Dr. Hilgenstock Consulting

Status of International Standardization on CO_2 Transportation

ISO 27913 / TC 265 Carbon dioxide capture, transportation, and geological storage – Pipeline transportation systems

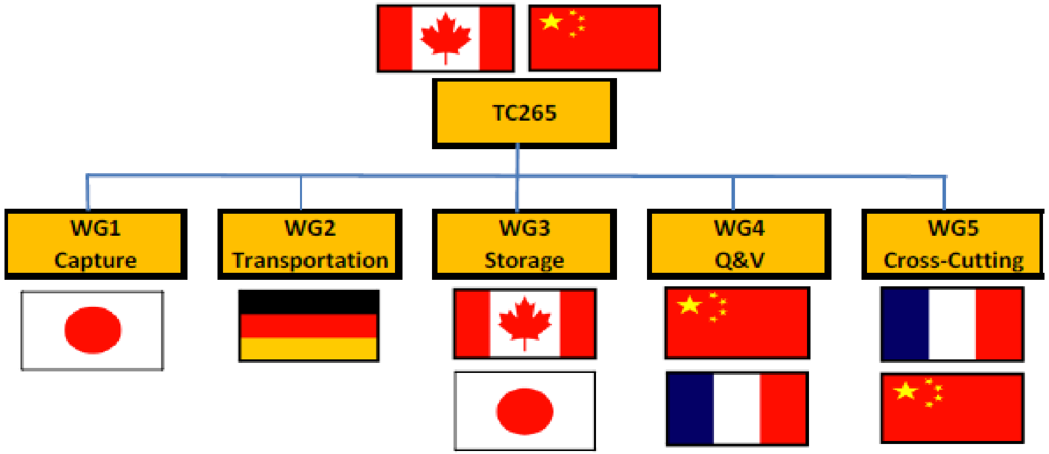
Content

- History
- Status
- CO_2 – Specific Main Issues
  - Boundaries to Capture and Storage
  - Fracture arrest
  - Corrosion
  - Non-discriminatory transportation

History of ISO TC 265

2011 June:

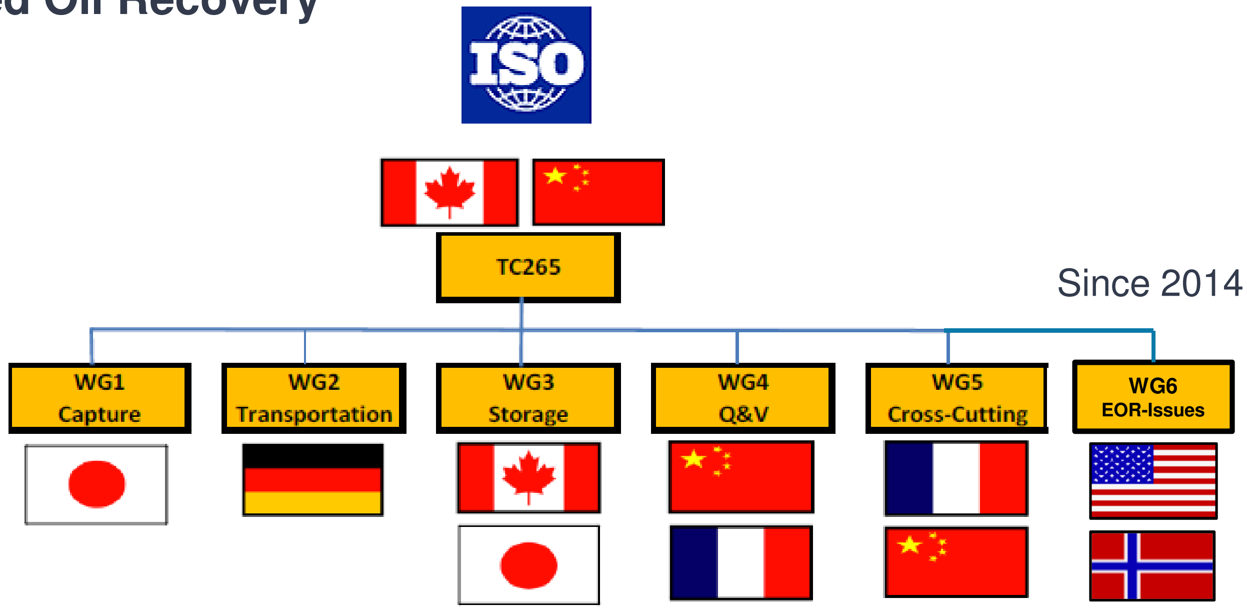
- Foundation of the ISO Technical Committee (TC) 265 for Carbon dioxide capture, transportation, and geological storage in Paris:
  - WG 1 Capture
  - WG 2 Transportation
  - WG 3 Storage
  - WG 4 Quantification and Verification
  - WG 5 Cross-Cutting Issues



History of ISO TC 265

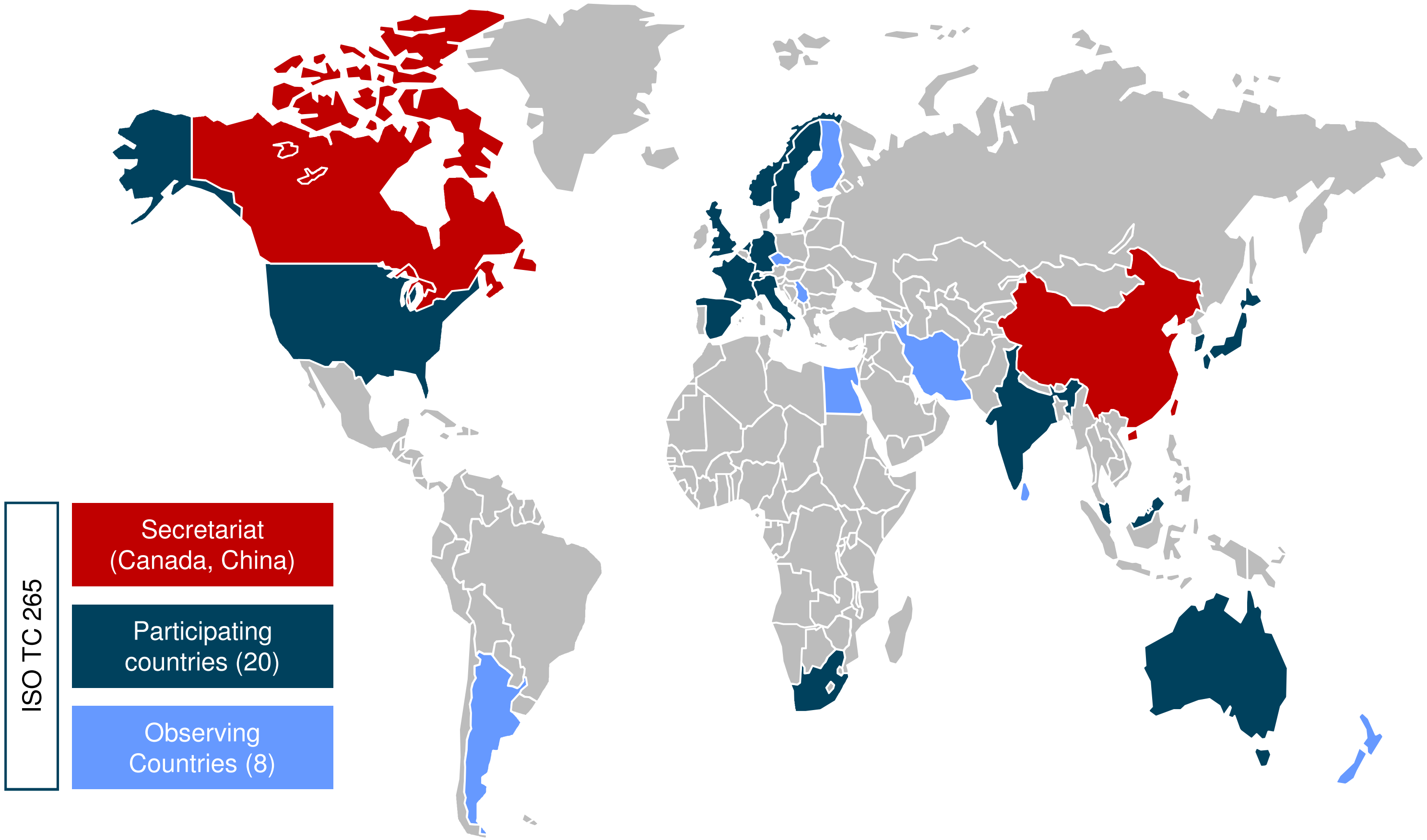
Today:

- WG 1 Capture
- WG 2 Transportation
- WG 3 Storage
- WG 4 Quantification and Verification
- WG 5 Cross-Cutting Issues
- **WG 6 Enhanced Oil Recovery**



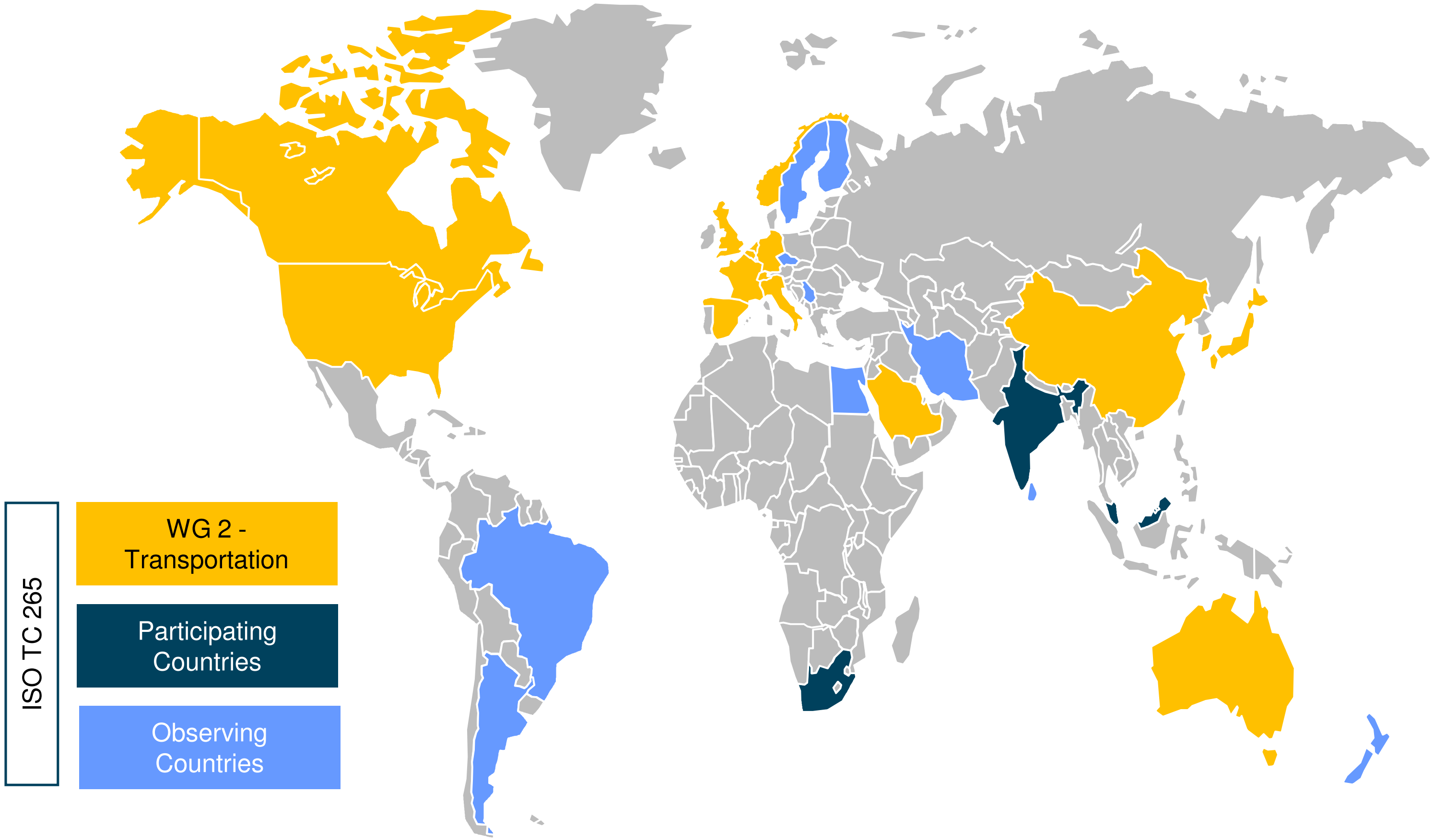
Since 2014

ISO/TC 265 Members

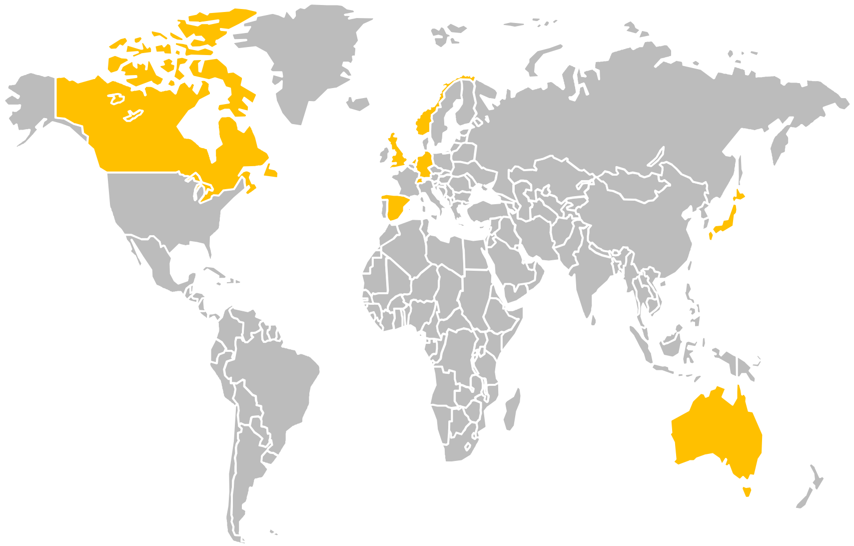


WG 2: Members of Working Group CO_2 Transportation

Total members: 50



WG 2 Meetings History

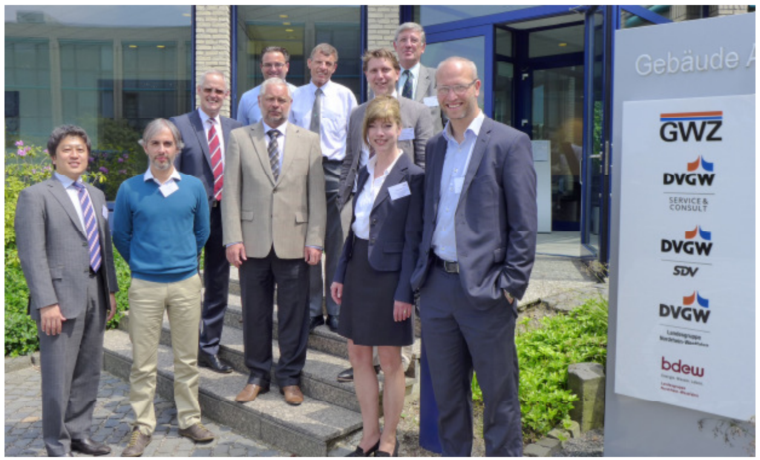


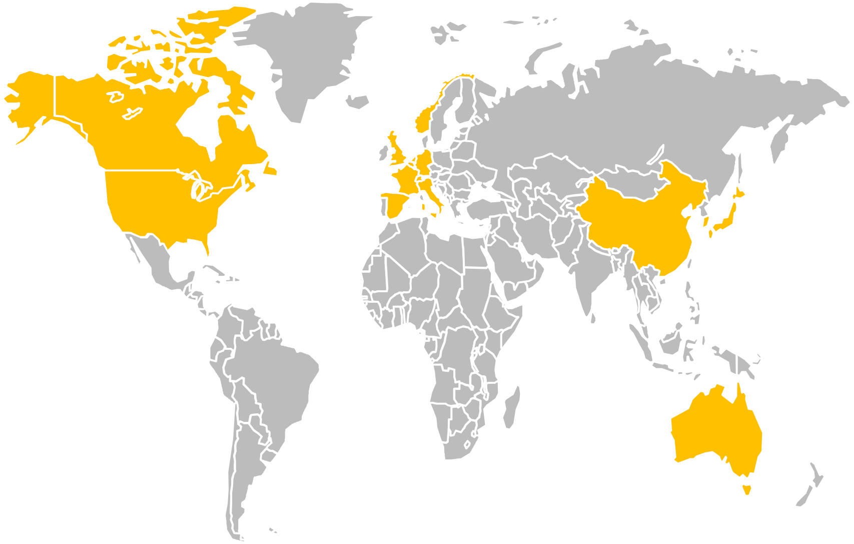
2013

ISO/TC 265/WG2

1st: 2013-06 Bonn, Germany, DVGW:

- Collect CCS-know-how
- Discuss available standards and needs for CO_2
- Develop strategy
- Take DNV RP-J202 as a starting basis
- Distribute work to experts around the world to derive a first **Working Draft (WD)**: **active participants in orange**
- Define Responsible Persons for WD Revision:
  - **Australia:** Michael Malavazos
  - **Canada:** Brian Rothwell
  - **Germany:** Sven Anders, Claudia Werner
  - **Norway:** Jock Brown
  - **UK:** Andy Brown





WG 2 Meetings History

2014

ISO/TC 265/WG2

2nd :2014-02 London, UK, BSI:

- Work on **Working Draft**
- Main topics: Fracture arrest assurance, corrosion, CO_2-composition

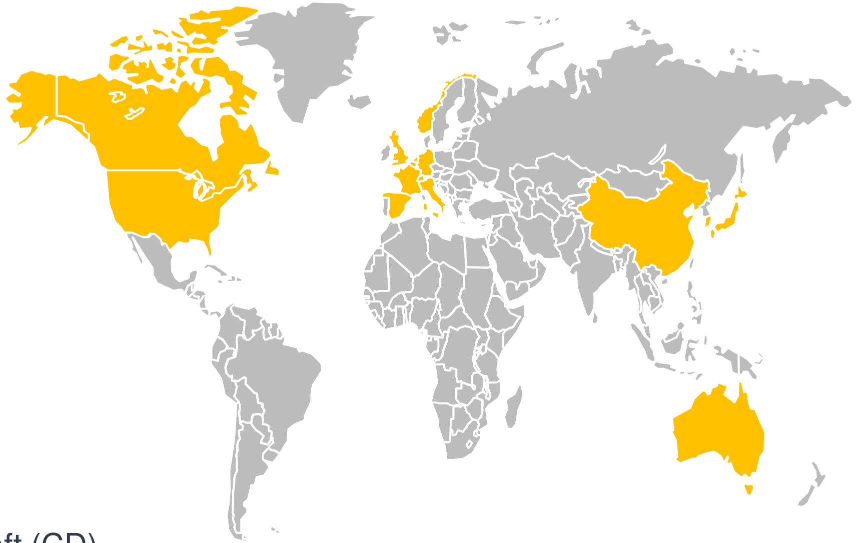
3rd: 2014-04 Berlin, Germany, DIN:

- Finalize Working Draft (WD)
- China and USA joined WG2 meeting
- Distribute Working Draft (WD) for comments inside WG2

4th: 2014-08 Gelsenkirchen, Germany, E.ON:

- Discussion and solution of comments on WD
- Prepare to submit **Committee Draft (CD)** for comments in September

WG 2 Meetings History



2015

ISO/TC 265/WG2

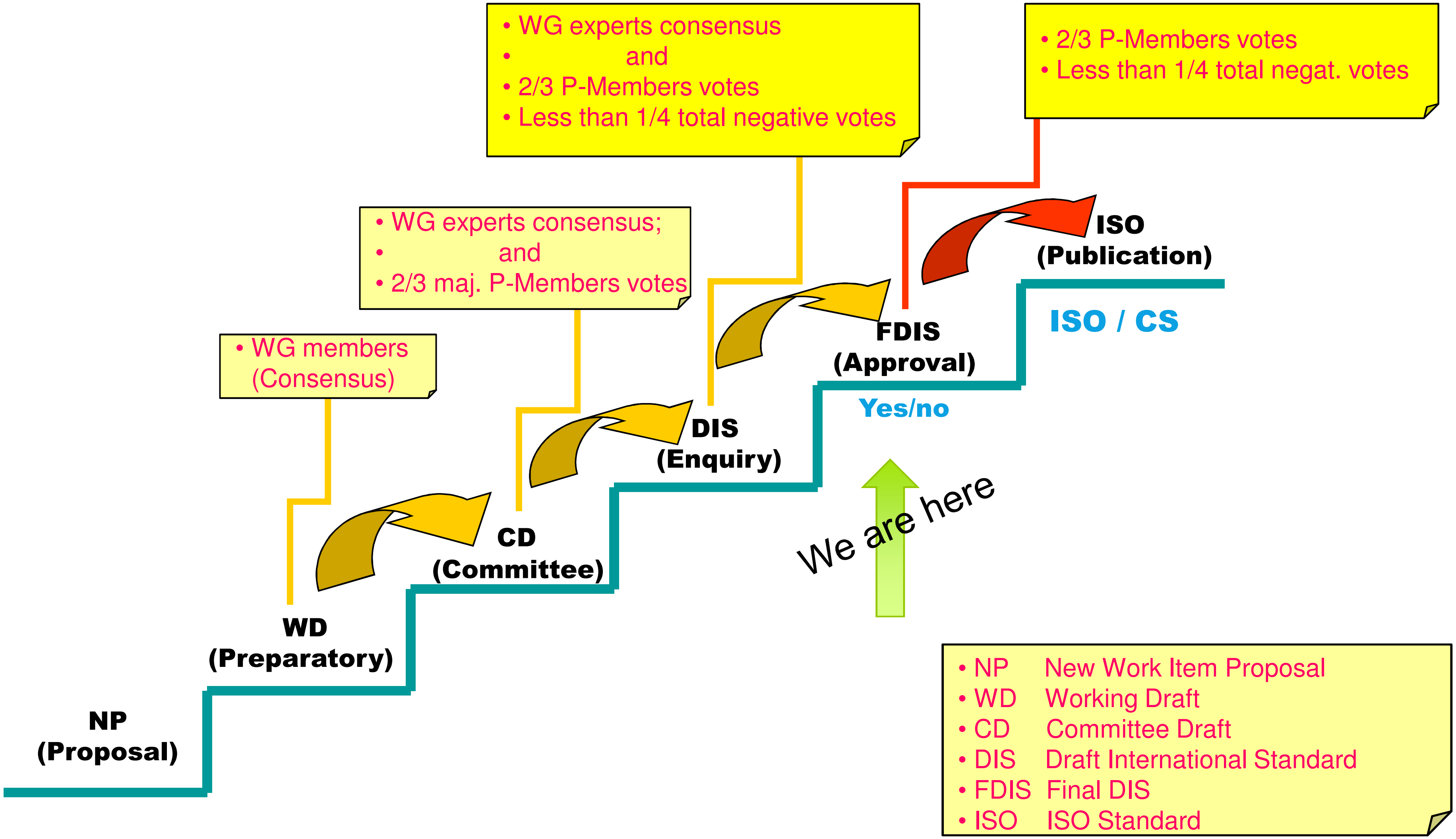
5th: 2015-01 Birmingham, USA, ANSI:

- Discussion and solution of 427 comments on Committee Draft (CD)
- Provision of **Draft International Standard (DIS)** (ISO/DIS 27913 CO_2-Transportation) in March 2015 for DIS Ballot (until October 2015)

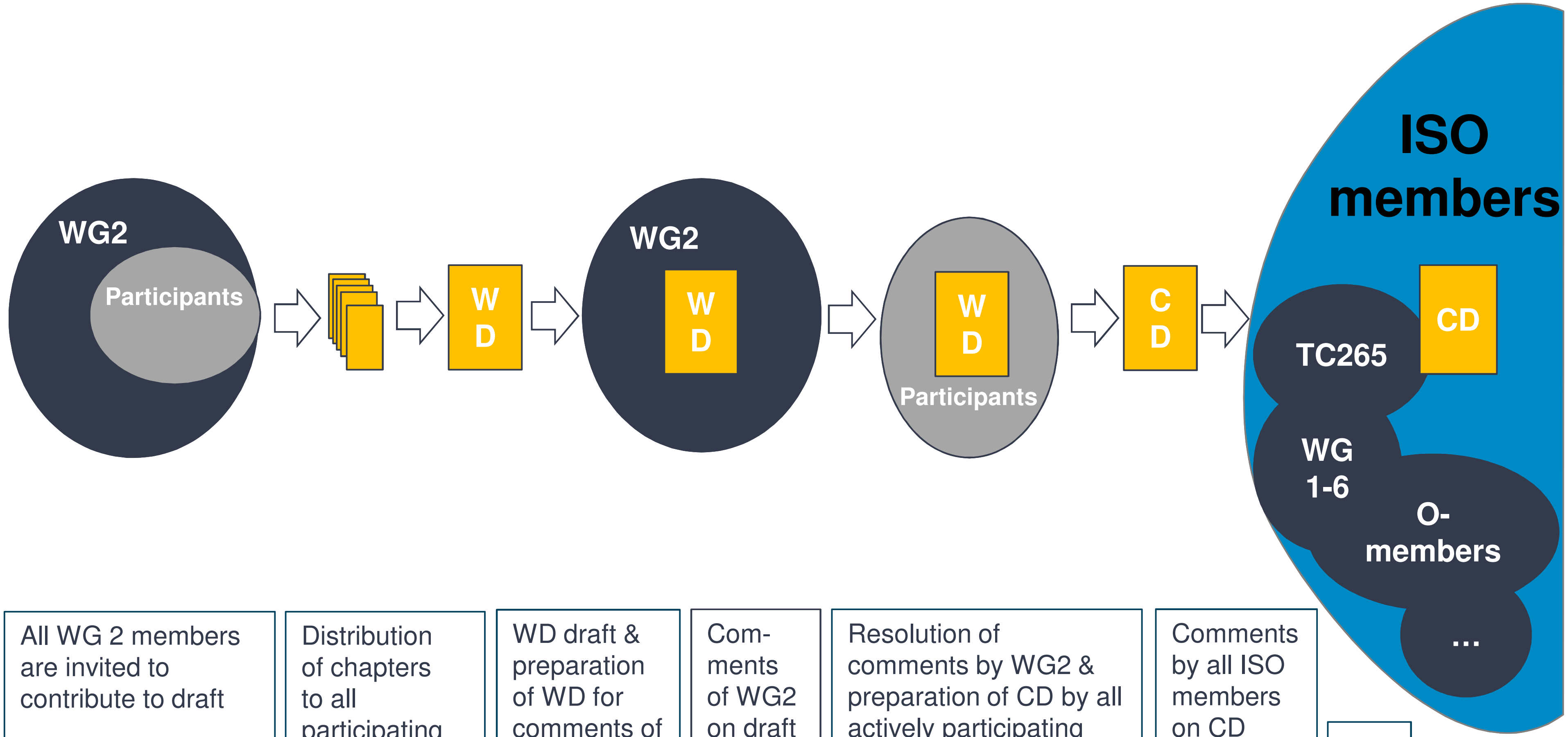
6th: 2015-12 Kjeller near Oslo, Norway, IFE:

- Discussion and solution of 216 comments on DIS
- Provision of ISO 27913

ISO Standards Development

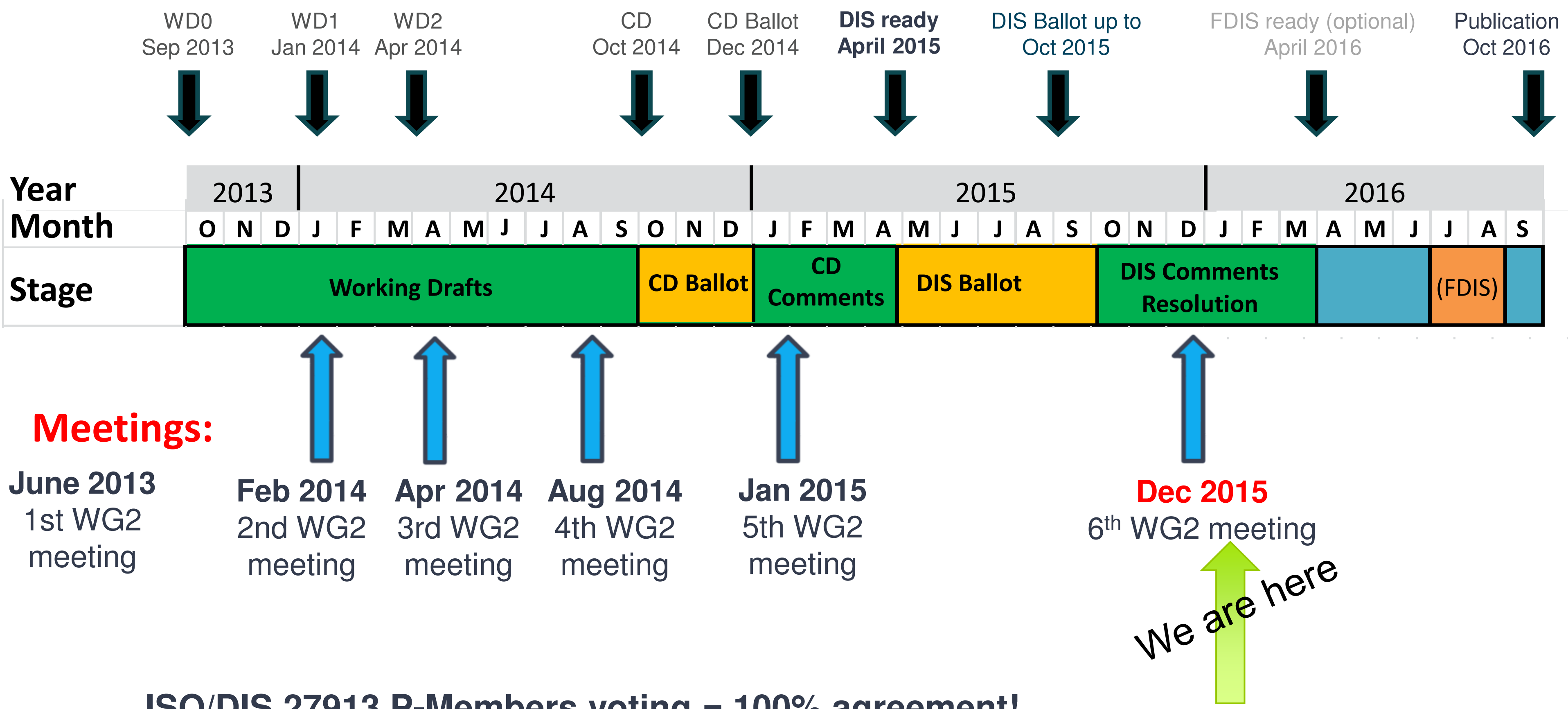


Worldwide participation at all stages of development



- All WG 2 members are invited to contribute to draft
- Distribution of chapters to all participating members
- WD draft & preparation of WD for comments of WG2
- Com- ments of WG2 on draft
- Resolution of comments by WG2 & preparation of CD by all actively participating members of WG2
- Comments by all ISO members on CD draft
- ...

Timeline



ISO/DIS 27913 P-Members voting = 100% agreement!

Content of the Standard ISO 27913

ISO/TC 265/SC

Date: 2015-12-03

ISO/DIS 27913

ISO/TC 265/SC /WG 2

Secretariat: SCC

Carbon dioxide capture, transportation and geological storage — Pipeline transportation systems

Élément introductif — Élément central

Warning
This document is not an ISO International Standard. It is distributed for review and comment. It is subject to change without notice and may not be referred to as an International Standard. Recipients of this draft are invited to submit, with their comments, notification of any relevant patent rights of which they are aware and to provide supporting documentation.

Basis for ISO 27913 Pipeline transportation systems

Existing pipeline standards, e.g.:

- **ISO 13623**
- **EN 1594**
- **AS 2885**
- **…**

+

ISO/TC 265/SC

Date: 2015-12-03

ISO/DIS 27913

ISO/TC 265/SC /WG 2

Secretariat: SCC

Carbon dioxide capture, transportation and geological storage — Pipeline transportation systems

Élément introductif — Élément central

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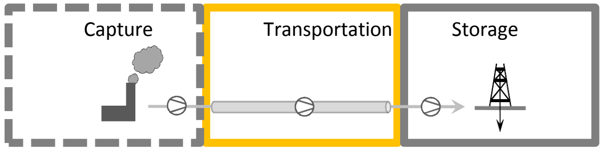
This new ISO 27913 contains **additional CO_2 specific requirements and recommendations** not covered in existing pipeline standards.

CO_2 – Specific Main Issues

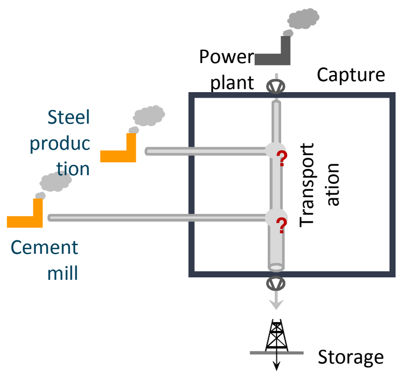
Boundaries to Capture and Storage



Fracture arrest

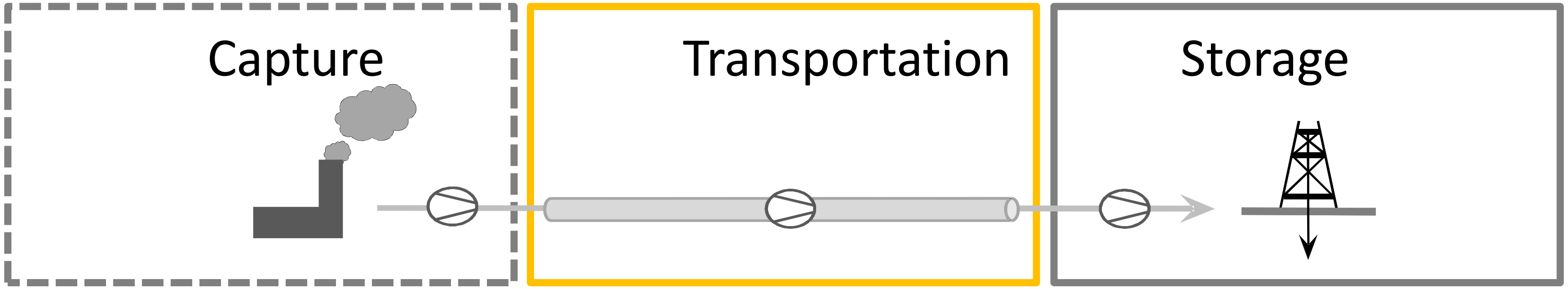
Corrosion

Non-discriminatory transportation



CO_2 – Specific Main Issues

CCS System boundaries 1



Capture/Transportation Boundary:

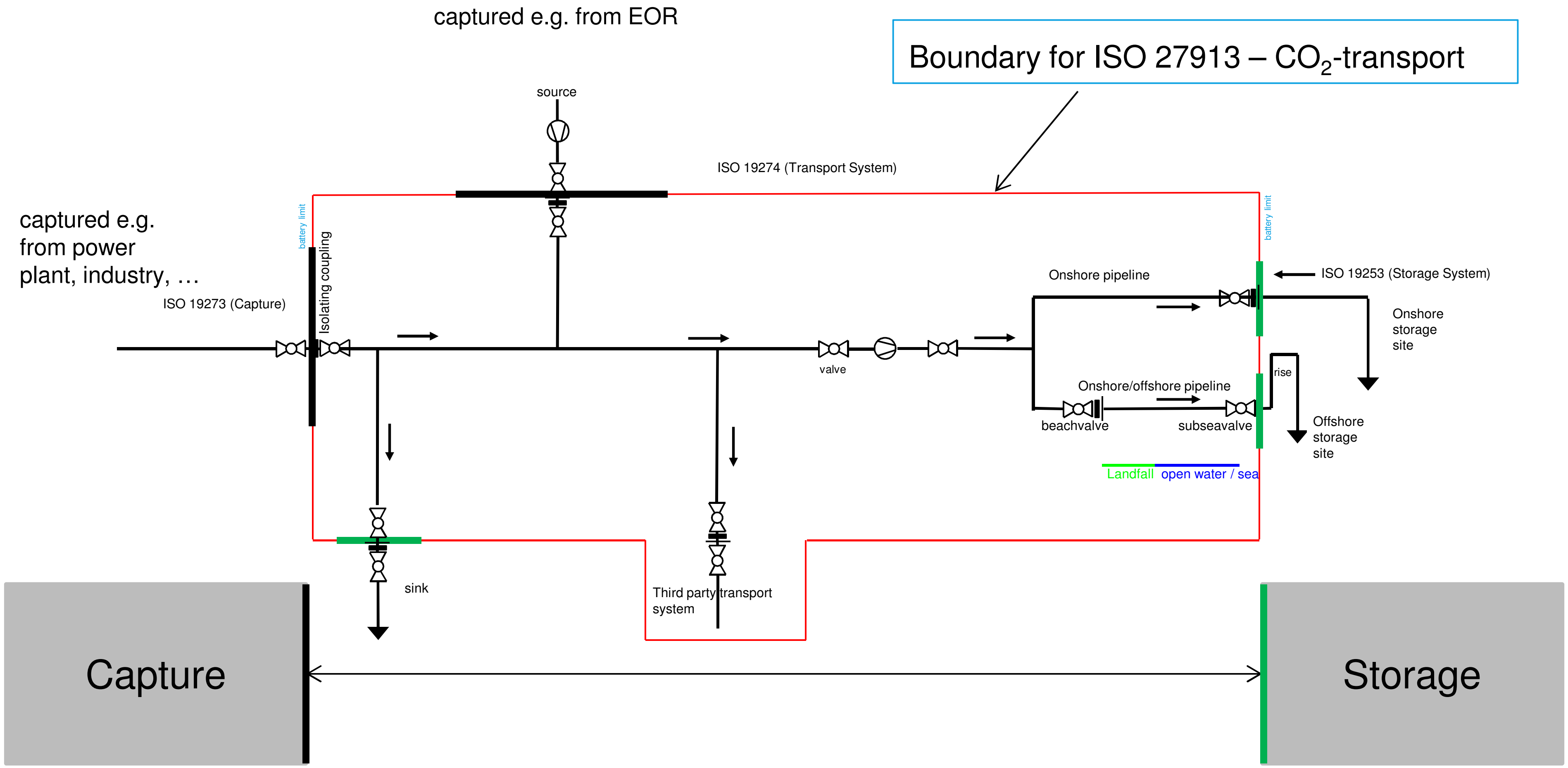
"The system boundary between capture and transportation is the point at the inlet valve of the pipeline, where the composition, temperature, and pressure of the CO_2 stream is within a certain specified range by the capture process or processes to meet the requirements for transportation as described in this International Standard."

Transportation/Storage Boundary:

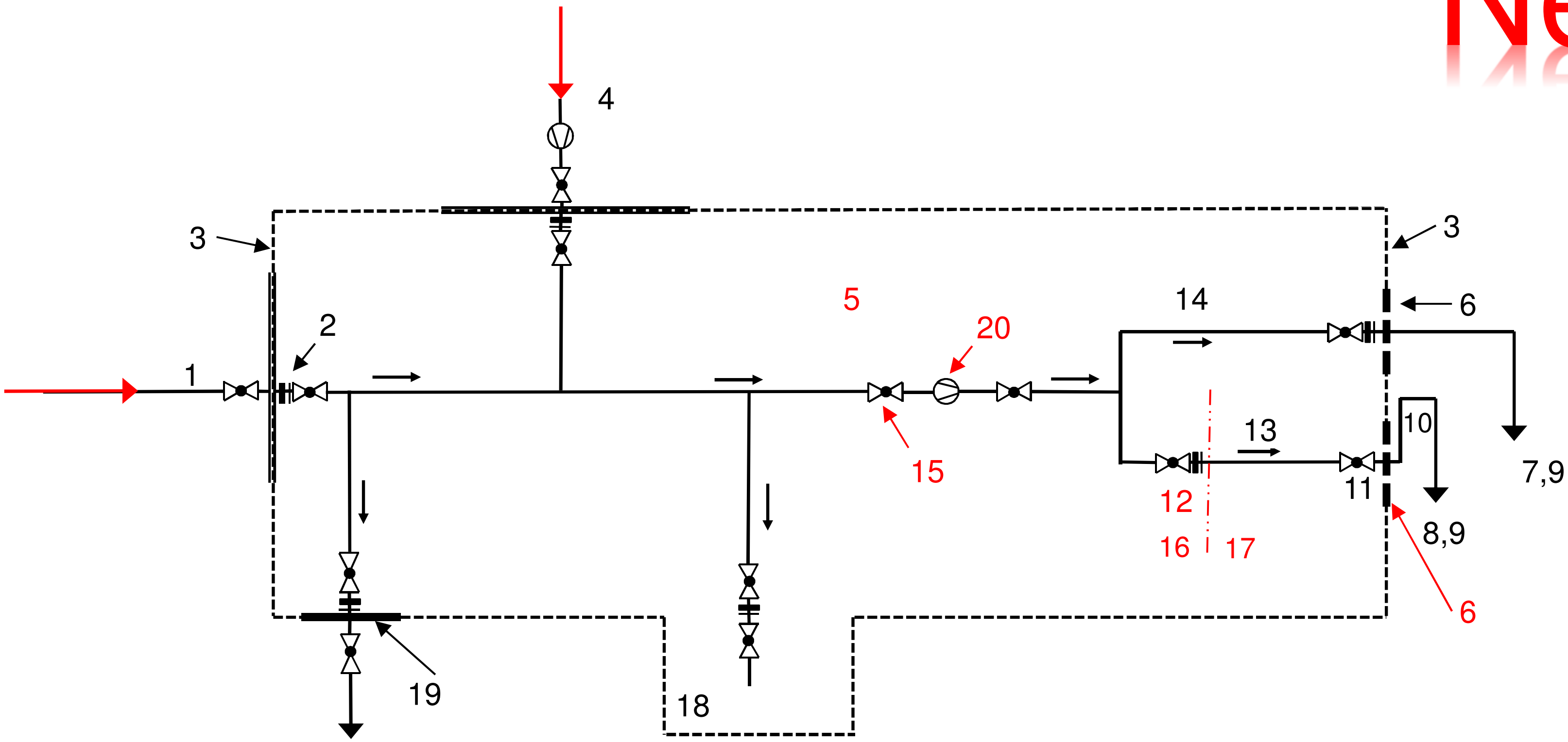
"The boundary between transportation and storage is the point where the CO_2 stream leaves the transportation pipeline infrastructure and enters the storage infrastructure."

Source: ISO/DIS 27913

Definition of CO_2 Transport Boundaries



New



Key

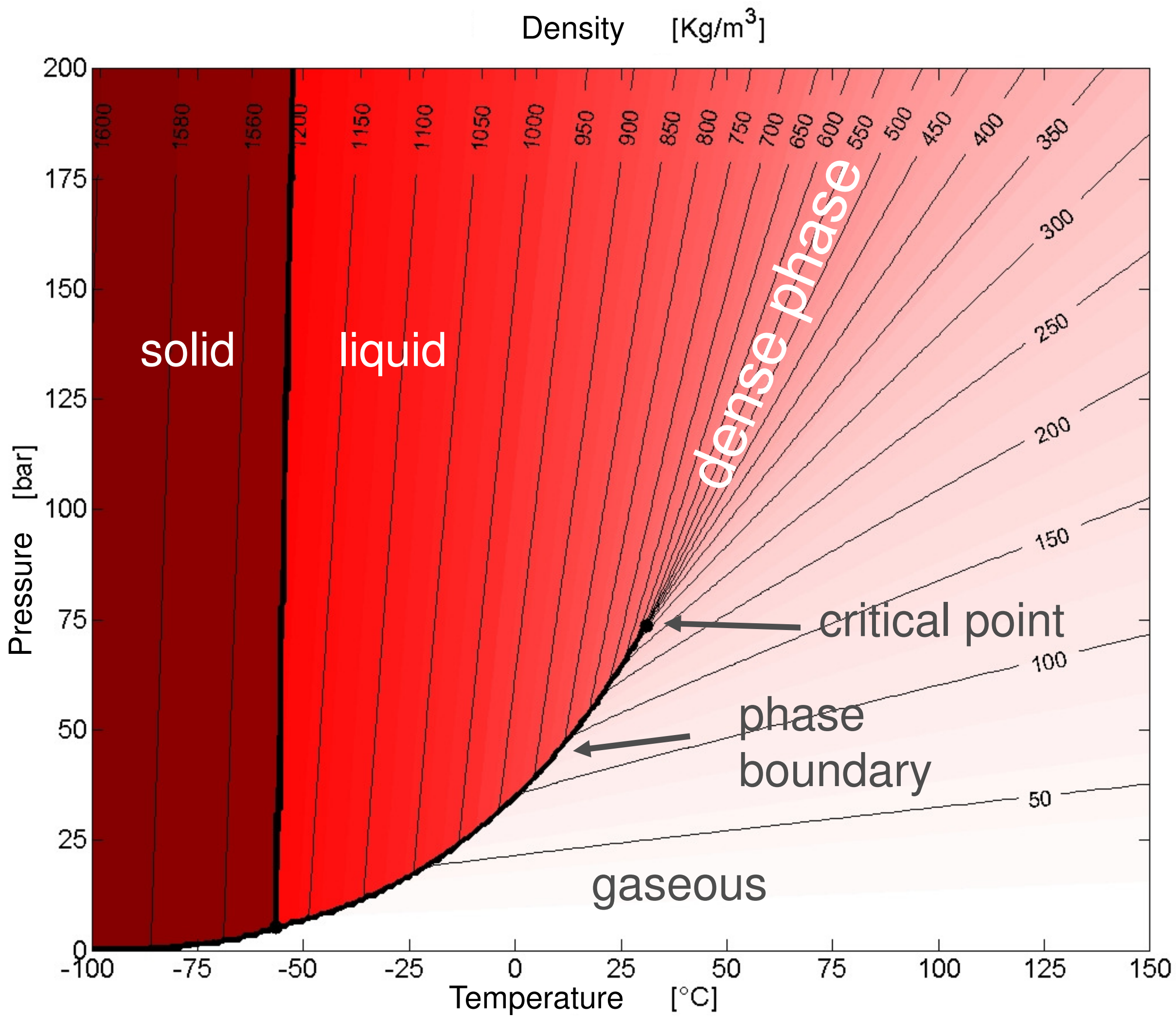
1 source of CO_2, from capture e.g. from power plant, industry, … , see ISO~~/AWI~~ TR 27912 (capture)
2 isolating joint
3 boundary limit
4 ~~source~~ other source of CO_2
5 ISO~~/AWI~~ 27913 (transportation system inside)
6 ~~ISO/AWI 27914~~ (storage system)
7 Onshore storage site
8 Offshore storage site
9 ~~ISO/AWI 27916~~ (EOR)
10 Riser (out of transport scope)
11 Subsea valve (Inside transport scope)
12 Beach valve
13 ~~Onshore~~/offshore pipeline
14 Onshore pipeline
15 Valve
16 Landfall
17 Open water/sea
18 Third party transport system
19 Export to other uses than 7, 8 and 9
20 Intermediate compression or pumping
~~21 Isolation joint~~

Figure 1 — Schematic illustration of the system boundaries of ISO 27913

CO_2 – Specific Main Issues

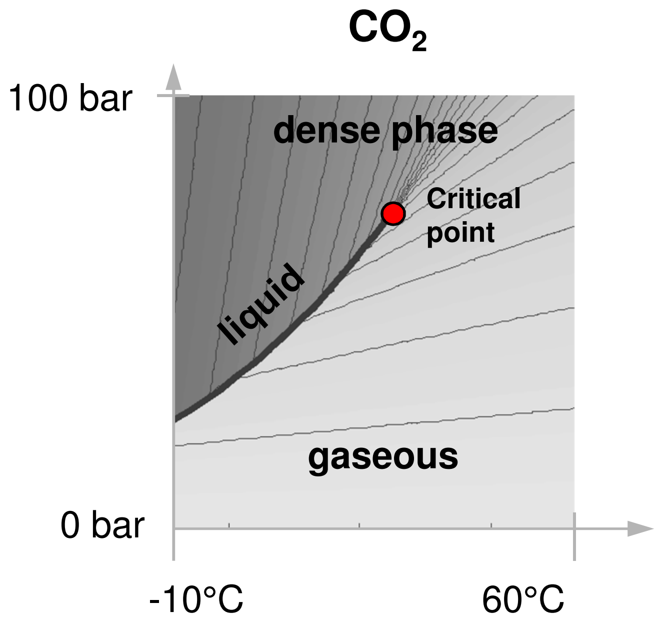
Fracture Arrest

Thermodynamic properties: Pure CO_2



Differences CO_2 versus natural gas

- Phase behavior (three different phases, depended on purity)
- Liquid and dense phase may result in hydraulic shocks
- Fracture propagation / arrest
- …



Fractuer propagation is a NO!-GO!

- Ductile / brittle fracture → crack
- Joule-Thomson effect promotes embrittlement
- CO_2 decompression behaviour promotes crack propagation

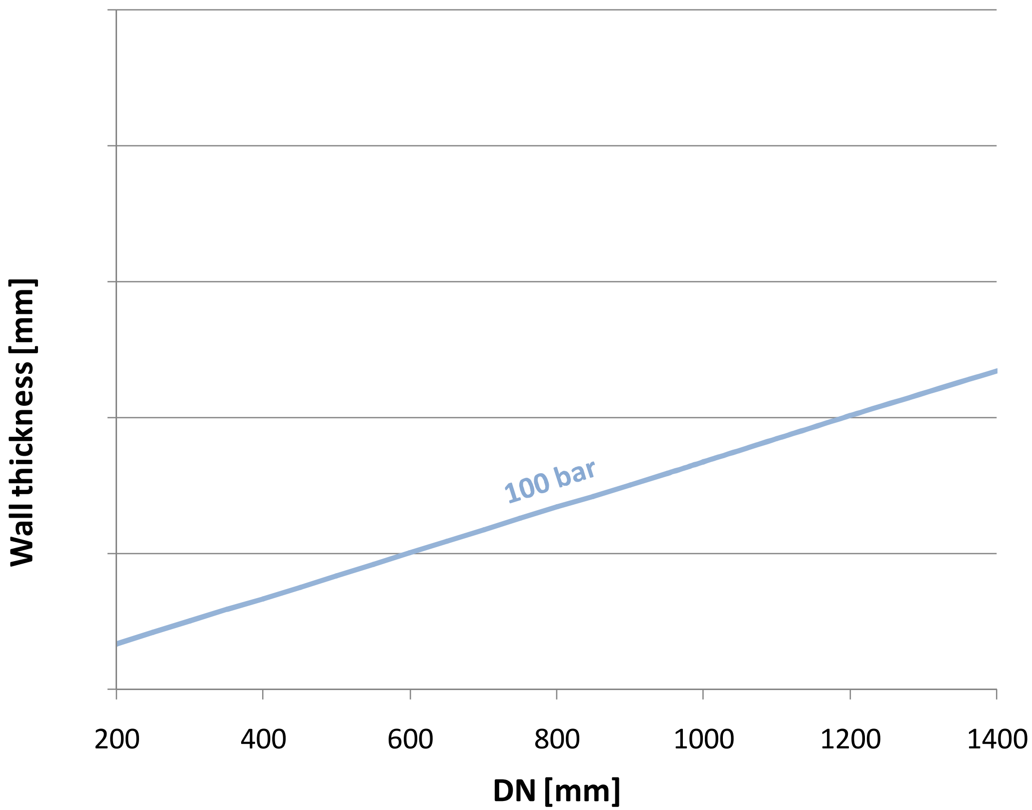
Countermeasures:

- Use of special steels
- Increased wall thickness
- Fiberglass-reinforced plastic cuffs (fracture arrestors)

fracture arrest

fracture propagation

Wall thickness against internal pressure



$$T_{min_{DP}} = \frac{DP \cdot DN}{20 \cdot f_0 \cdot R_{t0.5}}$$

T_{minDP}: Minimum wall thickness against internal pressure [mm]

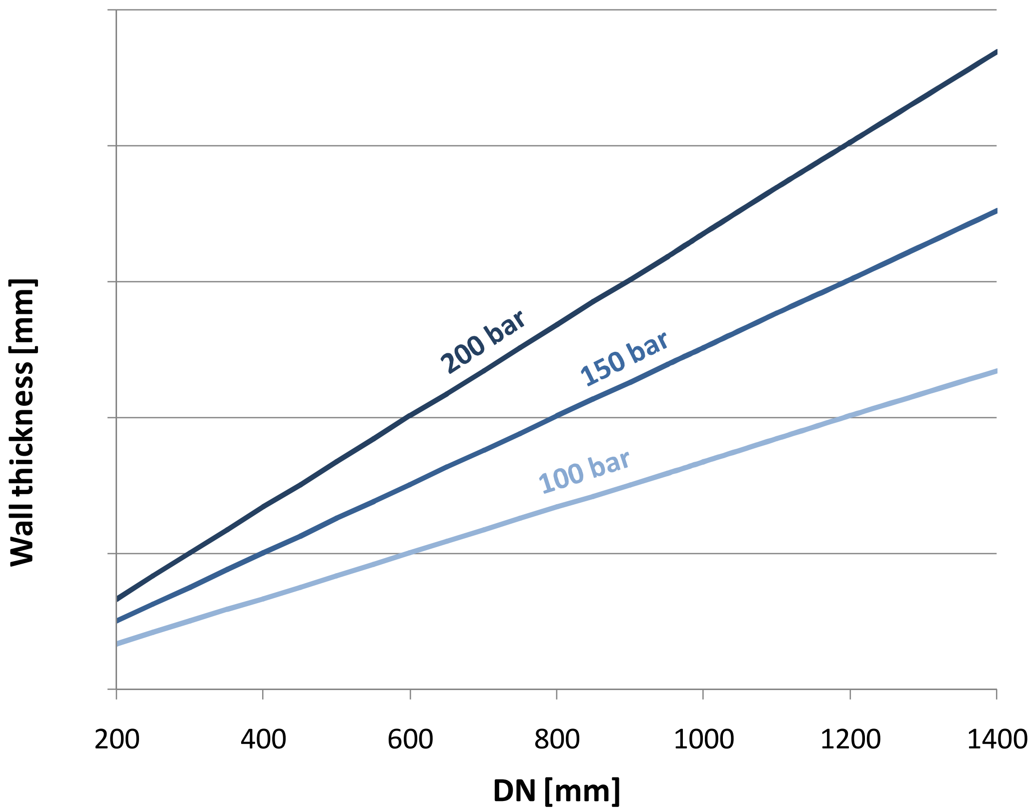
DP: Design Pressure [bar]

DN: Nominal Diameter [mm]

f_0: Load factor [-]

$R_{t0.5}$: Specified minimum yield strength [N/mm^2]

Wall thickness against internal pressure



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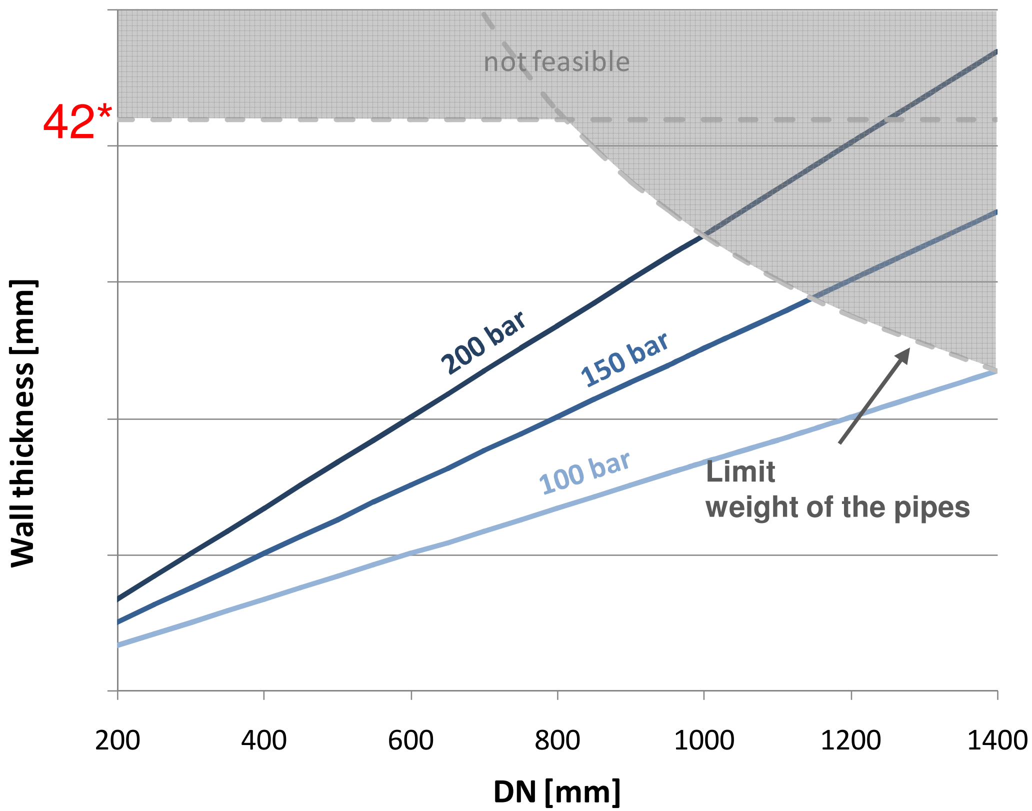

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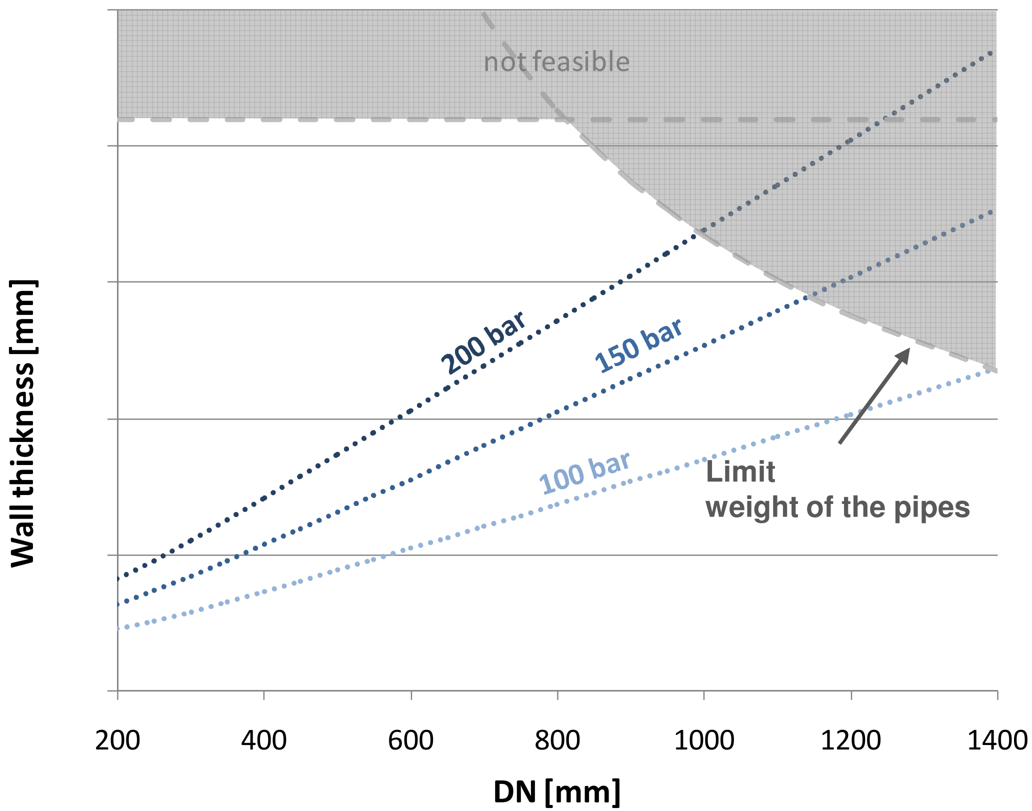
f_0: Load factor [-]

$R_{t0.5}$: Specified minimum yield strength [N/mm^2]

* The number 42 is, in The Hitchhiker's Guide to the Galaxy by Douglas Adams, "The Answer to the Ultimate Question of Life, the Universe, and Everything"

Wall thickness against internal pressure and hydraulic shock

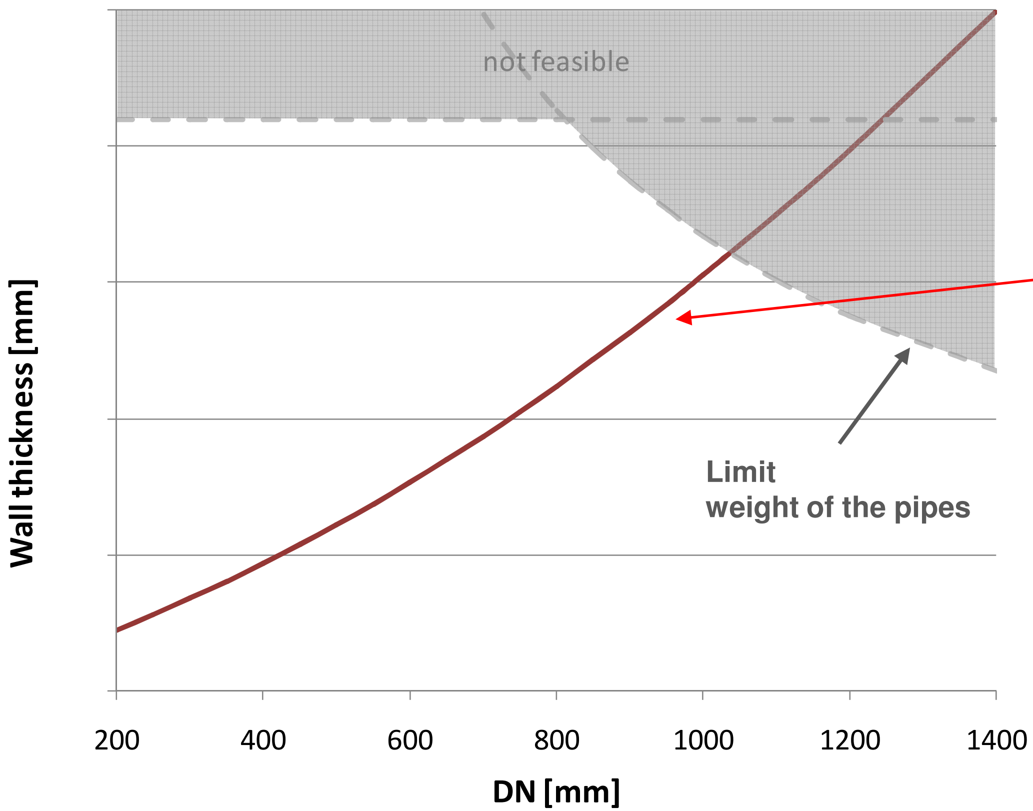


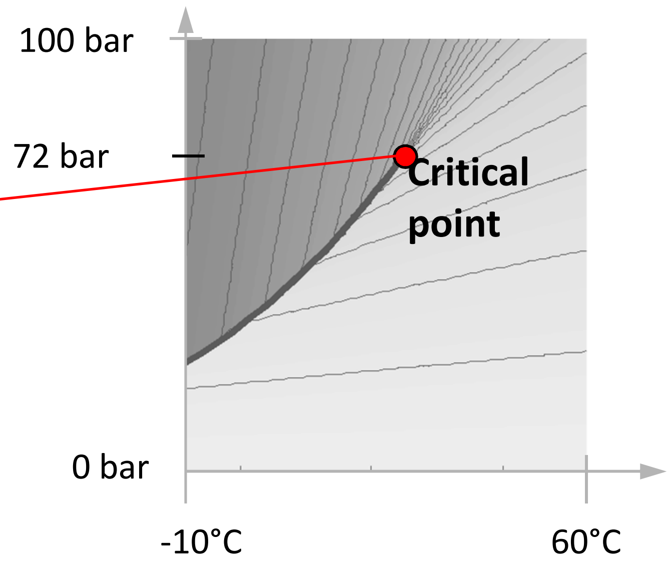
$$\Delta p_{Jou} = \rho \cdot a \cdot \Delta v \cdot 10^{-5}$$

Δp_{Jou}: Change in pressure [bar]
ρ: Density [bar]
a: Wave propagation velocity [m/s]
Δ v: Change in velocity [m/s]

Wall thickness for crack-arrest

$$\frac{C_V E}{A_c \bar{\sigma}^2 \sqrt{Rt}} = \frac{24}{\pi} \ln \sec\left[\frac{\pi}{2} \cdot \frac{3.33\sigma_a}{\bar{\sigma}}\right]$$





Parameters: Steel X 70, Cv > 100 J
Driving pressure at critical point

Modified Battelle-Two-Curve

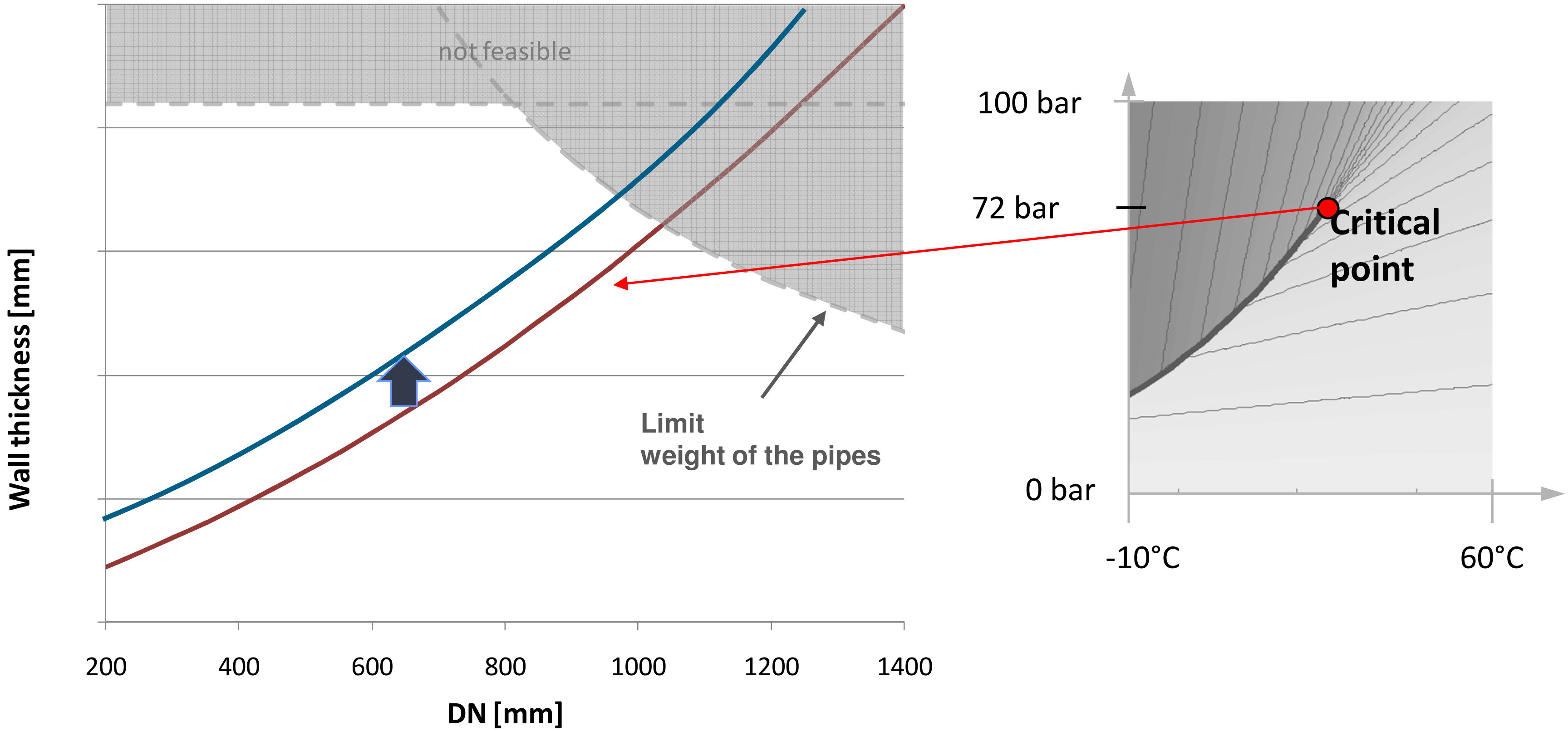
One approach to calculate the wall thickness against ductile fracture is the use of the standard Battelle Two-Curve approach. The Battelle Two Curve Model was originally derived from decompression tests using lean and rich gasses, which exhibited no plateau or a short plateau: since the decompression curve for CO_2 has a very long plateau, the Battelle-Two-Curve-Model has not been shown to be sufficiently conservative for CO_2 under some conditions [20]. These conditions particularly exist if a Charpy-V-notch toughness of > 100 Joule is required. However, because the relationship between Charpy V-notch impact energy and the ductile fracture propagation resistance of the steel is not linear, there is some additional uncertainty in the application of the Charpy V-notch test alone when the arrest toughness is very high (>330J), [20].

For line pipe material with Charpy-V-notch toughness < 330 J, and until additional test results permit a comprehensive mathematical solution, a suggested approach is to apply an additional correction factor to the relevant hoop stress. Based on the current knowledge a correction factor of $c_{cf} \geq 1{,}2$ is recommended unless it can be demonstrated otherwise. Specialist advice can be obtained to determine an alternative correction factor $c_{cf} \geq 1$.

$$1000 \frac{C_v \cdot E}{A_c \cdot \sigma_f^{\,2} \cdot \sqrt{R \cdot t}} = \frac{24}{\pi} \cdot \ln\left(\sec\left[\frac{\pi}{2} \cdot \frac{c_{cf} \cdot 3{,}33 \cdot \sigma_a}{\sigma_f}\right]\right) \qquad (1)$$

Wall thickness for crack-arrest

$$\frac{C_V E}{A_C \bar{\sigma}^2 \sqrt{Rt}} = \frac{24}{\pi} \ln \sec\left[\frac{\pi^{1,2}}{2} \cdot \frac{3.33\sigma_a}{\bar{\sigma}}\right]$$



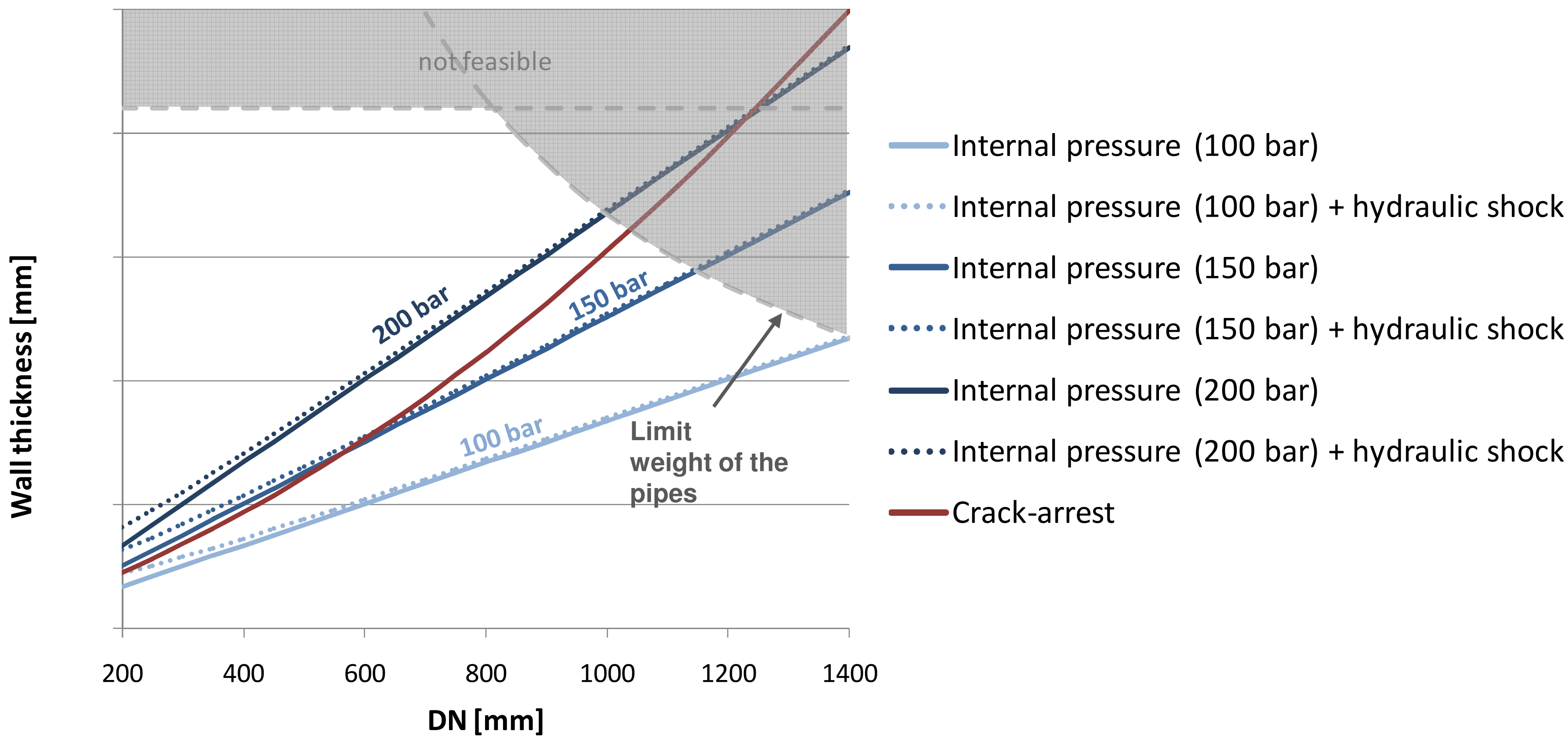
Parameters: Steel X 70, Cv > 100 J
Driving pressure at critical point

Calculation of wall thickness

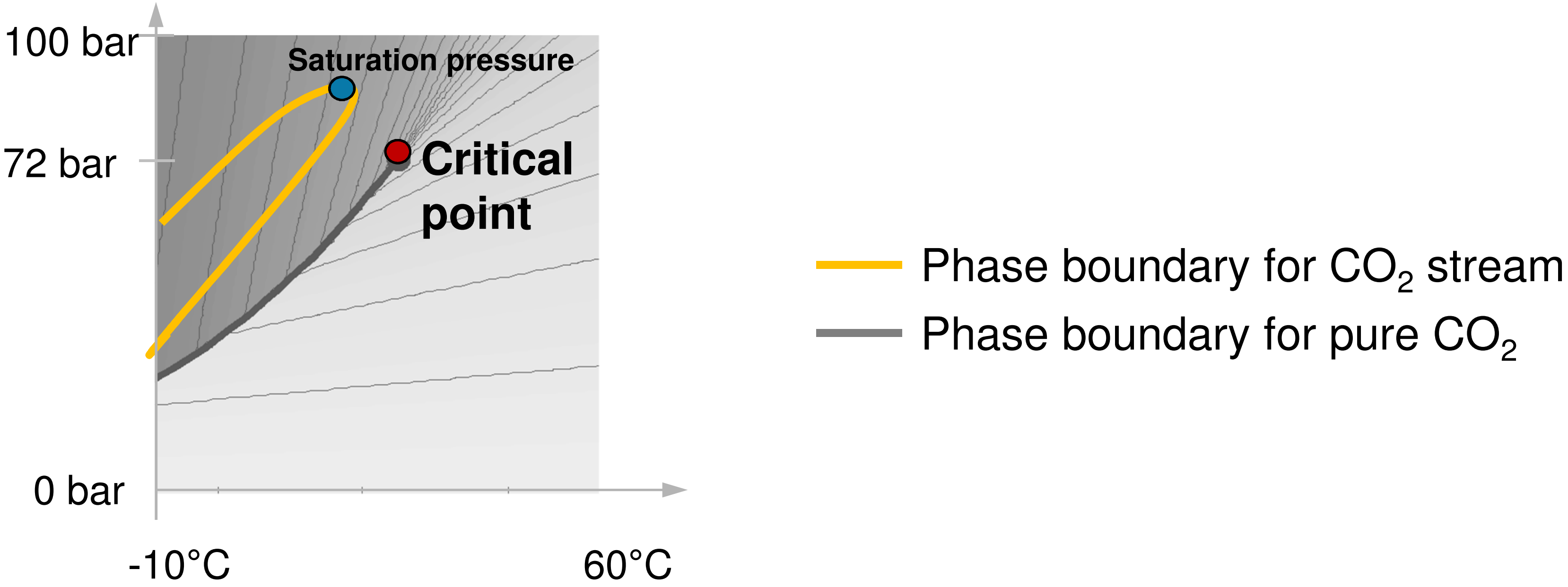
$$T_{min} = max\left(T_{min_{DP}}, T_{min_{HS}}, T_{min_{CA}}\right)$$

T_{min}:	Minimum wall thickness
T_{minDP}:	Minimum wall thickness against **internal pressure**
T_{minHS}:	Minimum wall thickness against **hydraulic shock**
T_{minCA}:	Minimum wall thickness to assure **crack-arrest (which is a function of CO_2 stream composition)**

Minimum wall thickness



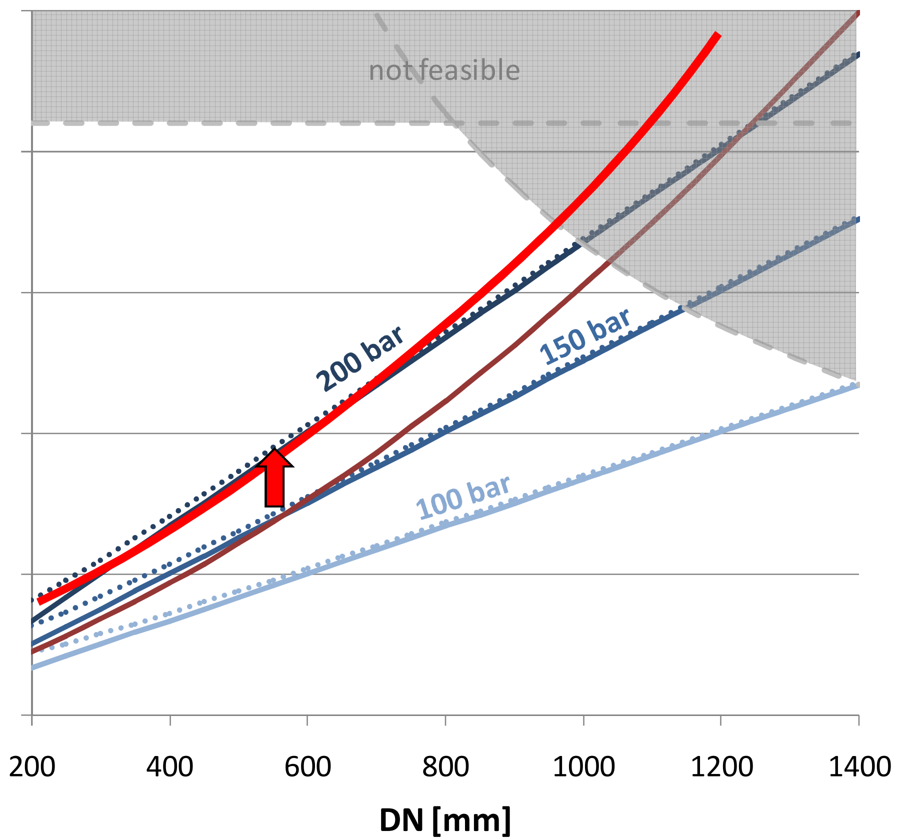
Thermodynamic properties: CO_2 stream with impurities



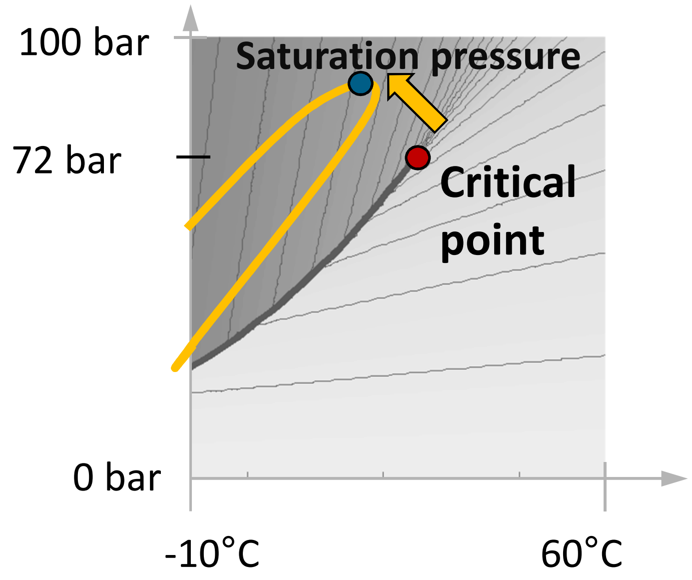
- **The CO_2 composition determines the required wall thickness, what has to be considered in the design phase or limits the operational window**.

- Impurities have impact on thermodynamic properties of a CO_2 stream which cannot be predicted out of the properties of pure CO_2
- Impurities can effect corrosive or generate chemical reactions
- Further properties of a CO_2 stream, like viscosity can change

More wall thickness for crack-arrest for CO_2 streams with impurities



- Wall thickness for CO_2 stream
- Wall thickness for pure CO_2



- Phase boundary for CO_2 stream
- Phase boundary for pure CO_2

Pure CO_2, CO_2-streams with impurities

Pure CO_2, CO_2 streams with impurities have significant consequences on design, construction and operation, e.g.:

Design:

- internal pressure, hydraulic shock and fracture arrest

Construction:

- pipeline bending, pipeline welding

Operation:

- operational envelope

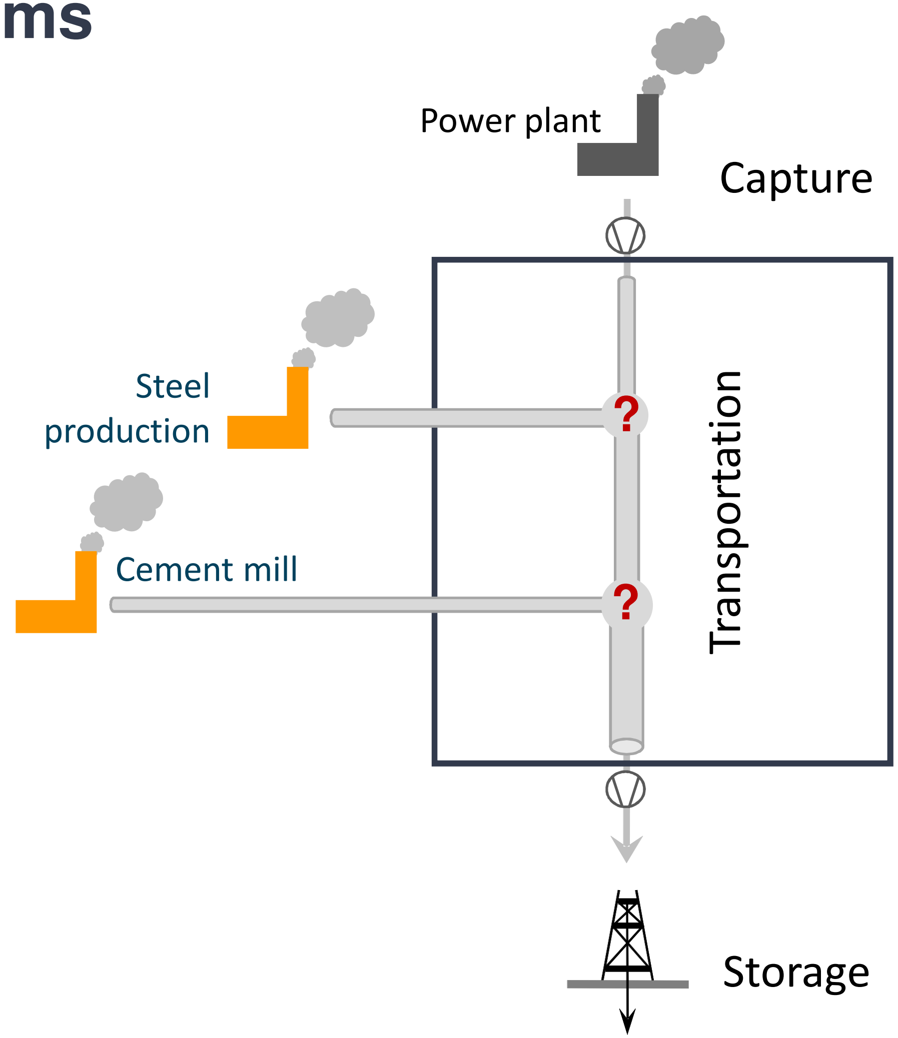
All that has consequences to:

- Fracture arrest design
- Corrosion protection
- Operational window
- Avoidance of two phase flow

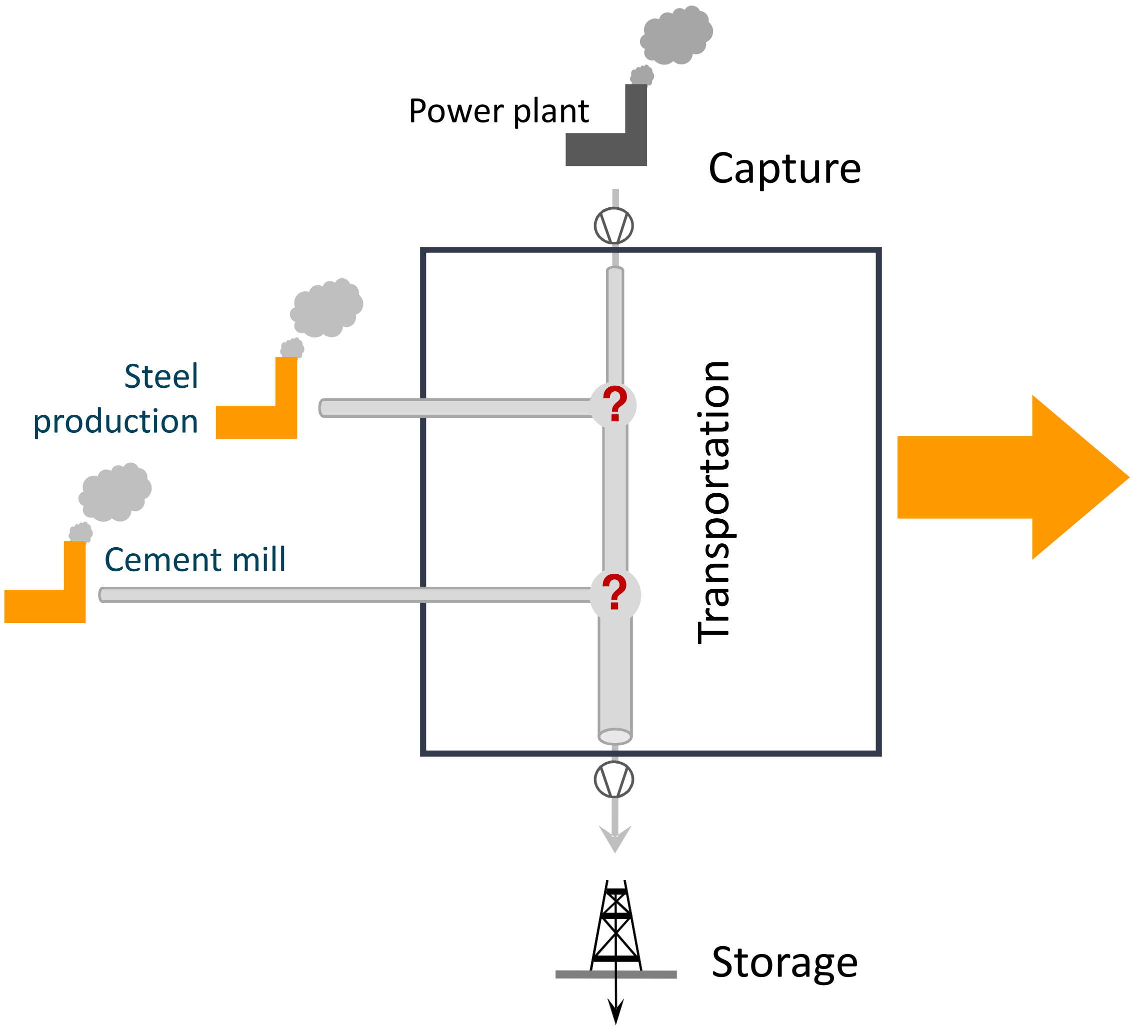
Mixture of different CO_2 streams

In case of mixing of different CO_2 streams in a pipeline network, it must be assured that the mixture of the individual compounds from the different CO_2 streams do not cause:

- Risk of corrosion
- Undesired cross chemical reactions /effects



Grid access and implications for design and operation



Grid access for everybody possible if the specification of the CO_2-stream is within the operational envelope

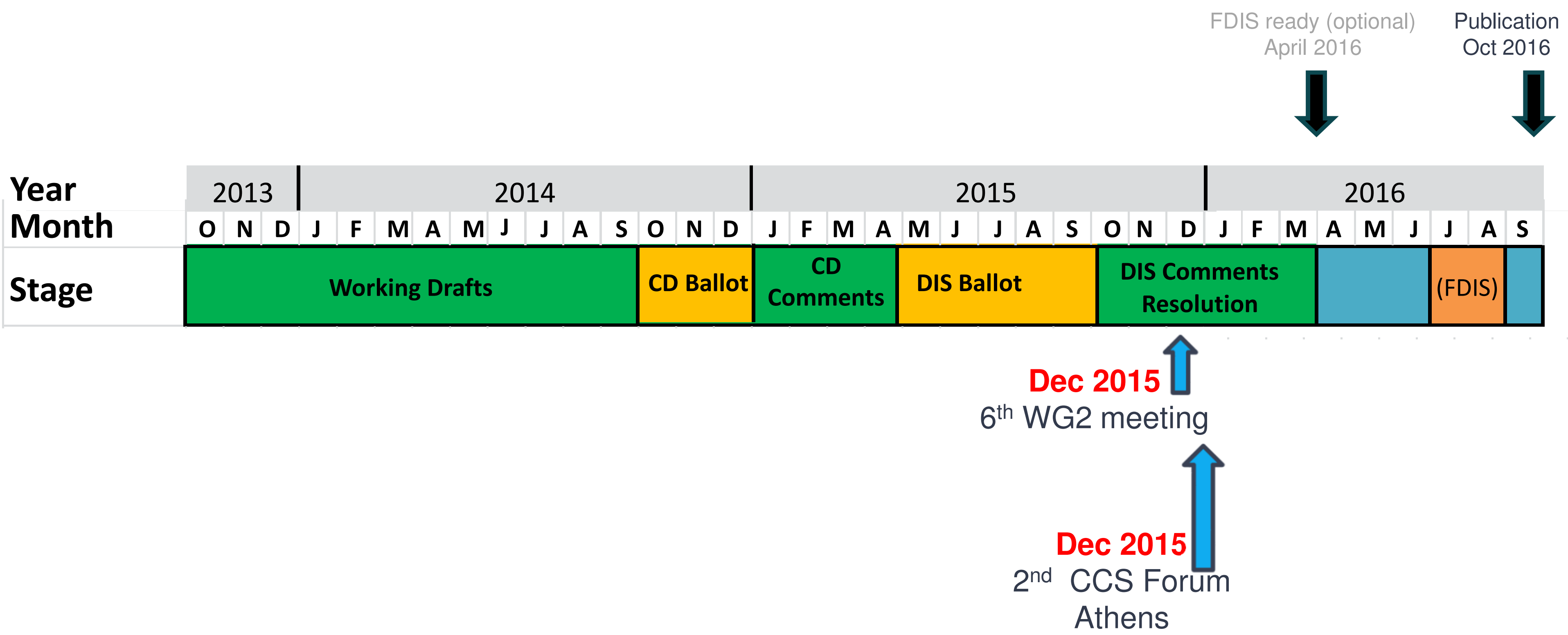
Internal corrosion

- CO_2 pipelines should be designed for corrosion to be within design margins under normal operational conditions.

- For upset conditions a corrosion management plan shall be developed as part of the design. Its scope shall include a plan to recover from failure of the control. Failures can occur upstream of or within the pipeline system.

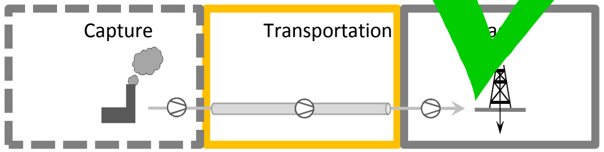
- For additional information see
  Annex C – Internal corrosion (informative)
  - C.1 Measures to minimise internal corrosion
  - C.2 Impact of impurities on internal corrosion
  - C.3 Internal corrosion control

Current status and publication date of Standard



Main Issues

Boundaries to Capture and Storage



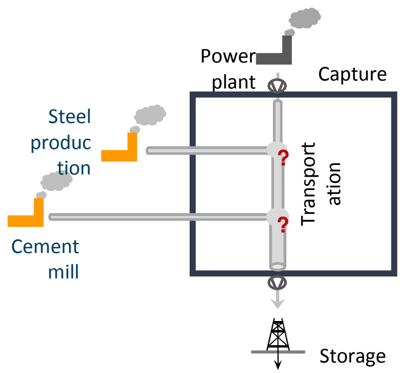
(state of the art)

Fracture arrest

Corrosion

(state of the art)

Non-discriminatory transportation



Summary

- Efficient collaboration on international basis
- Active international participation in the standard development assures broad agreement
- Standard ISO 27913 gives a good framework for design, construction and operation of CO_2 pipelines
- The CO_2 Standard is a valuable supplement to existing Standards for Natural Gas
- This ISO describes the **state of the art** – but **state of the art will develop** in future

Acknowledgement

- Convenor expressed his appreciation

  to e·on for financing the work in 2012 – 2014 and

  to DVGW for financing the work in 2015

- Secretary expressed her appreciation

  to DVGW for financing the work in 2012 – 2015

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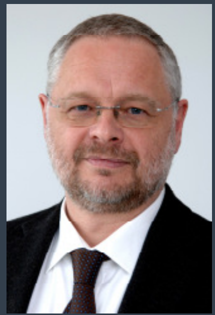

Thank you for your attention

Back up

Dr. Hilgenstock Consulting

Dr.-Ing. Achim Hilgenstock

Education

- Mechanical Engineering — Ruhr-University Bochum, Germany and Texas A&M University, USA
- Doctoral thesis — DLR – Göttingen, University Karlsruhe, Germany

Professional Experience

2015 -	Consultant	Dr. Hilgenstock Consulting
2012 -	Convenor for ISO/TC 265/WG 2 CO_2 Transportation	
2012 -	Convenor of DVGW expert group CCS	
2012 -	Convenor and national representative of the DVGW/DIN mirror group for CO_2 transport	
2012 – 2014	Head of Gas Technology and Trading Support	E.ON SE
2010 – 2012	Vice President Technical Cooperation	E.ON Ruhrgas AG
2007 - 2010	Head of Pipeline Projects	E.ON Ruhrgas AG
1999 - 2007	Project Manager Pipeline Projects	Ruhrgas AG
1996 - 1999	Head of Department Numerical Simulation	Ruhrgas AG
1992 - 1996	Head of Division Industrial Gas Application	Ruhrgas AG
1986 - 1992	Research Assistant Theoretical Fluid Dynamics	DLR

Standardization activities for CCS

DVGW	DIN	CEN	ISO
DVGW TK-CCS *New C-Standard for CO2* E.g.: • C463 • C260 • …	**TC 265 –** **Mirror committee** working group (NA 119-01-04 AA) since 2012 for national standardization: • CO_2-Capture • CO_2-Transportation • CO_2-Storage • Quantification and Verification TB6 • Cross-Cutting Issues TB5	Only observing, no own activity	**TC 265** • WG 1 Capture • WG 2 Transportation • WG 3 Storage • WG 4 Quantification and Verification • WG 5 Cross-Cutting Issues • (WG 6 EOR-Issues)
Participation in TC 265 WG 2	Participation in TC 265 WG 2		
National Standardization		European Standardization	International Standardization

Folie 45

TB5 Auf Deutsch: Übergreifende und Querschnittsaufgaben. Soll ich das so übersetzen?
Baumeister; 25.10.2015

TB6 Siehe obiger Kommentar: Bilanzierung und Verifizierung
Baumeister; 25.10.2015