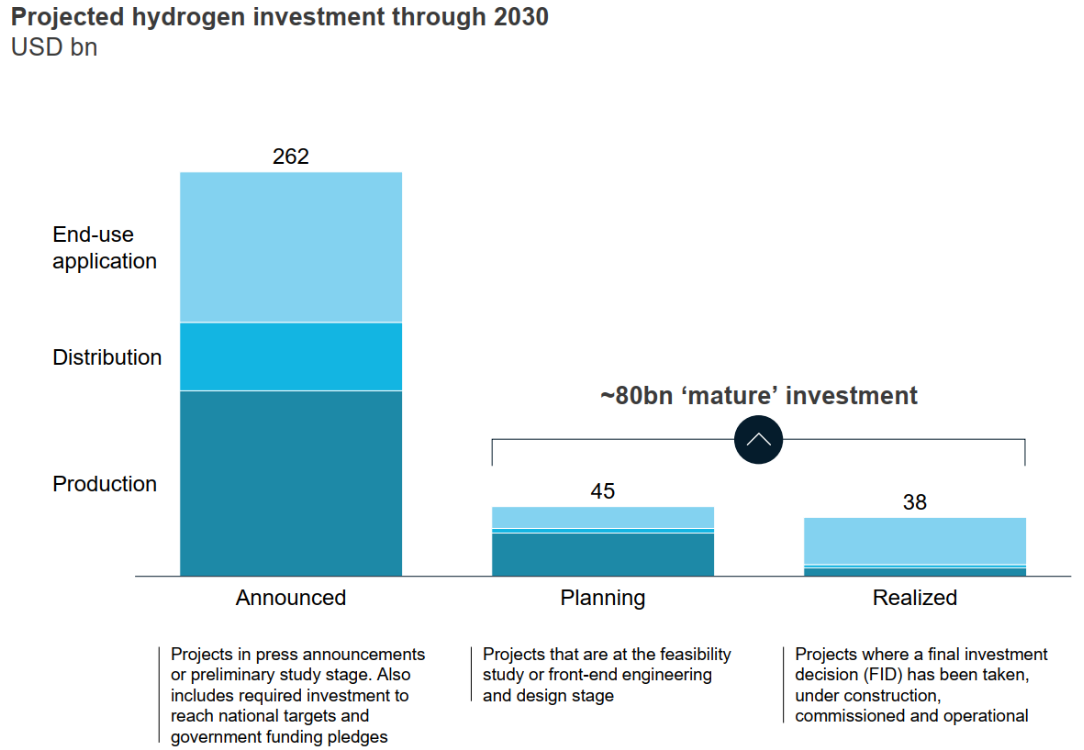
Principal Engineer

INVESTMENTS INTO HYDROGEN ARE GATHERING MOMENTUM

Announced clean hydrogen capacity through 2030



Breakdown of announced investments by maturity



Source: Hydrogen Insights Report 2021, Hydrogen Council, McKinsey & Company, February 2021

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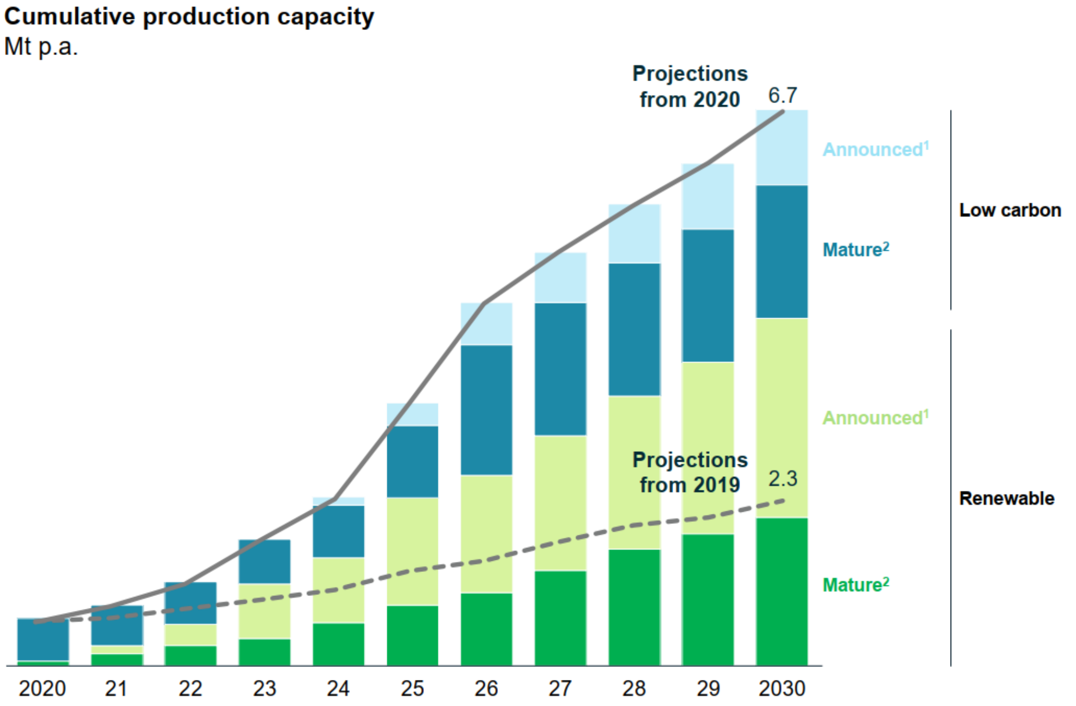
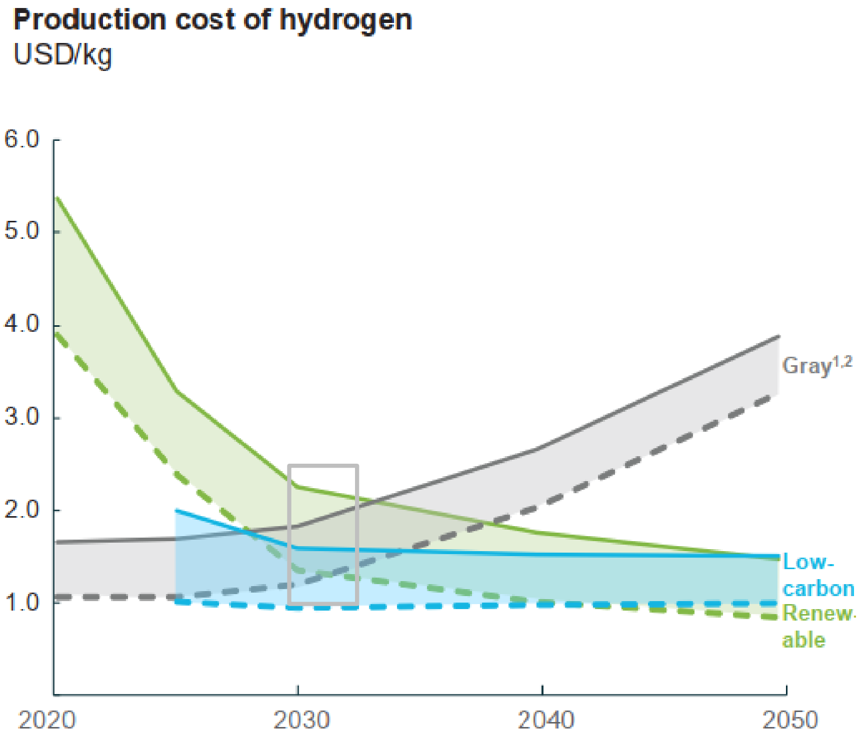


Role of 'Blue hydrogen' in transition



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‘Investments into hydrogen are gathering momentum’

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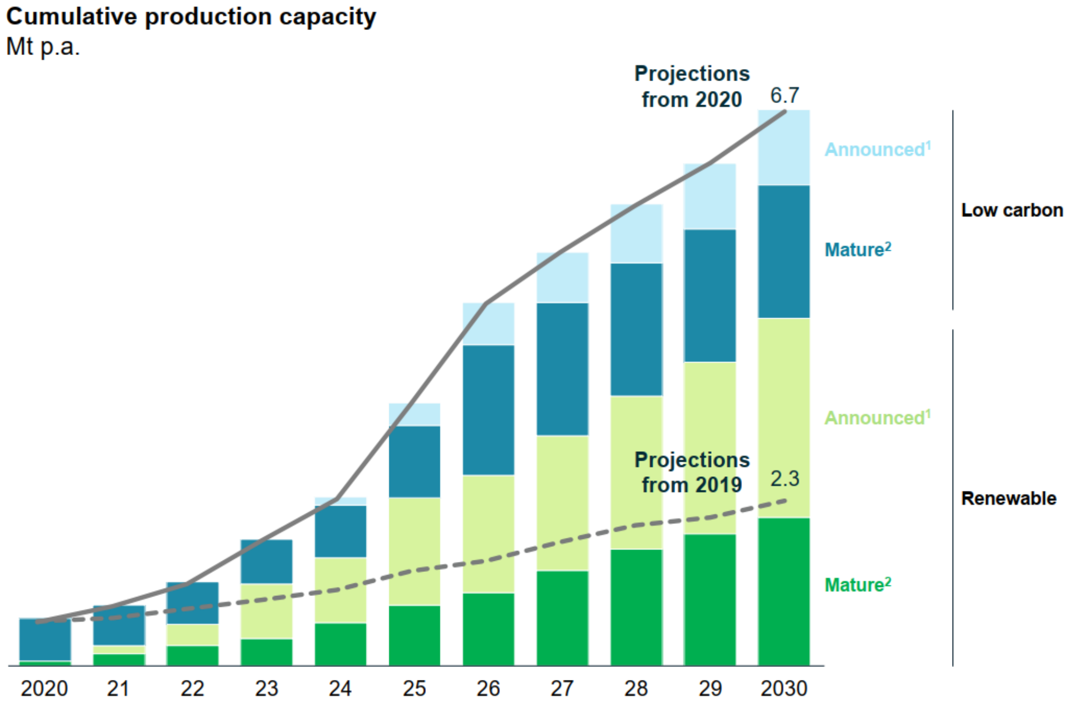
Announced clean hydrogen capacity through 2030



Role of ‘Blue hydrogen’ in transition

“Without CCUS, the transition would become much more challenging”

- ~2.5 Mt blue H_2 by 2030 (SMR)
- **~ 50 million tons CO_2**
- **+ CO & H_2S by-products**
- ***‘CCUS is necessary’***

Source: Hydrogen Insights Report 2021, Hydrogen Council, McKinsey & Company, February 2021

Retrofitting existing pipelines for H_2

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Connecting industrial clusters to an emerging infrastructure in 2030

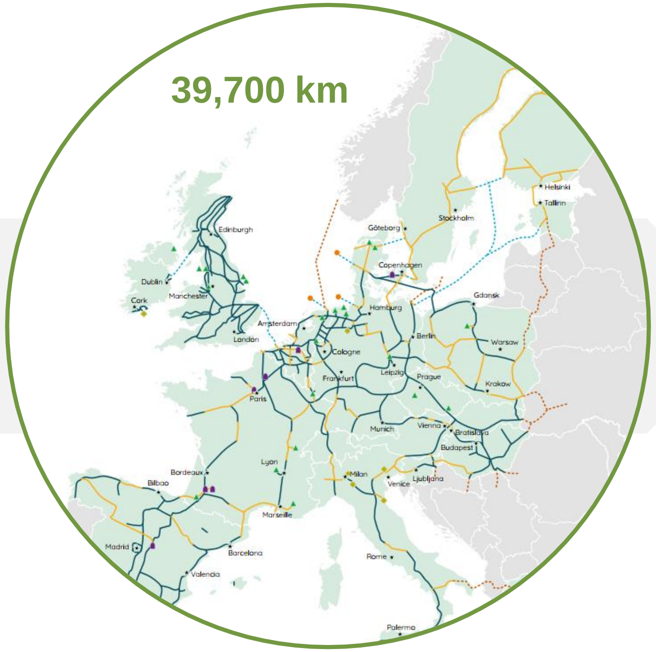
Dedicated European Hydrogen Backbone can develop with a total length of approximately 11,600 km, consisting mainly of retrofitted existing natural gas pipelines.

Regional backbones are expected to form in and around first-mover hydrogen valleys.

Growing network by 2035 covers more countries and enables import

The European Hydrogen Backbone will continue to grow, covering more regions and developing new interconnections across member states.

Dedicated hydrogen storage facilities such as salt caverns, depleted fields and aquifers become increasingly important to balance fluctuations in supply and demand.



Mature infrastructure stretching towards all directions by 2040

The proposed backbone can have a total length of 39,700 km, consisting of approximately 69% retrofitted existing infrastructure and 31% of new hydrogen pipelines.

Total estimate investment is expected to be between 43 and 81 billion euros

Retrofitting existing pipelines for CO_2

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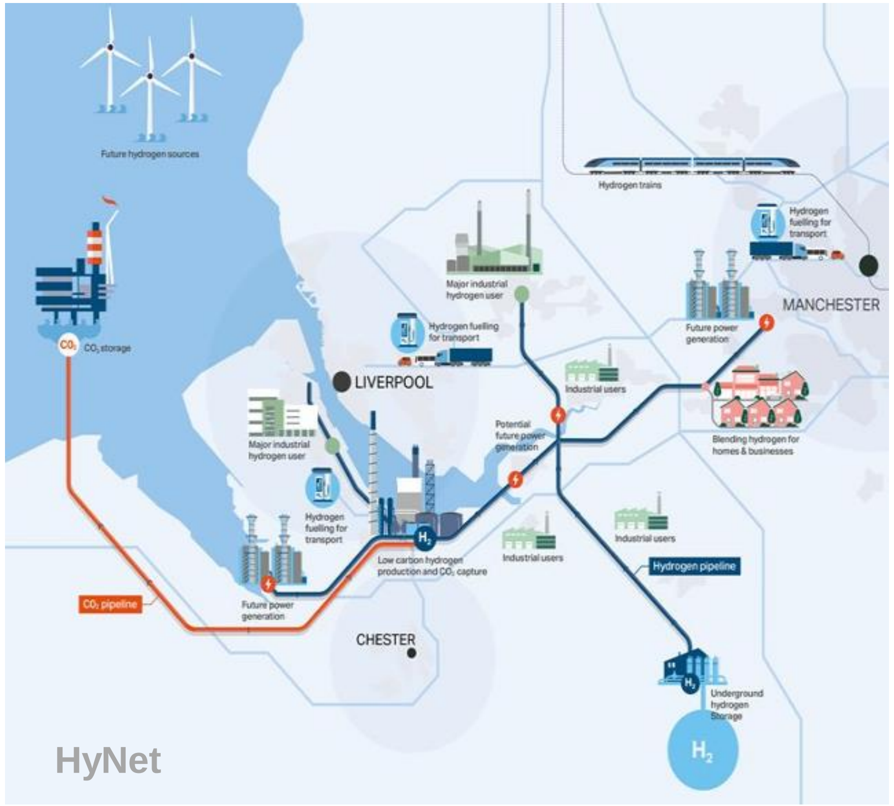
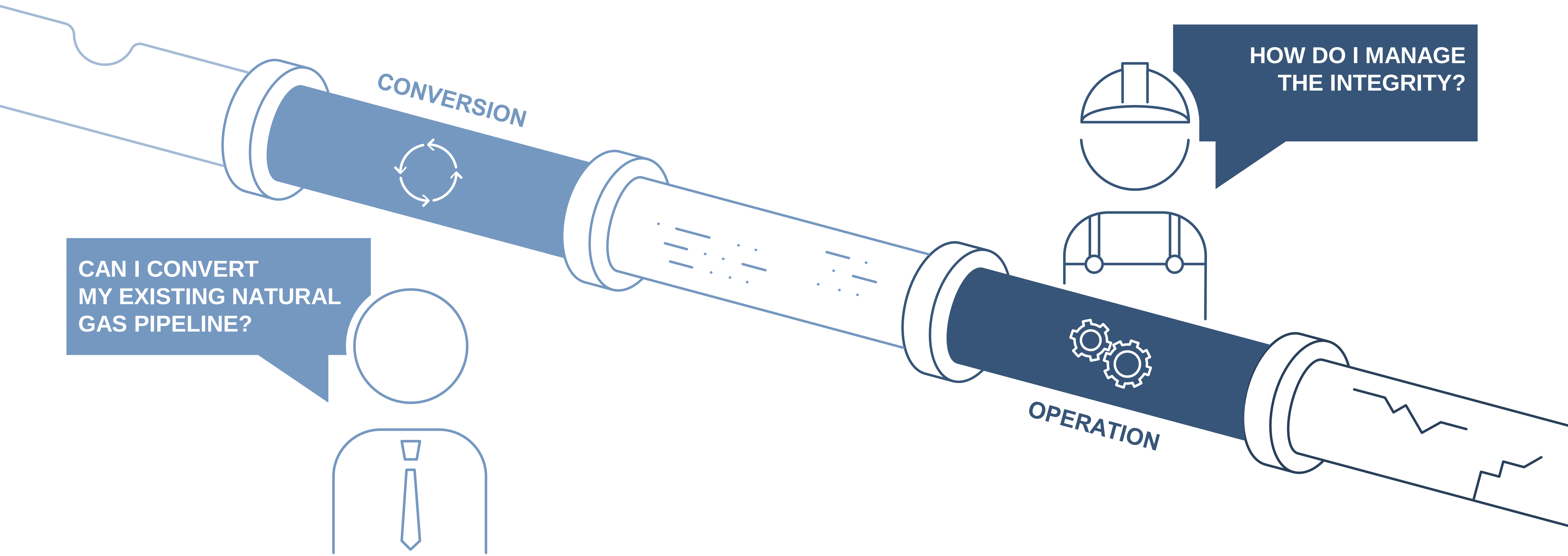
“Transportation infrastructure to be built in the coming 30-40 years to be ~ 100 times > than current”

Repurposing Existing Assets



Conversion management

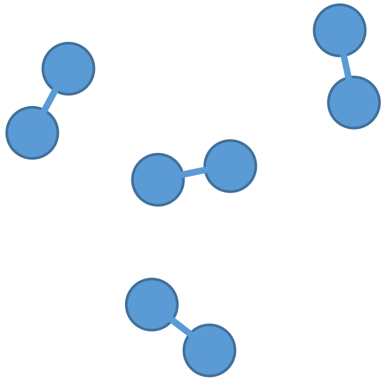


- *Safely Managing the Transition of Pipelines to H_2, E.-Peppler M et al. World H_2 congress 2021*
- *Crack Management in Hydrogen pipelines, Sandana D et al., ICHS 2021*
- *Existing pipeline materials and the transition to hydrogen, Gallon N et al., PTC 2021*

Conversion management

Conversion management

H_2

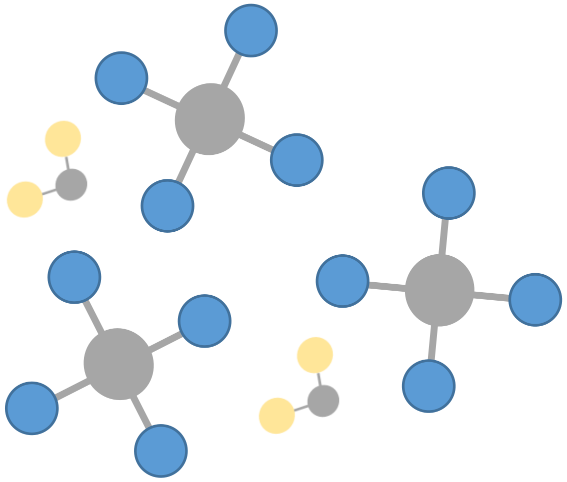


- ✓ Material prop.?
- ✓ Crack Management?

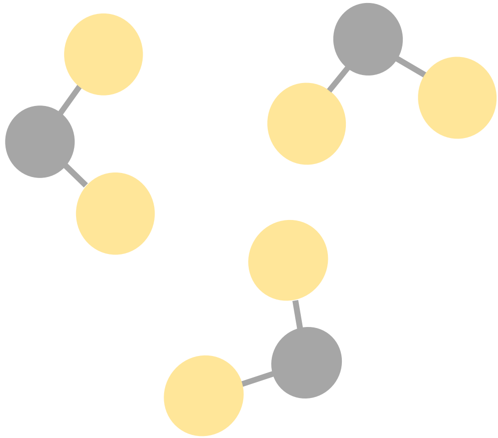
…Pre-existing vs new threats…

- ✓ FFP / ERLs?

Hydrocarbon



CO_2

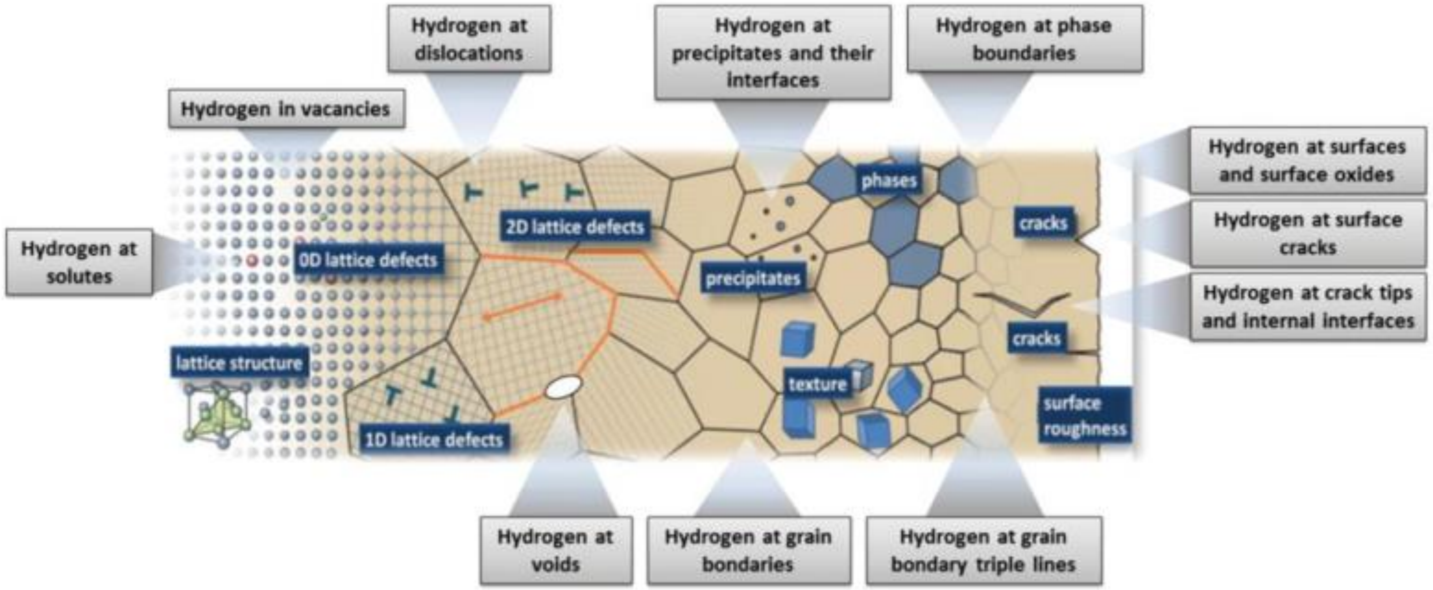


- ✓ New IC threats?
- ✓ IC Threat Severities?
- ✓ Loss of containment behav.?

Conversion management
…Hydrogen challenges

Hydrogen Interaction

Koyama et al.



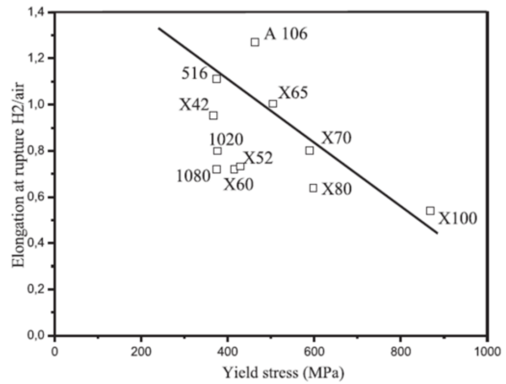
Interaction vs Steel Materials
…Hydrogen Embrittlement…

..Microstructure driven!...
(Not just grade!)

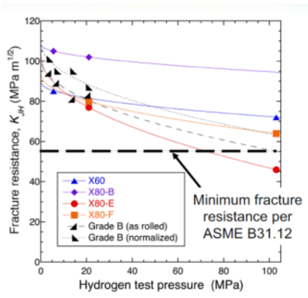
Don’t assume lower bound Properties!

Conversion management
…Hydrogen challenges

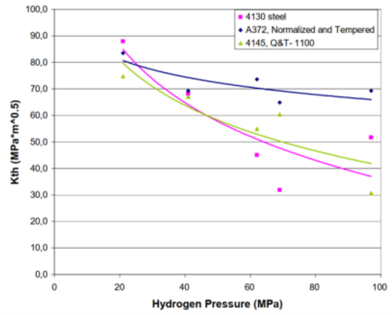
Property	Effect of Hydrogen
Strength	↔ (?)
Ductility	↓
Fracture Toughness	↓
Time-dependant crack threats (e.g. fatigue, SCC)	↑



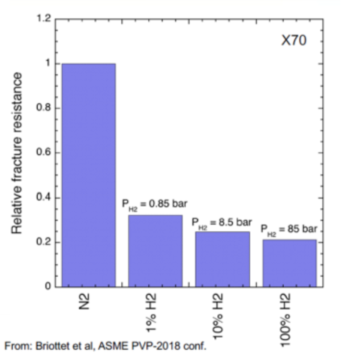
From Boukortt et al., Hydrogen Embrittlement Effect on the Structural Integrity of an API 5L X52 Steel Pipeline, International Journal of Hydrogen Energy, 2018



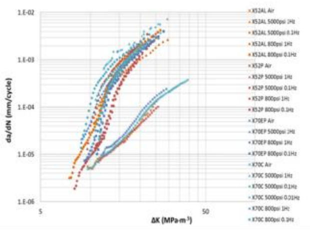
From: San Marchi et al. ASME PVP-1011 conf.

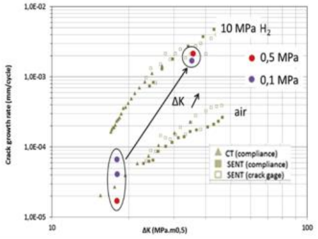


From: Barthelemy, Effects of Purity and Pressure on the Hydrogen Embrittlement of Steels and Other Metallic Materials,
http://conference.ing.unipi.it/ichs2009/images/stories/papers/149.pdf

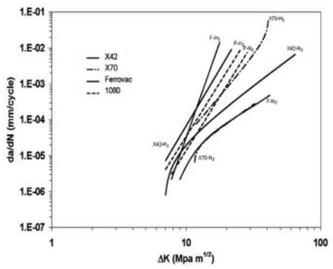


From: Briottet et al, ASME PVP-2018 conf.


From: Chen et al., Performance Evaluation of High-Pressure Gaseous Hydrogen Transportation, CRES Report 2013.

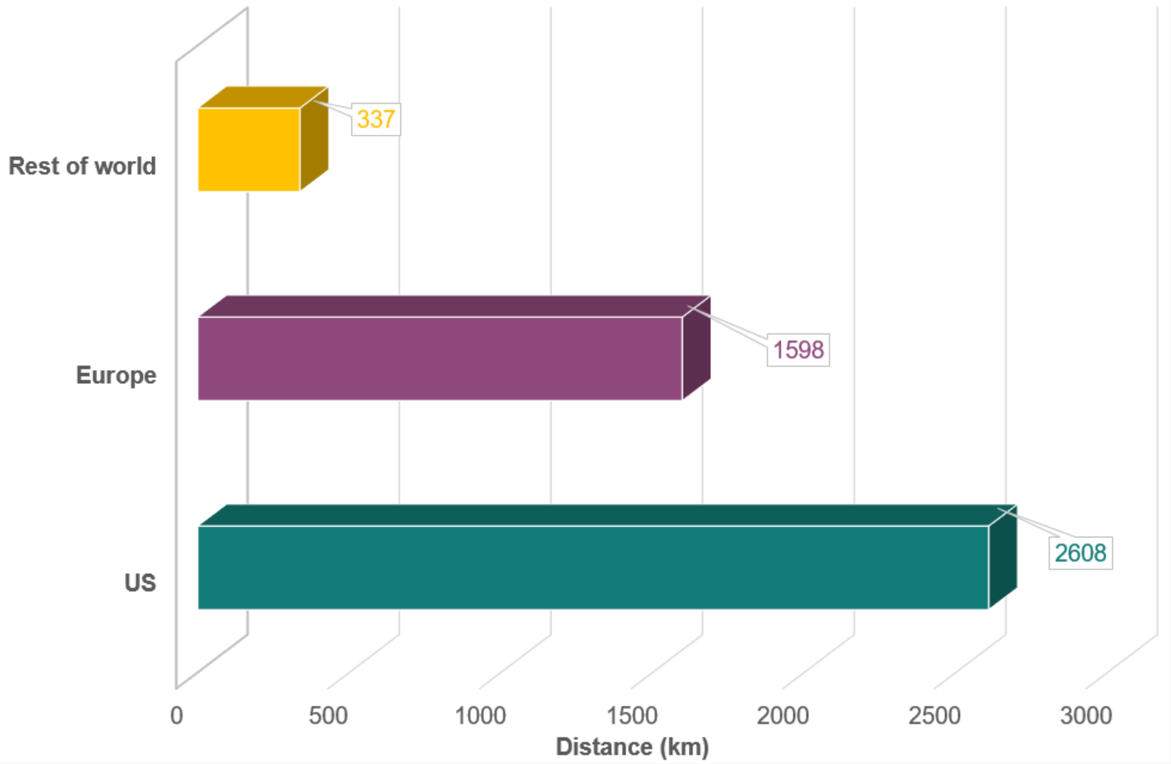


From Briottet et al., Fatigue Crack Initiation and Growth in a CrMo Steel Under Hydrogen Pressure, International Journal of Hydrogen Energy, 2015.

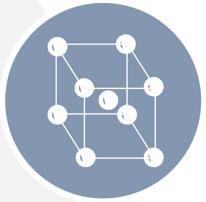


From Nanninga et al., A review of Fatigue Crack Growth for Pipeline Steels Exposed to Hydrogen, NIST Journal, 2010.

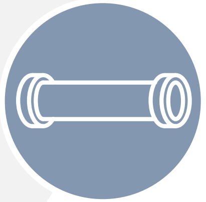
Conversion management
…Hydrogen challenges(?)



ASME B31.12 / EIGA / AIGA



Low grade



Relatively small diameter

Low utilisation

Conversion management
…Hydrogen

H_2 codes

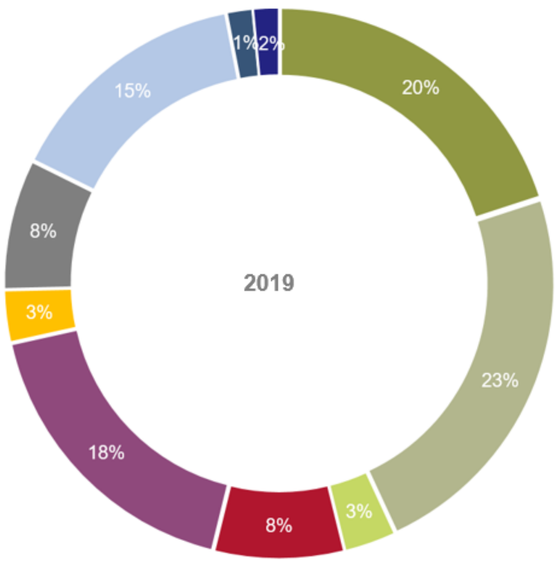
ASME B31.12 / EIGA / AIGA

Low grade <=X52

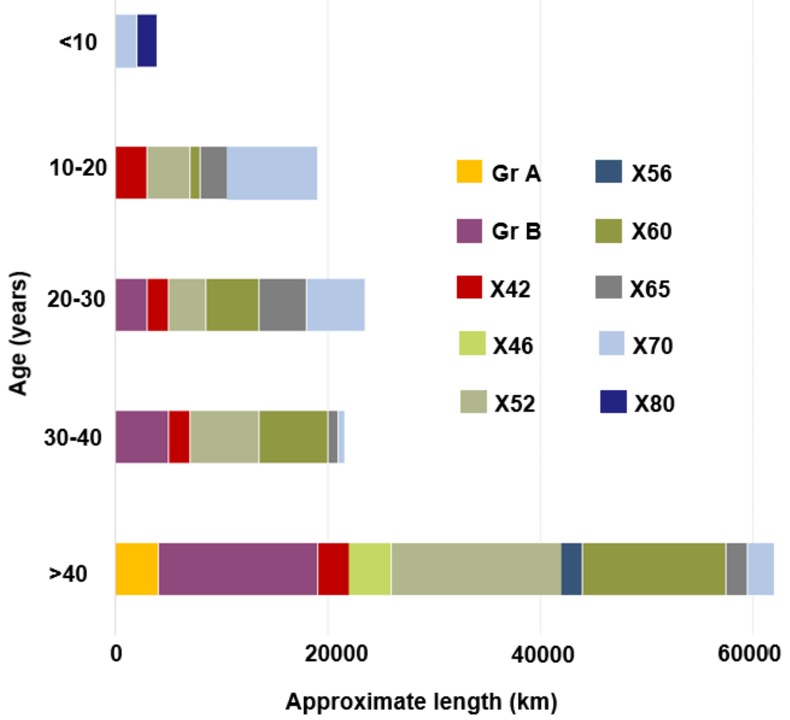
Relatively small diameter

Low utilisation

Hydrocarbon NG pipelines (EU)



Caution! (SMYS vs AYS)



Conversion management

…Hydrogen

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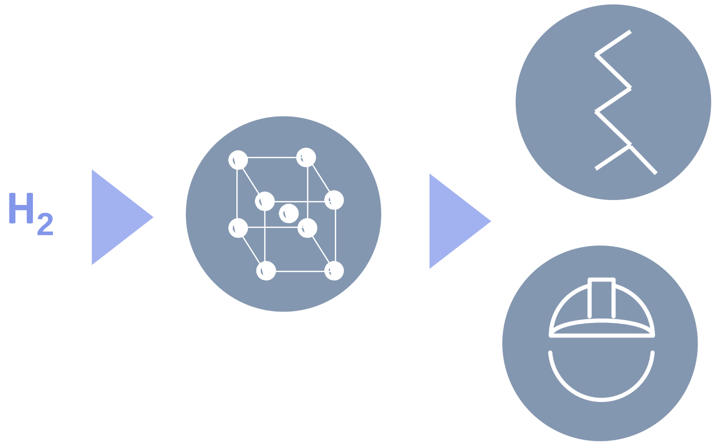
Hydrocarbon pipelines converted to H_2



Crack threats escalation
Pre-existing/New

FFP/ERL

"ID material DNA, targeted material sampling & testing … at core of conversion strategies"

Management ('crack')

Pre-conversion

- ✓ Understand 'Materials' DNA
- ✓ ID Crack baseline
- ✓ ID hard spot baseline
- ✓ ID high plastic deformation baseline
- ▶ *Mat. Segmentation & Testing (Prop., CGRs)*

Service

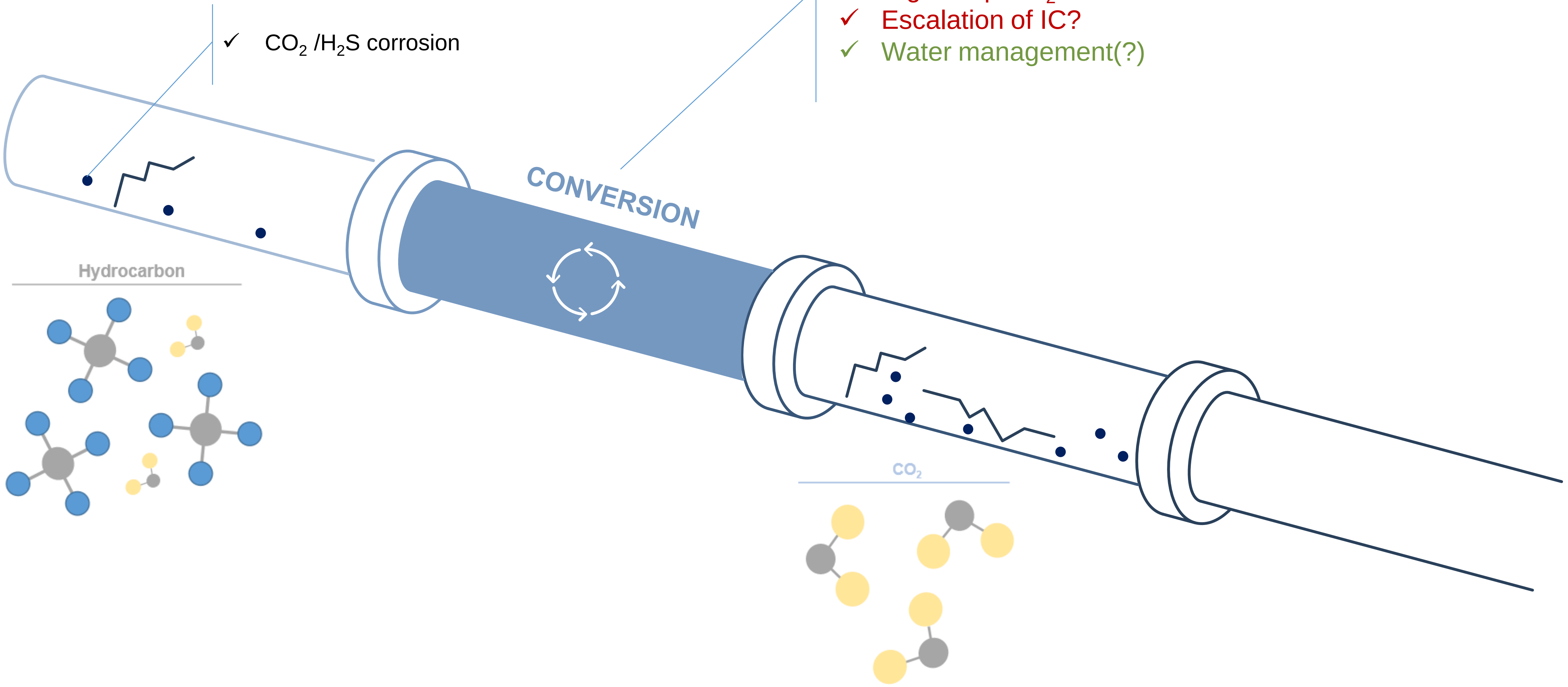
- ✓ Monitor Cracks (service)
- ✓ Monitor high plastic deformation (service)
- ✓ *Etc.*

- *Crack Management in Hydrogen pipelines, Sandana D et al., ICHS 2021*
- *Existing pipeline materials and the transition to hydrogen, Gallon N et al., PTC 2021*

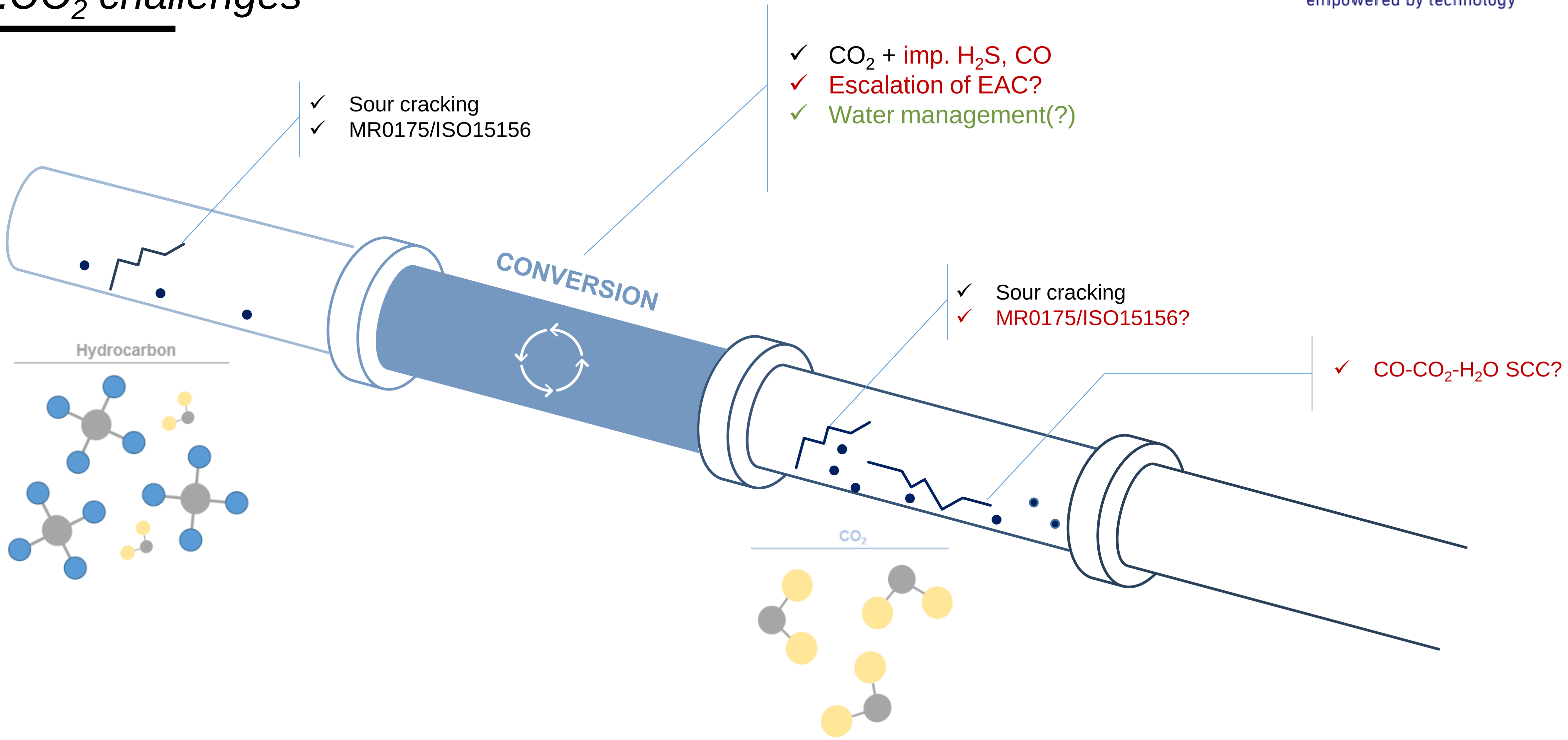
Conversion management

…CO_2 challenges

- ✓ Extension of Oil & Gas knowledge
- ✓ Higher Pp CO_2
- ✓ Escalation of IC?
- ✓ Water management(?)

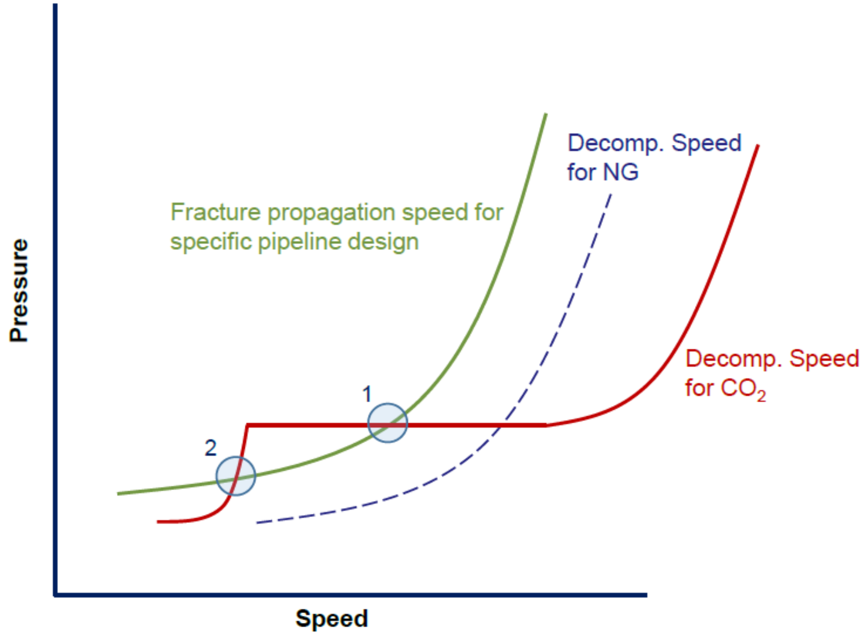


Conversion management
…CO_2 challenges



Conversion management
…CO_2 challenges

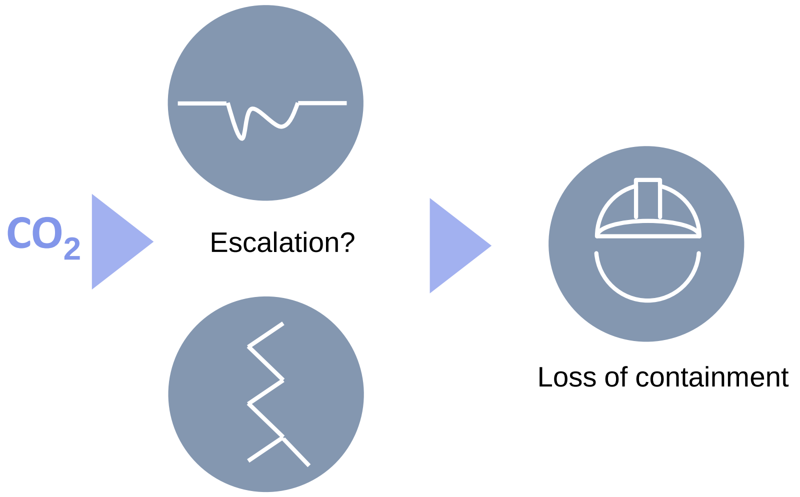
Fracture control (LoC)



- ✓ Dense CO_2
- ✓ Ductile running fracture (LoC)
- ✓ Crack arrestors
- ✓ Fracture toughness
- ✓ API 5L/ISO 3183… No mandatory requirements (hydrocarbon design)

Conversion management
…CO_2

Hydrocarbon pipelines converted to CO_2



Management

Pre-conversion

- ✓ ID Water Solubility thresholds
- ✓ Mat. segm. & fracture toughness testing
- ✓ Requirements for crack arrestors (Practical?)

(*dense*)

- ✓ ID baseline corrosion & cracks (pre-service)

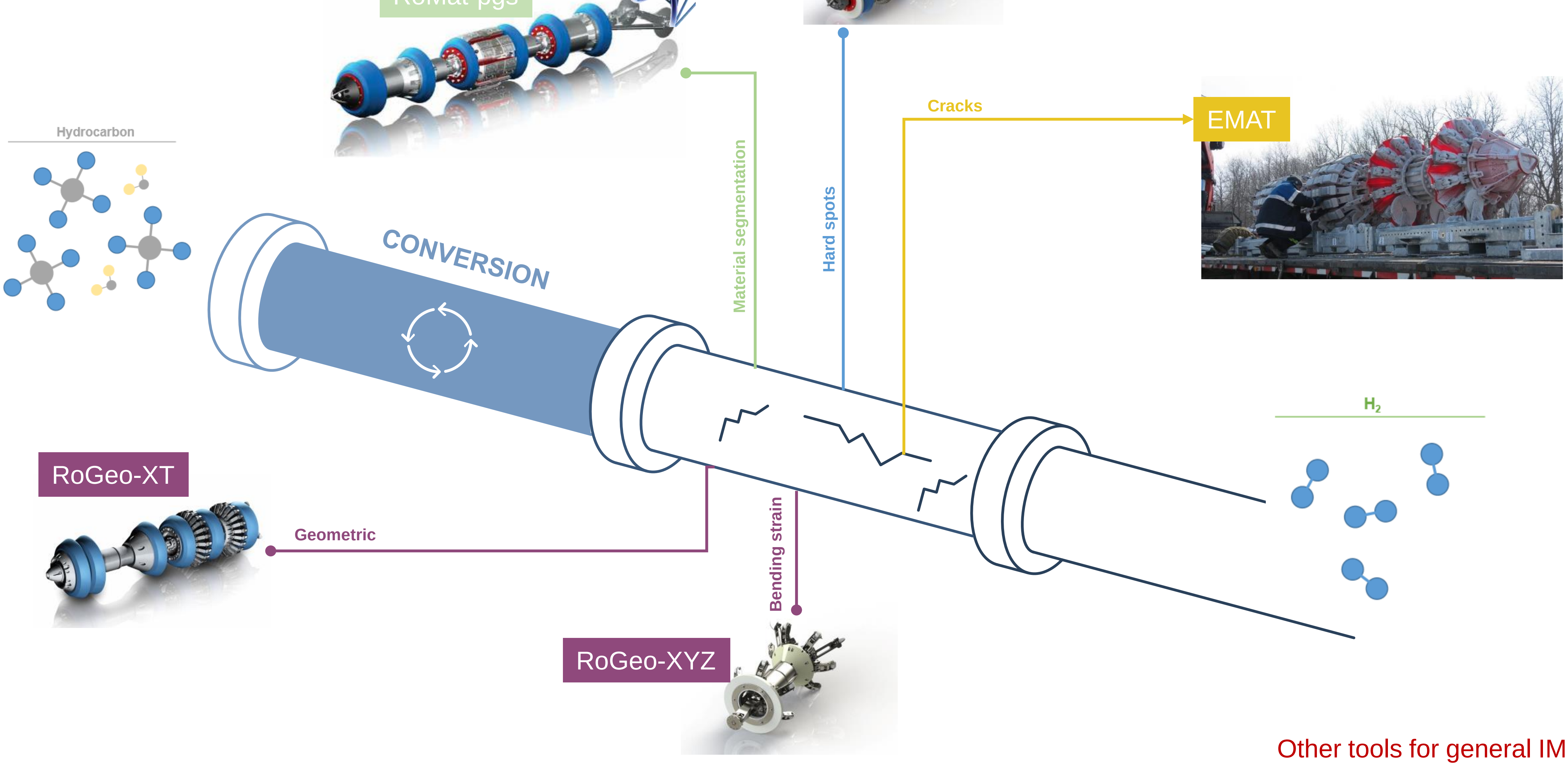
Service

- ✓ Water management
- ✓ Monitor metal losses & cracks (operations)

➢ *Crack Management in Hydrogen pipelines, Sandana D et al., ICHS 2021*

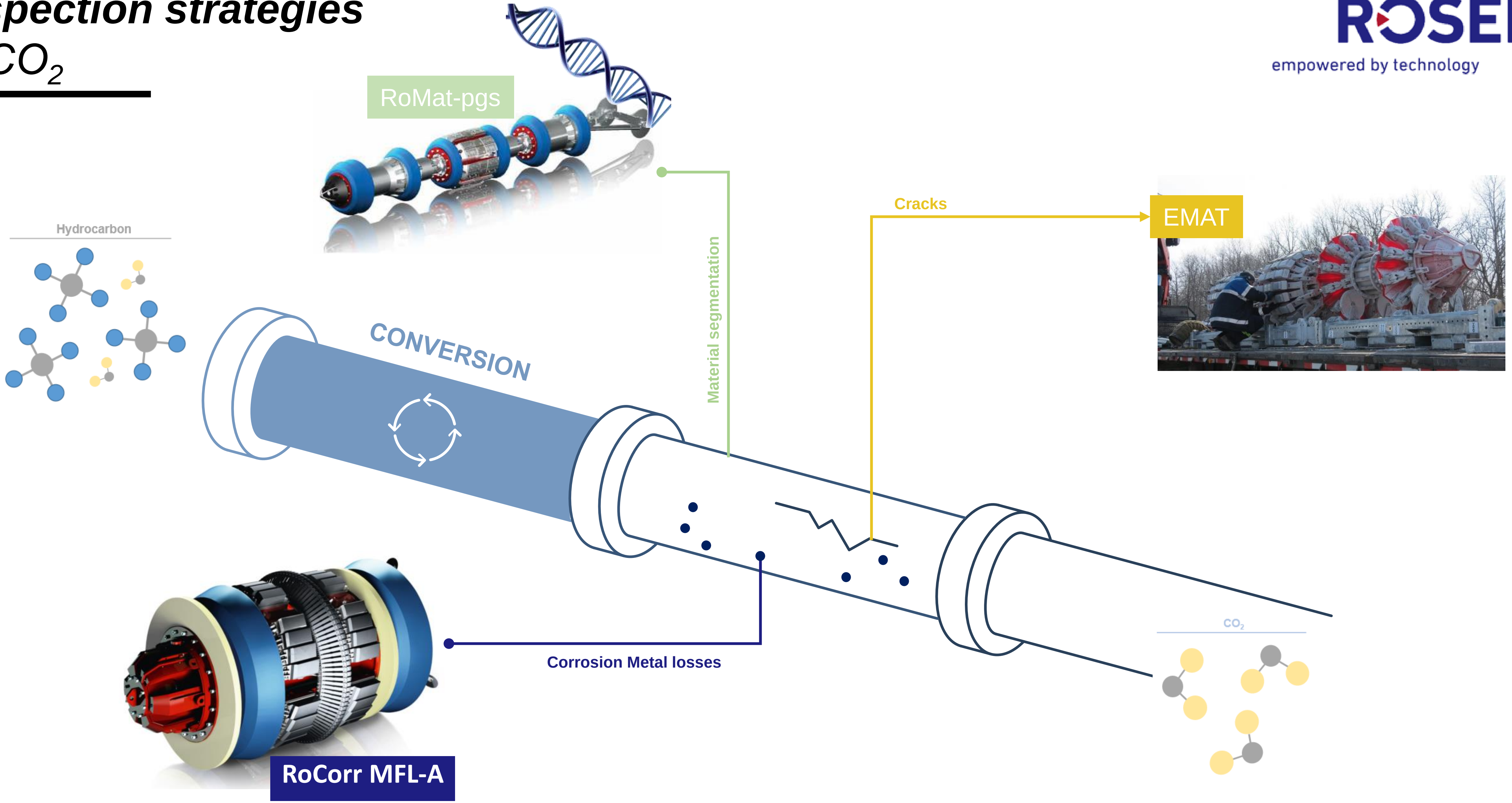
ILI strategies & challenges

Inspection strategies …Hydrogen



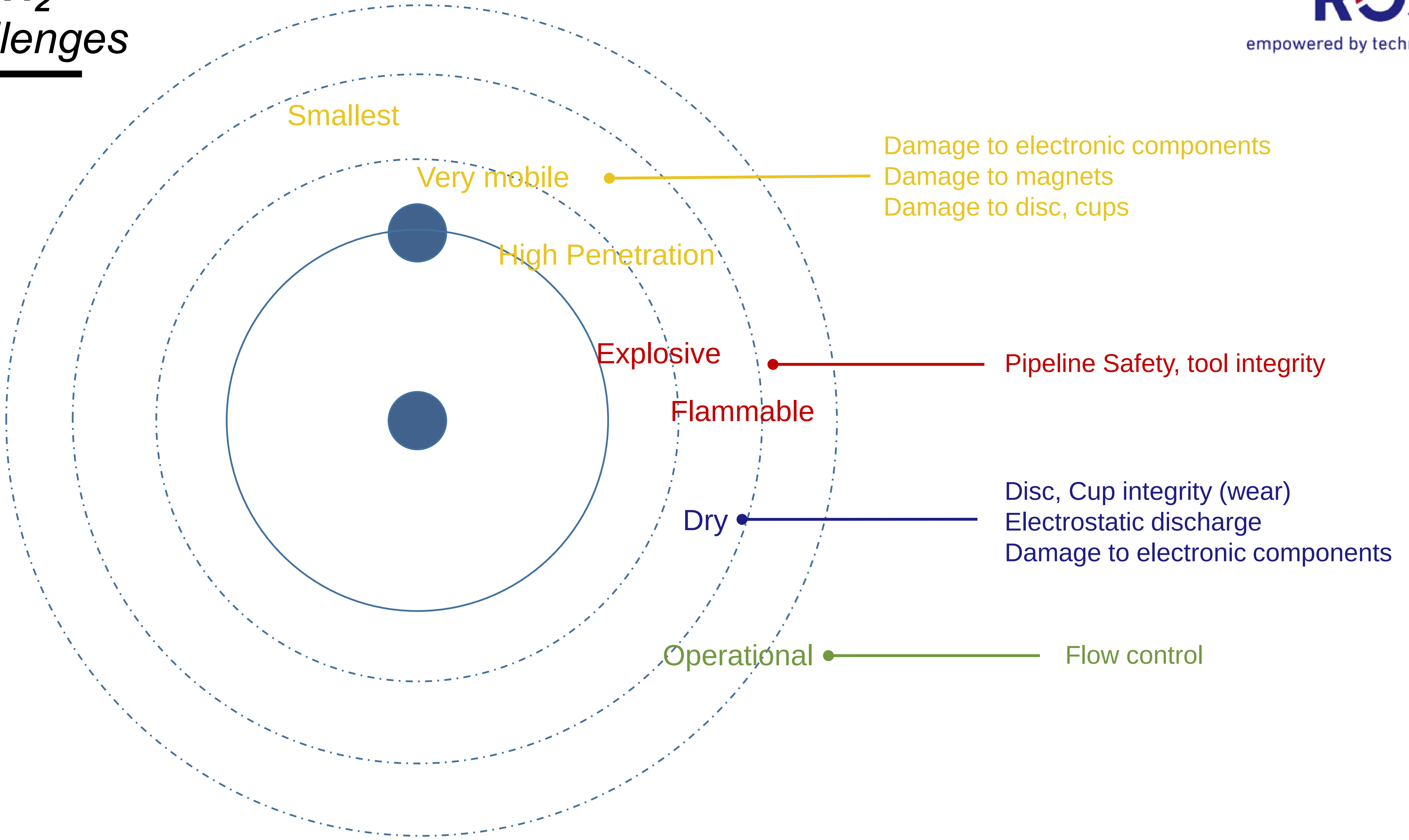
Other tools for general IM!

Inspection strategies …CO_2



Other tools for general IM!

ILIs in H_2
…Challenges

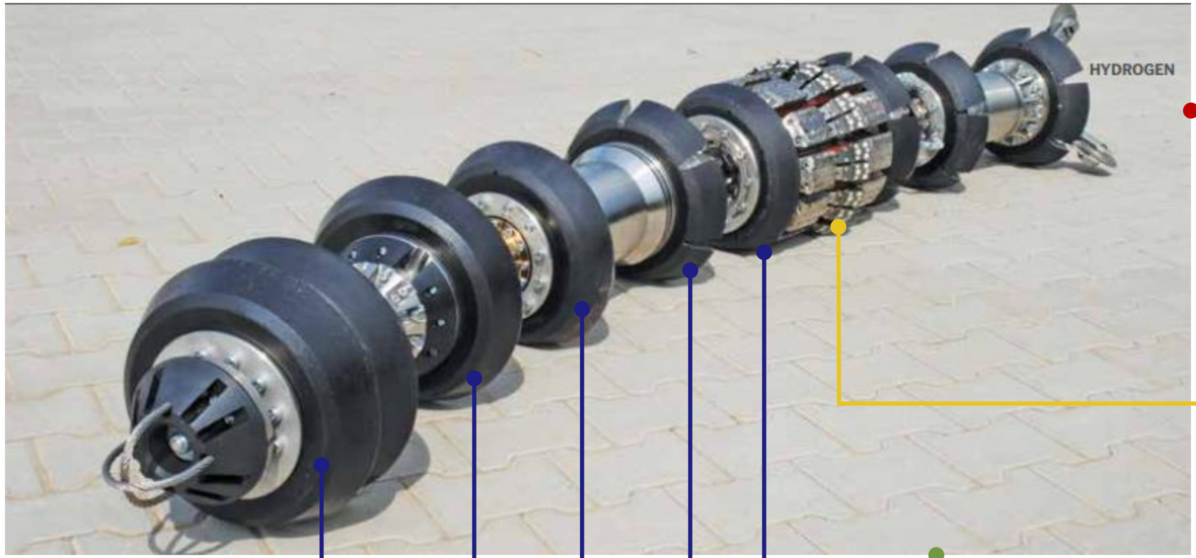


ILIs in H_2
…Case study

- 10” x 10 km
- Service - Gaseous H_2
- Installed – 1996
- Inspection practices for H_2 lines costly and time-consuming

- 2015 – ROSEN ILI MFL & geometric in H_2

ILIs in H_2
…Case study



European Union's ATEX directives
- ✓ *Flameproof enclosure for the components*
- ✓ *Pressurised enclosure for the electronics*
- ✓ *Intrinsic safety with voltage-restricted electrical circuits*

Magnets protection
- ✓ *Protection against H_2*

Non-standard cups (different hardness)
- ✓ *Lower the risk of static electricity*
- ✓ *Resistance to decomposition*
- ✓ *Resistance to uneven wear*

Assessment of flow conditions
- ✓ Standard set-up – P_{min} of 435 psi.
- ✓ P of ~270 psi & flow rate of 11 MMscfd required.
- ✓ Application of various bypass holes and notches to design for reduction of excessive velocity from pressure build-up in installations while still providing enough seal to propel the tool through the line.

ILIs in H_2
…Case study

- 100% sensor coverage (Geometry and MFL)
- 100% magnetisation levels (MFL)
- Overall Data quality acceptable for EL
  (velocity spikes at installation)
- No evidence of tool damage
- Minimum wear damage

Safely inspected in 2017 ✓

ILIs in dense CO_2
…Challenges

Challenges	Affected components	Reasons
Chemical degradation & explosive decompression	Non-metallic – multiple e.g. cables, sensors, seals	Interaction with dense CO_2 Explosive decompression (end of ILI run)
High wear	Tool cup & discs	Dry environments
Damage of electronic components	Electronic components	Build-up of electrostatic charge on tool due to movement of cups along pipe wall in dry environment Leads to high voltages generated between tool & pipeline, resulting in a discharge Depends on position and intensity of discharge

ILIs in dense CO_2
…Challenges

Challenges	Affected components	Management
Chemical degradation & explosive decompression	Non-metallic – multiple e.g. cables, sensors, seals	Control of decompression rate & material selection
High wear	Tool cup & discs	Material selection or engineering design solutions e.g. use of support wheels, wear reinforced cups & brushes.
Damage of electronic components	Electronic components	Development of conductive PU to minimise electrostatic build-up / protective shielding on delicate electronic components

ILIs in dense CO_2
Case studies

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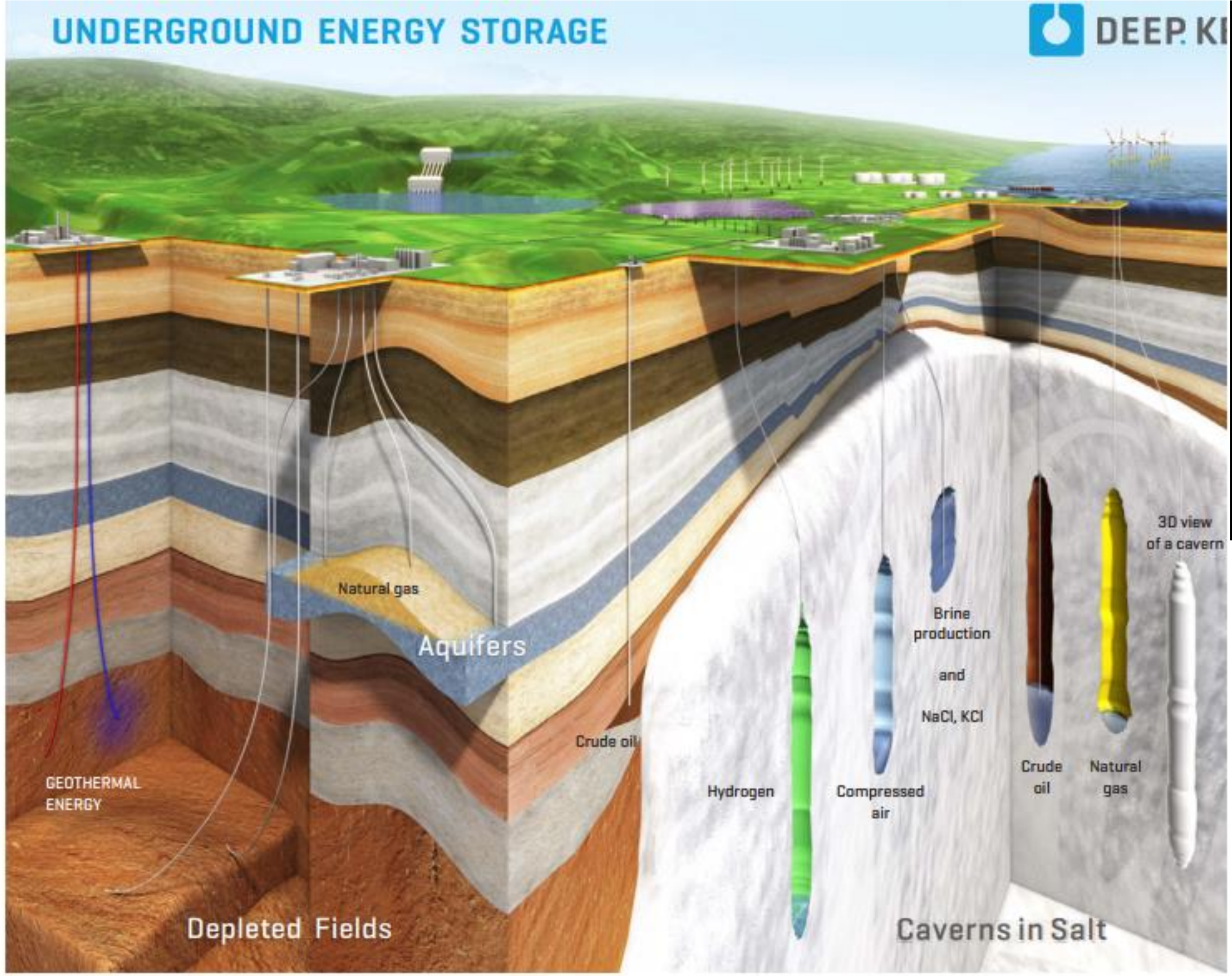
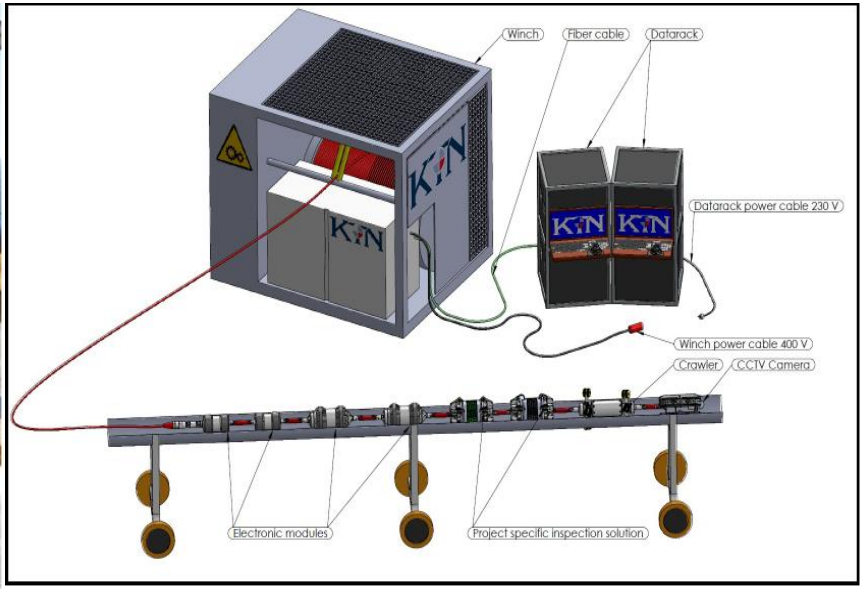
Pipeline Design	Operations	Tool deployed
24” OD x 116 km	131 bar, 16ºC	Geometric EGP & Metal loss MFL
24” OD x 120 km	134 bar	Geometric EGP & Metal loss MFL

Post-run

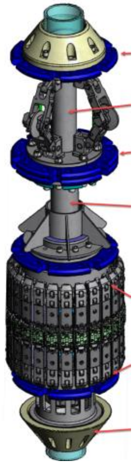
Storage



UNDERGROUND ENERGY STORAGE
DEEP.KI
Natural gas
Aquifers
Crude oil
GEOTHERMAL ENERGY
Depleted Fields
Hydrogen
Compressed air
Brine production and NaCl, KCl
Crude oil
Natural gas
3D view of a cavern
Caverns in Salt



Winch
Fiber cable
Datarack
Datarack power cable 230 V
Winch power cable 400 V
Crawler
CCTV Camera
Electronic modules
Project specific inspection solution



Conclusions

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Integrity Management
…NG vs Hydrogen & CO_2…

…Understand your <u>materials</u>…

…Understand your Hot spots…
Hard spots, bending strain, geometric, etc.

…ILIs…
Challenges but NOT insurmountable

Storage

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THANK YOU FOR JOINING!

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