USAGE OF CORROSION RESISTANT ALLOYS – CRA – FOR OIL AND GAS PRODUCTION (OCTG)

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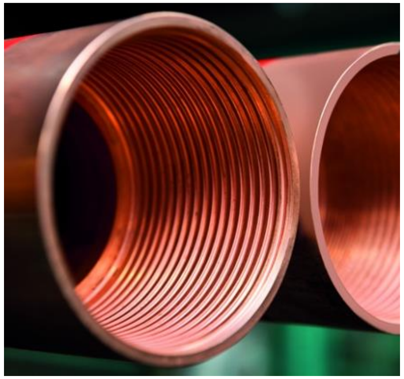


Agenda

- **Critical parameters for downhole Corrosion**
- **Main challenges of corrosive environments**
  - CO_2 corrosion, H_2S cracking
  - Geographic overview
- **Material Selection**
  - From the challenges to the consequences on OCTG
  - Material Selection decision matrix
  - Testing
- **Conclusions**

- **Open discussion – questions**

Critical parameters for downhole Corrosion

- O_2, CO_2 and H_2S concentration
- Water chemistry (Water cut / Water breakthrough)
- pH
- Temperature (min and max)
- Pressure (BHP)
- Cl^- concentration
- Flow rate / particles
- Service (e.g. change from oil/water to water or production to injection)
- Addition of “new” chemicals e.g. corrosion inhibitor, biocides, etc.
- Presence of elemental sulphur (S), Mercury (Hg) or other corrosive elements.

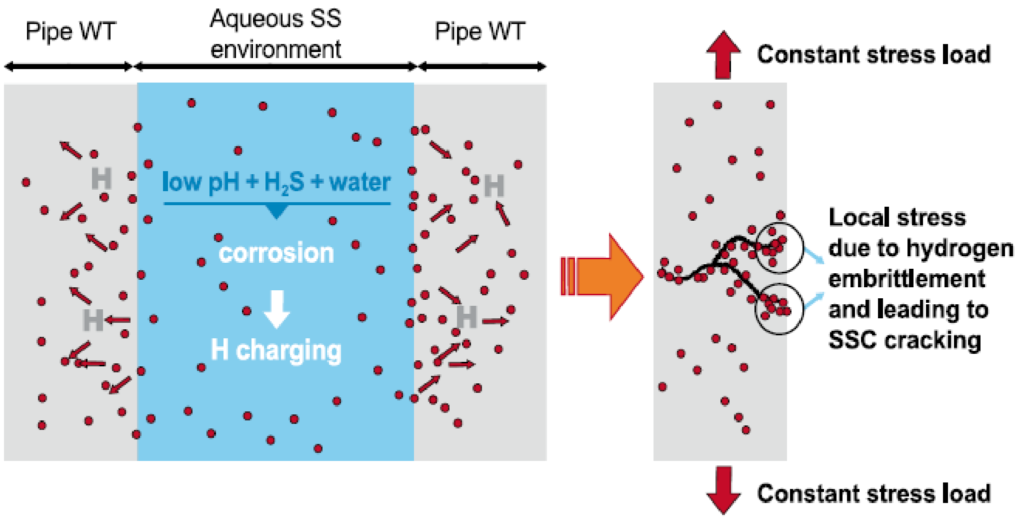
Main challenges of corrosive environments

H_2S	$H_2S + CO_2$	CO_2
☠ (warning sign)	☠ (warning sign)	! (warning sign)
Sour Gas	Highly corrosive Gas	Sweet Gas
FAST	FAST	SLOW
Cracking	Cracking + Metal Loss	Metal Loss
SSC Sulfide Stress Cracking	SSC: Sulfide Stress Cracking SCC: Stress Corrosion Cracking	Mass loss corrosion Pitting – Crevice
To be avoided Zero Risk approach	**To be avoided** Zero Risk approach	**Can be controlled** Life Cycle Cost approach
Severe at low T°C	Severe at low & High T°C	Severe at high T°C

COMPLEX

Main challenges of corrosive environments
H_2S corrosion

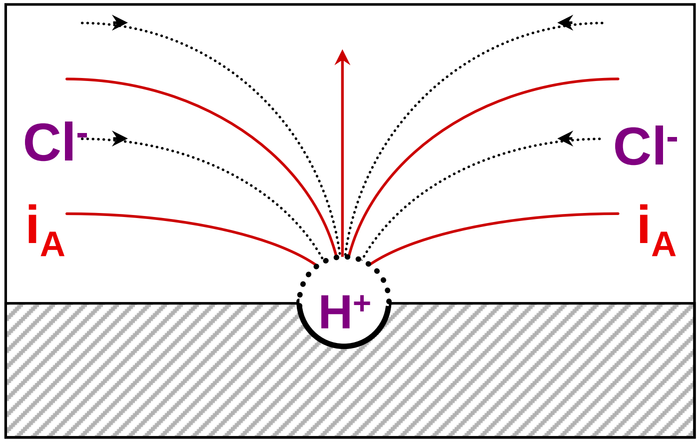
- **Sour gas is natural gas or any other gas containing significant amounts of hydrogen sulfide (H_2S)**
- **Due to their small sizes, the hydrogen atoms penetrate the material and interact with the steel which <u>becomes brittle</u>**
  ➔ risk of crack under stress



- **Corrosive phenomenon is Sulphide Stress Cracking (SSC), due to stress concentrations**
- **Failures can be catastrophic and unpredictable (as fast as few minutes)**
- **Tubing and Production Casing (as 2nd barrier) and on case by case Intermediate Casing shall be H_2S resistant**
- **Lower temperature and high stresses emphasize risk of SSC**

Main challenges of corrosive environments
CO_2 corrosion

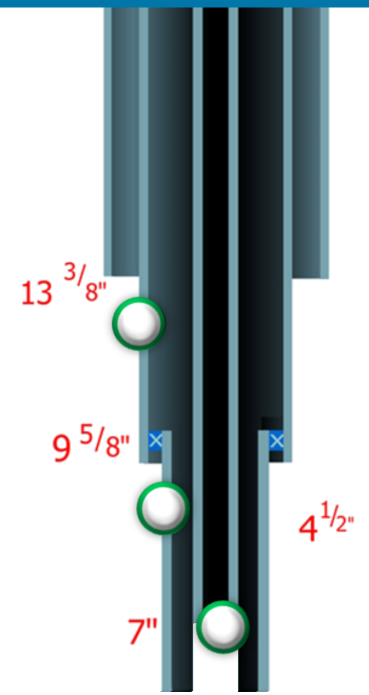
- Referred to as **"Sweet" Gas** – CO_2 is a carbonic acid when dissolved in water
- CO_2 leads to general metal loss & local pitting (+ **Stress Corrosion Cracking – SCC,** when H_2S is also present)
- CO_2 corrosion becomes more **severe at higher temperatures**
- A **minimum of 12% Chromium** is required to resist CO_2



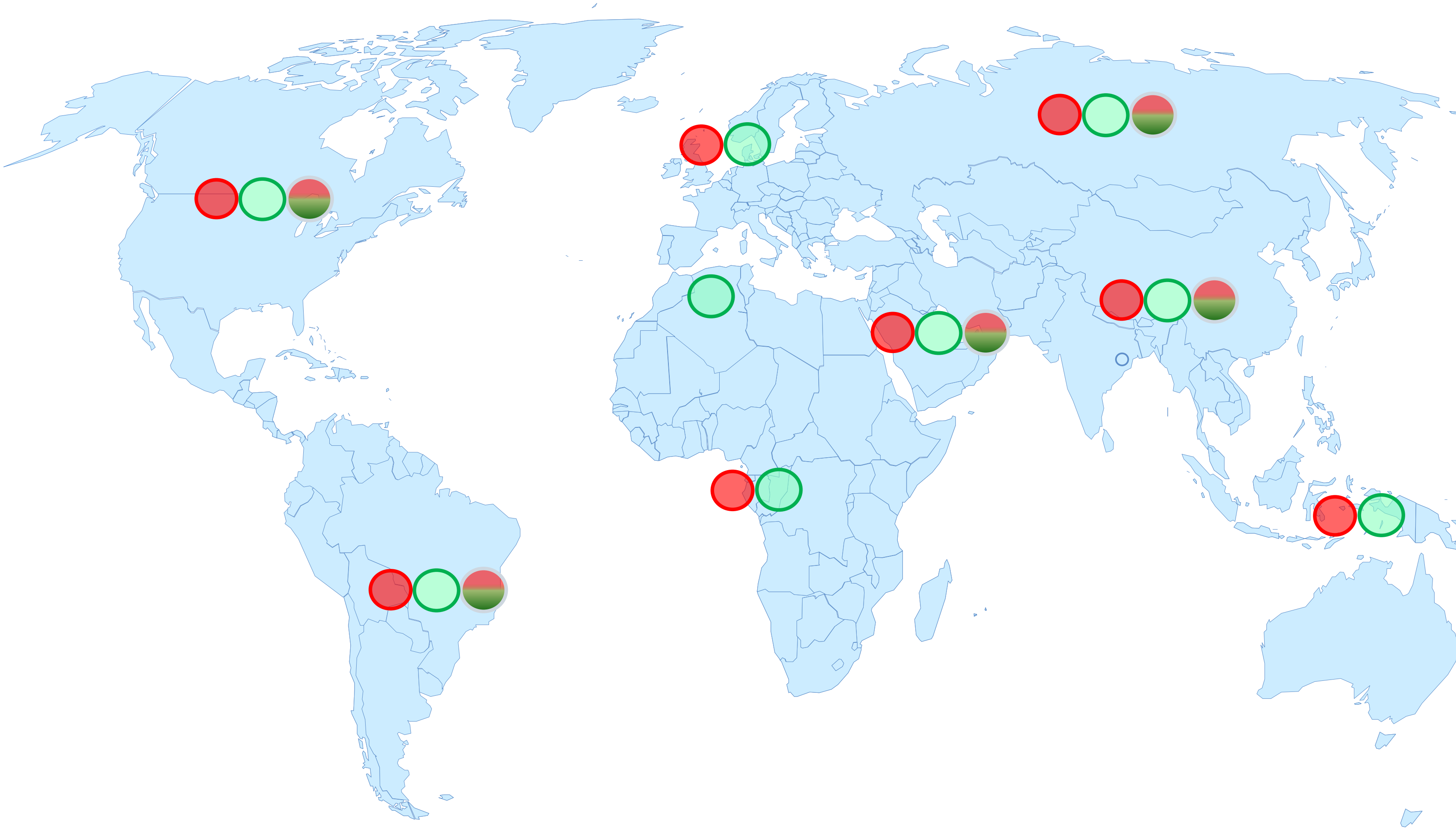
- Uniform Corrosion affects **tubing / liner**

Main challenges of corrosive environments

H_2S	$H_2S + CO_2$	CO_2
Mitigate even if short exposure		Long exposure possible
Surface Casing		Surface Casing
Intermediate Casing **case by case**		Intermediate Casing
Production casing		Production casing **Bottom Part (below packer) case by case**
Production Liners		**Production Liners**
Completion Tubing		**Completion Tubing**



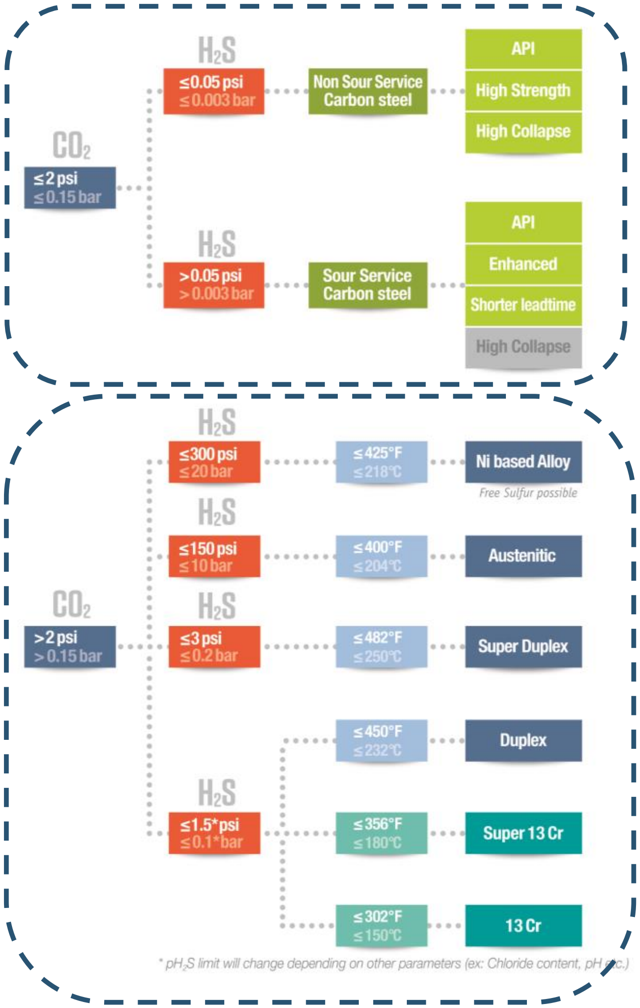
Main challenges of corrosive environments
Geographic overview

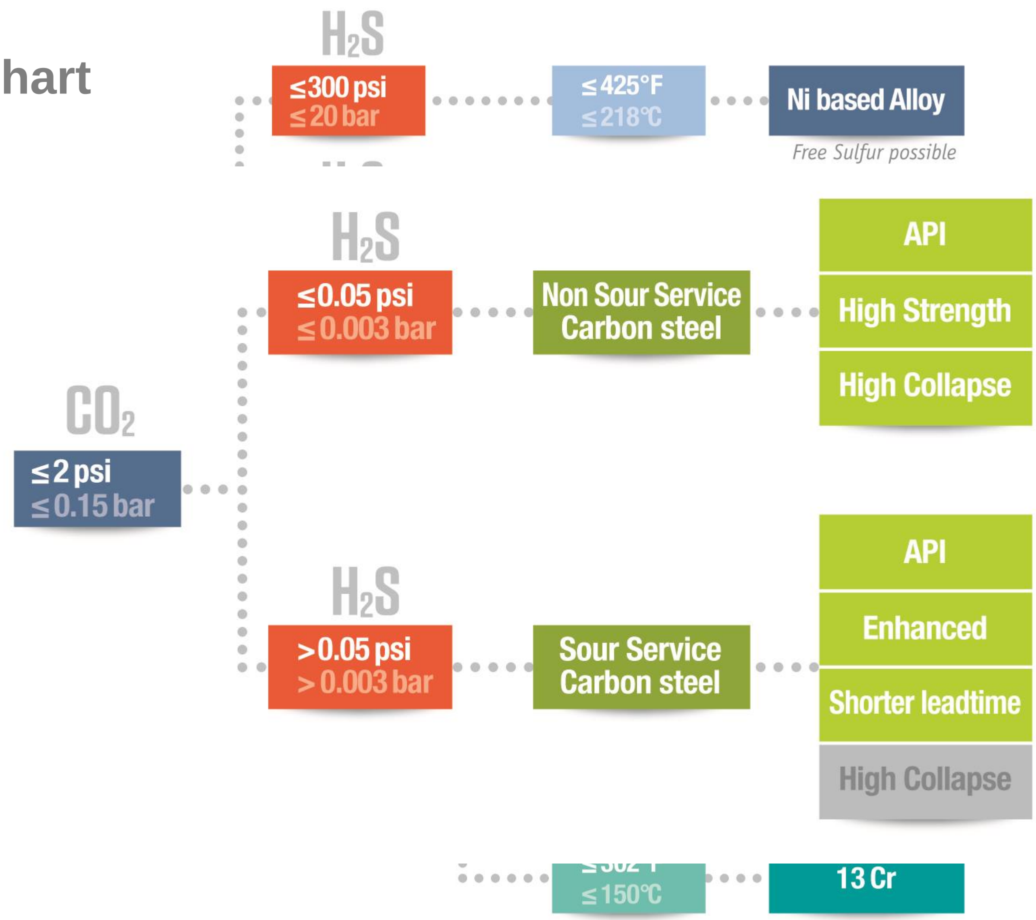


Main « H_2S » areas   Main « CO_2 » areas   Main « H_2S + CO_2» areas

Material Selection

Simplified Material Selection Chart

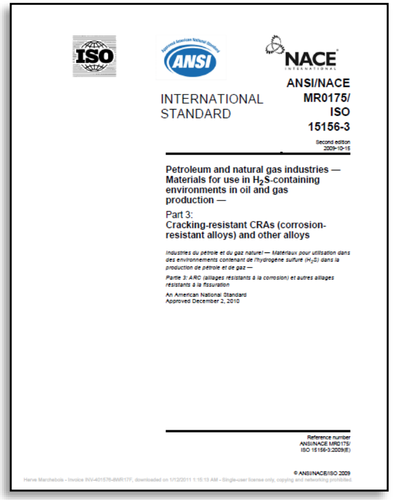




- Usage domain of Chrome and Nickel Alloys
- Usage domain of standard Carbon Steel and Sour Service Grades
- Higher CO_2 content (>2psi)
- ppH_2S and temperature dependant
- Low ppCO_2 (<2psi)
- Other parameters like chloride content and pH, will also influence
- Strong influence of the H_2S content

Material Selection
Definition & normative requirements

- **Corrosion Resistant Alloys (C.R.A.)**
  - Materials with ability to resist corrosion in presence of water & corrosive species
  - Products governed by :
    - API 5CRA / ISO 13680 specifications
      - 4 groups defined by their composition and mechanical properties
      - 2 Product Specification Levels (PSL) : PSL 1 is basis of API 5CRA
      - PSL 2 : restricted chemical composition & mechanical properties (in some cases)
    - NACE MR0175 / ISO 15156 :
      - Guideline for selection and qualification of metallic materials used in Oil & Gas
      - Part 3 of this specifications focuses on CRA :
        - Environmental limits for any equipment
        - Chemical composition per material type



INTERNATIONAL STANDARD

ANSI/NACE MR0175/ ISO 15156-3

Second edition 2009-10-15

Petroleum and natural gas industries — Materials for use in H_2S-containing environments in oil and gas production —

Part 3:
Cracking-resistant CRAs (corrosion-resistant alloys) and other alloys

Industries du pétrole et du gaz naturel — Matériaux pour utilisation dans des environnements contenant de l'hydrogène sulfuré (H_2S) dans la production de pétrole et de gaz —

Partie 3: ARC (alliages résistants à la corrosion) et autres alliages résistants à la fissuration

An American National Standard
Approved December 2, 2010

Reference number
ANSI/NACE MR0175/
ISO 15156-3:2009(E)

Note: 13CR grade L80 is still included into API 5CT specification and not API 5CRA

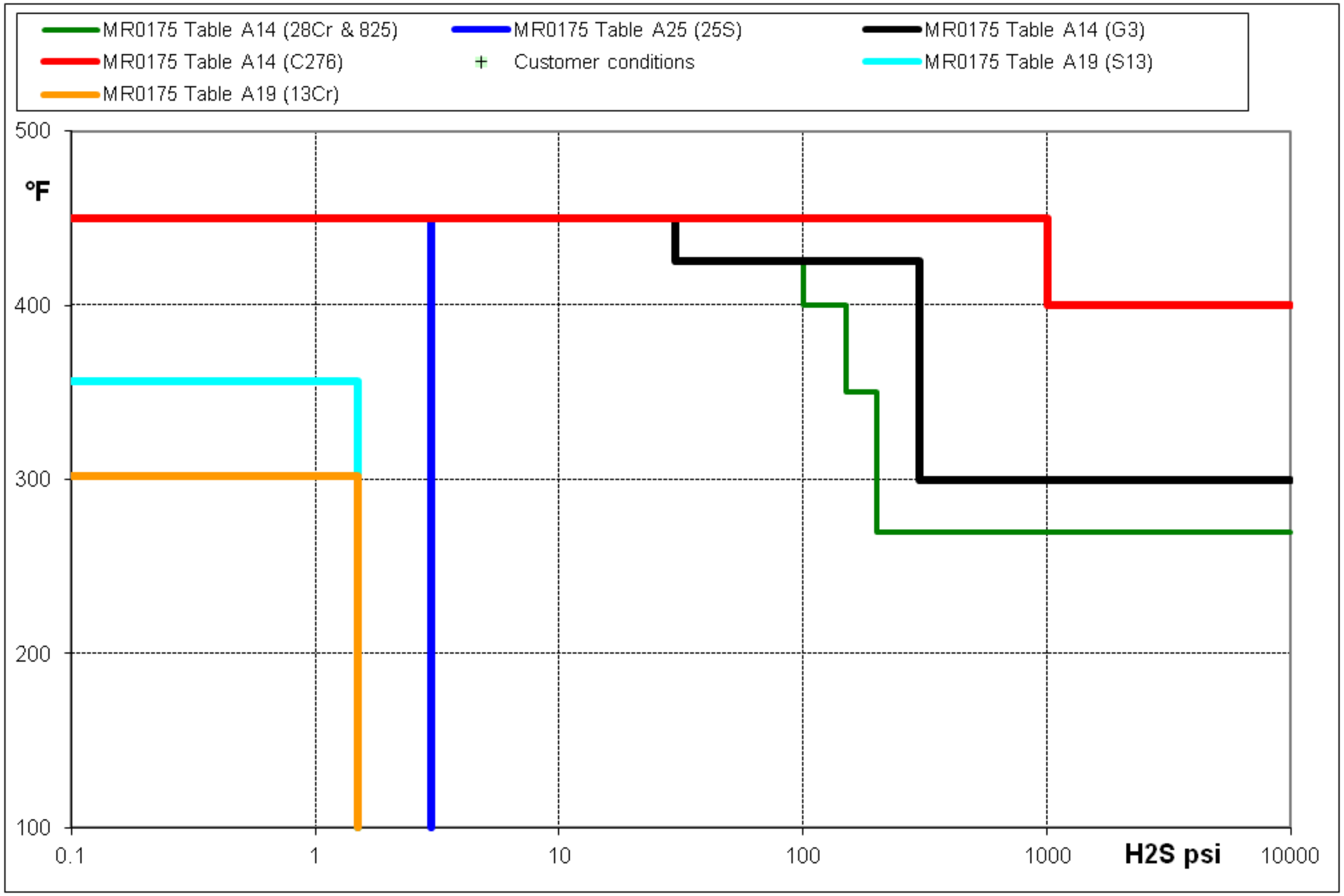
Material Selection

NACE MR0175 / ISO 15156 - usage domains

Alloy	Material Group	Table – NACE Part 3	H2S Limit (psi)	Temp Limit (°F)
13Cr Grade L80	Martensitic Stainless Steel	A.19	1.5	None (*)
Super 13Cr	Super Martensitic Stainless Steel	A.19	1.5	None (*)
25CR PREN>40	Super Duplex	A.25	3	None (*)
825, 28CR	Nickel Base (4C)	A.14	200	350
Alloy G3	Nickel Base (4D)	A.14	300	425
C-276	Nickel Base (4E)	A.14	1000	450

- **(*) Temp limit was not necessarily determined but mechanical properties will suffer too much at very high temperatures**

Material Selection
SSC and SCC Domain



- Usage domain based on NACE MR0175 recommendations
- Usage domain also dependent on CO2 and Chloride level

Material Selection
Simplified decision matrix

	Hydrocarbon production	Gas Injection	Water injection (*)	Turnaround well
Carbon Steel			Avoid!	Avoid!
3%Cr Alloyed Steel			Avoid!	Avoid!
Martensitic 13Cr			Avoid!	Avoid!
Supermartensitic 13Cr-5 Ni-2Mo			Avoid!	Avoid!
Super Duplex 25Cr-7Ni-2Mo (PREN>40)				
Nickel-base alloy			Not normally considered	Not normally considered
Titanium alloys	Not normally considered	Not normally considered		
GRE lined steel	Not normally considered	Not normally considered		

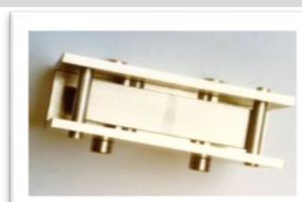
- **(*) depending on the quantity of Oxygen dissolved in water**

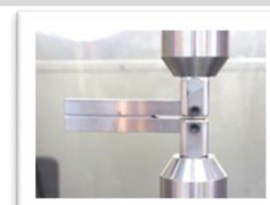
Material Selection
Testing

- **Qualification testing to assess corrosion resistance of various materials in a specific well conditions.**
- **Fit For Purpose (FFP) tests can be performed, to evaluate the material susceptibility in a specific environment.**
  - **Tests in autoclave:**
    - Metal loss
    - Pitting
    - Crevice
    - SCC

  - **NACE testing according to all 4 methods (A/B/C/D) of NACE TM0177 – 2005**

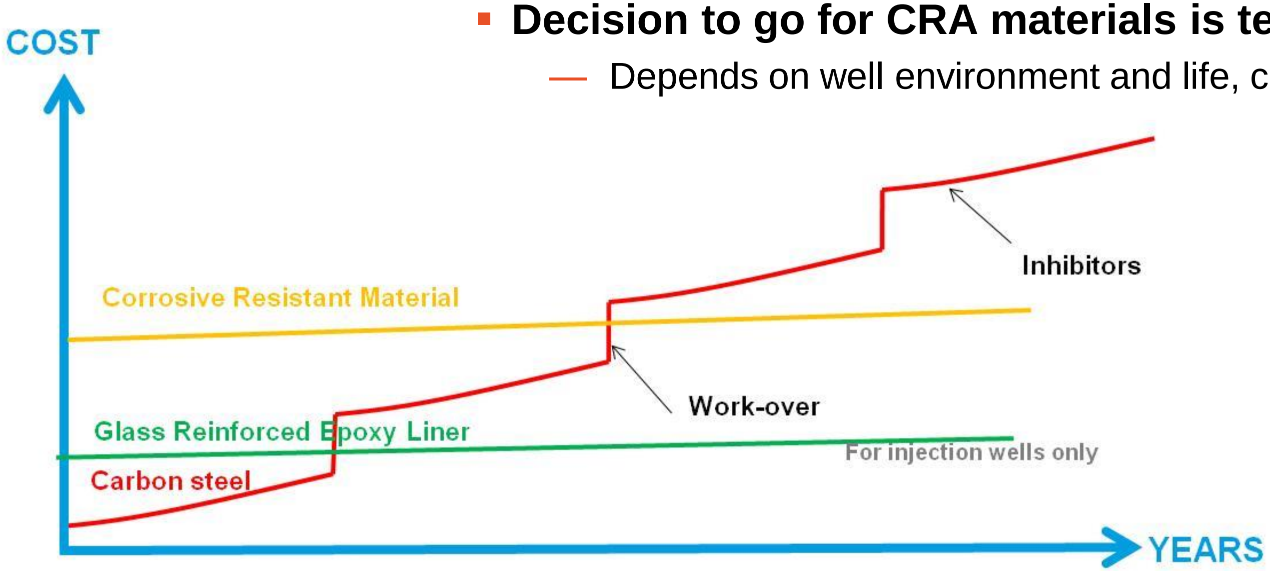
Test method	NACE A	NACE B	NACE C	NACE D
Stress application	Tensile % of SMYS	3 points bent	C ring	Wedge
Duration		720 hours		360 hours
Results	Rupture / No rupture	S_c	Rupture / No rupture	Stress Intensity Factor



Material Selection
Focus on CRA

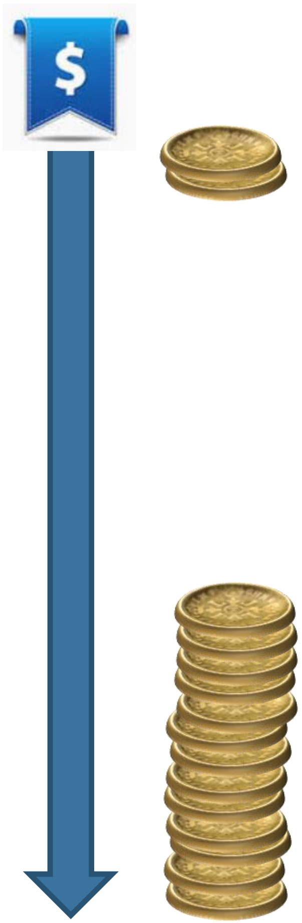
- **Corrosion can be mitigated by**
  - Regular tubing replacement (Work-over)
  - Use of down hole inhibitors (or internally coated tubings)
  - Use of corrosion resistant alloys (CRA)
- **Ferritic-austenitic & Austenitic grades are the most reliable & economical solution when:**
  - Costs and frequency of work-overs are high
  - There is a high cost of lost production
  - Harsh conditions – acid gas fields (CO2+H2S), high temperature
- **Decision to go for CRA materials is technical vs cost based**
  - Depends on well environment and life, company policy etc.



Material Selection
Focus on CRA

- **CRA prices are very sensitive to Cr, Ni and Mo price variation**

Steel or Alloy	Alloy low price	Alloy high price
Carbon steel for SS	1	1.1
Martensitic 13Cr	2	2.2
Martensitic Super 13 Cr	3.0	3.5
Austenitic – Ferritic	4.6	5.4
Super Austenitic – Ferritic	5.0	6.0
Austenitic (Ni < 50%)	10.0	12.5
Austenitic Ni-based (Ni > 50%)	16 / 25	21 / 32



Material Selection OCTG – Conclusions

- **Complex process with a lot of uncertainties**
  - Consider complete well life and potential scenarios
- **Reservoirs containing H_2S (SSC)**
  - Even at low levels of H2S, the material can be susceptible to SSC phenomenon
    - Zero Risk approach!
- **Reservoirs containing CO_2 (Metal Loss)**
  - Well Strategy will be decisive for Material Selection:
    - Price of the metallurgy vs workover / well stoppage
- **Reservoirs containing CO2 + H_2S (SCC + SSC)**
  - SCC and SSC criticity will vary as function of the temperature
    - Zero Risk approach!
- **CRA metallurgy**
  - Combine SCC and SSC resistance