Well Abandonment Practices

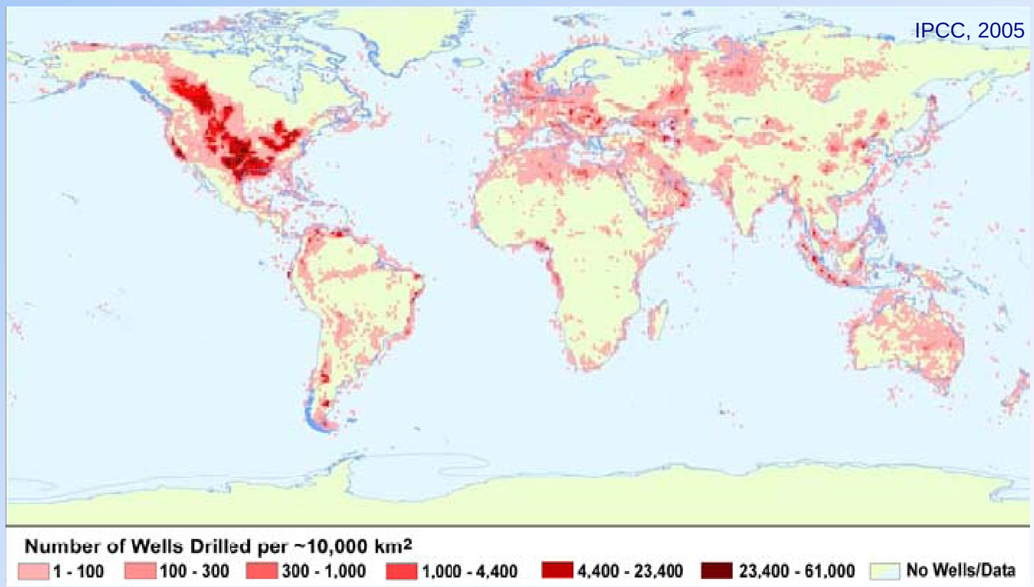
IEA GHG Wellbore Integrity Network Meeting
Calgary, May 13, 2009

TNO | Knowledge for business

Tjirk Benedictus

Introduction

- In 2008 TNO was contracted by IEA GHG to conduct a review study into well abandonment practices based on available literature
- Results are to be published as IEA GHG report
- Draft results presented here: any feedback is appreciated!



Scope of the study

- Previously abandoned deep oil and gas wells
- Well abandonment techniques
- High order evaluation of abandonment practices, through:
  - Expert opinions (questionnaire)
  - Governing regulatory frameworks
- Suitability for CO_2 storage
  - Overview of state of knowledge on well material degradation
- Risk assessment
- Recommended best practice

Types of wells

- Regarding CO_2 storage, different types of wells need to be distinguished (after Watson & Bachu, 2007):

  - Future wells
    - Wells directly related to the storage operations (i.e. CO_2 injection or monitoring wells)
    - Wells penetrating or transecting CO_2 storage reservoirs aiming at reservoirs at deeper levels

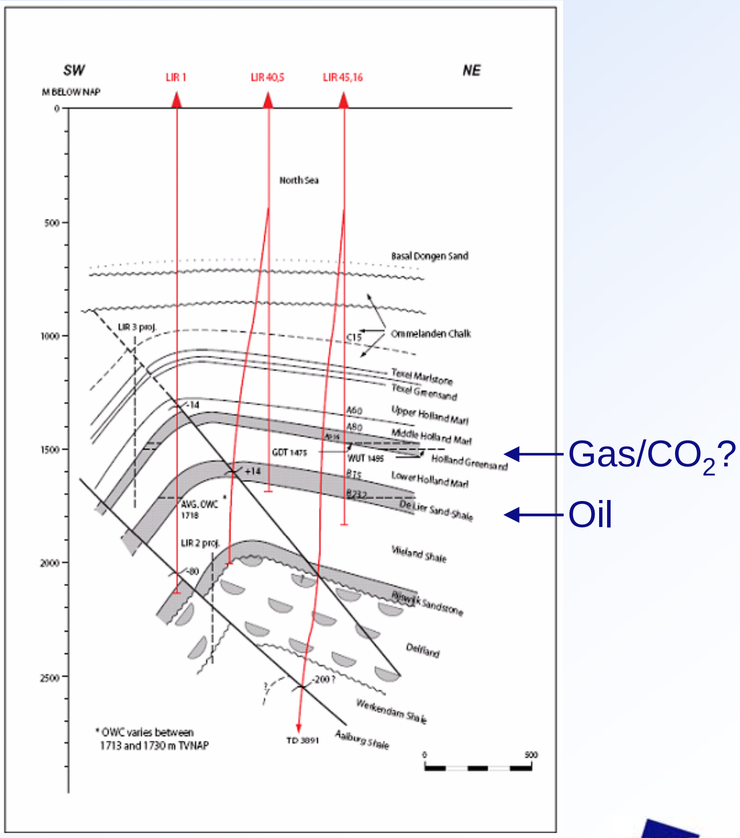
    To be designed and abandoned taking into account CO_2 storage
  - Existing wells **To be abandoned taking into account CO_2 storage**
    - Accessible wells (e.g. operating, shut-in)
    - Previously abandoned wells

    Main risk for well integrity (leakage)

Case study: De Lier (the Netherlands)

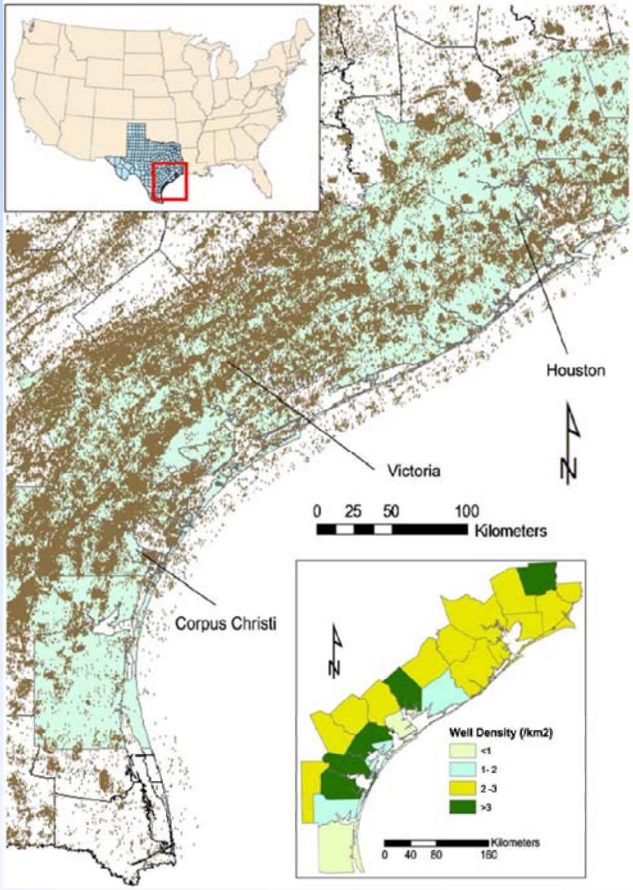
previously presented at the 3rd Wellbore Integrity Network meeting

- Feasibility study to store CO_2 in the depleted gas reservoir of the onshore, stacked De Lier field
- Penetrated by 51 abandoned wells
- Wells are abandoned according to regulations; abandonment did NOT take into account CO_2 storage
- Some wells would need reabandonment
- Consequently, the proposed storage project was discontinued

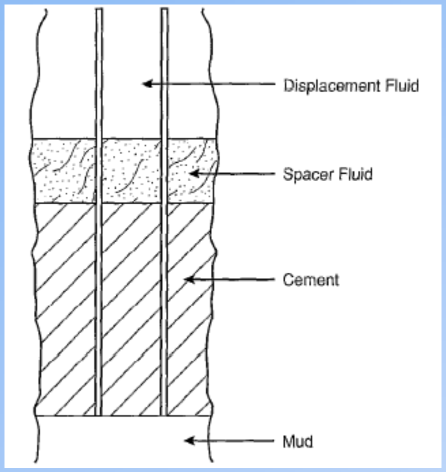


Case study: Gulf Coast, Texas (USA)

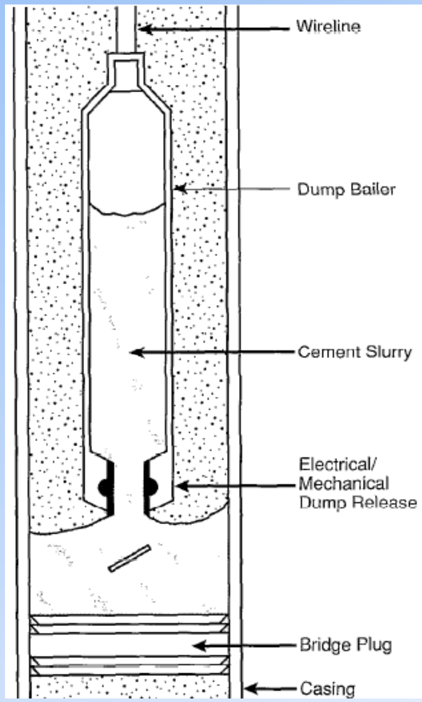
- Suitable geology for CO_2 storage, but…
- Extremely high well density (although decreasing with depth): high probability of encountering (abandoned) wells
- No comprehensive database on oil and gas wells ever drilled (especially older wells, i.e. pre-1930s, are lacking): high uncertainty regarding abandoned wells (e.g. location, abandonment status)
- After: Nicot et al., 2006; Nicot, 2008



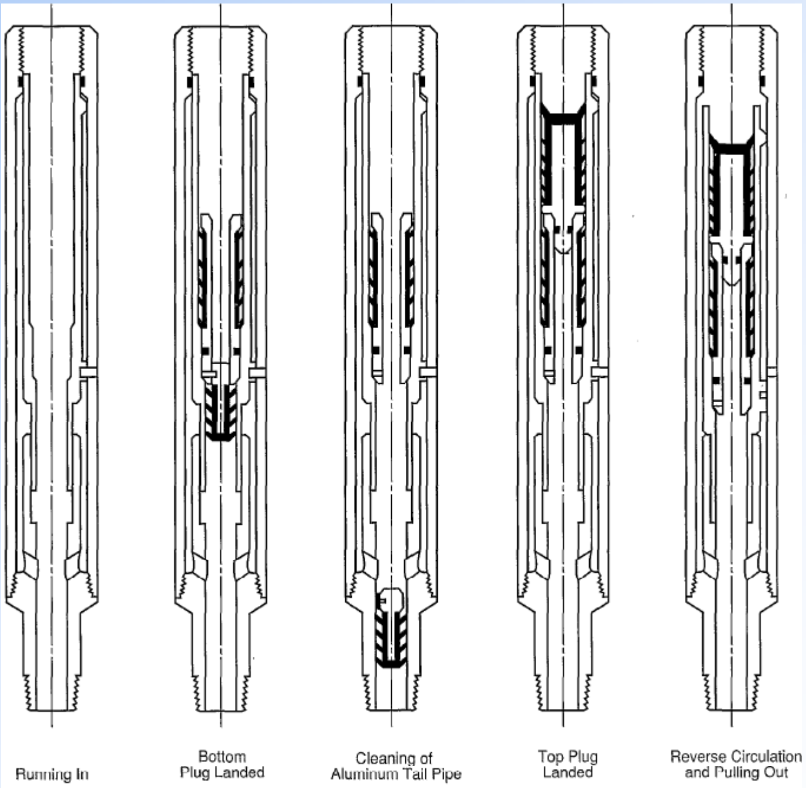
Plugging techniques



Balanced plug method



Dump Bailer method

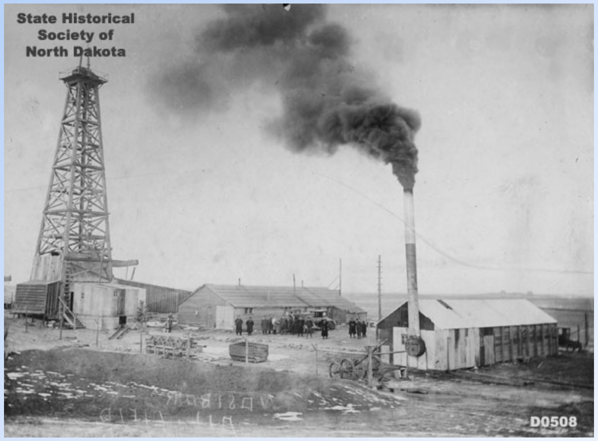


Two-plug method

Cement squeeze method

After: Nelson and Guillot, 2006

Historical developments in plugging



- 1922: Patent on Two-plug method by Halliburton, limiting potential mud contamination
- 1928: Multiple cement types became available for plugging
- ~1930: Introduction of centralizers, enabling more uniform cement distribution in wells
- 1940: Introduction of two types of Portland cement and three types of additives
- 1940s: Invention and widespread use of caliper, enabling calculation of the exact quantity of cement
- 1953: Publication of API standards on well cements

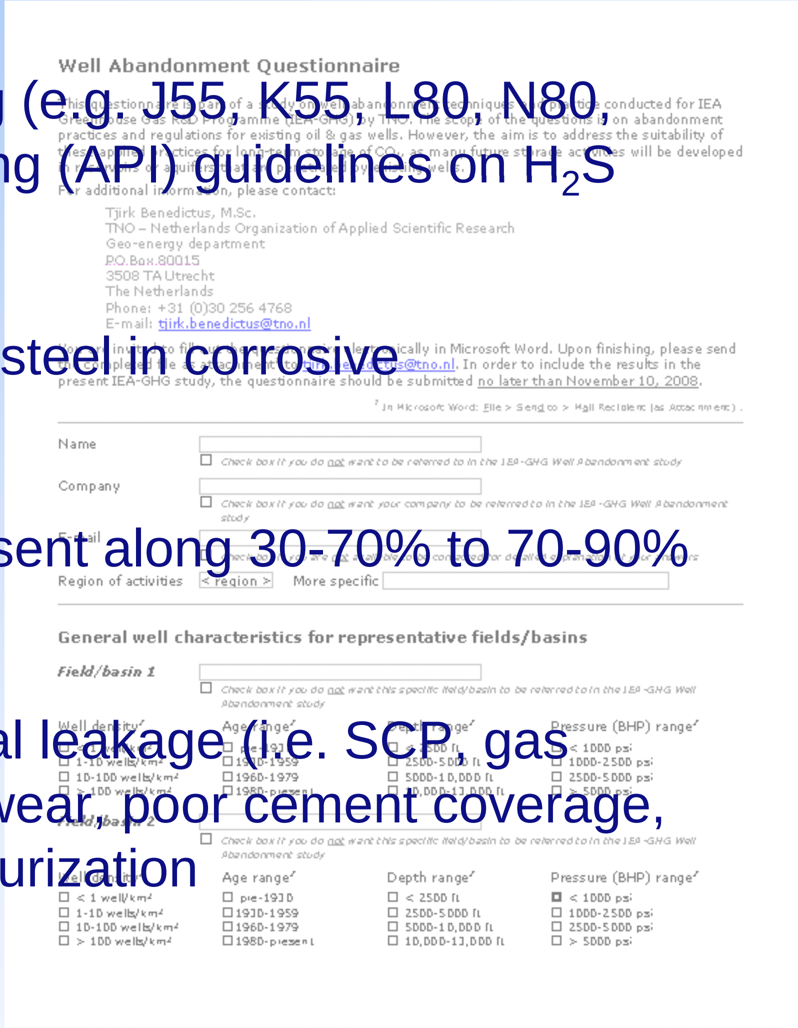
- Wells that were abandoned prior to 1953 are often not considered to have effective cement plugs

Abandonment practices

- Results based on a survey/questionnaire presented to approximately 200 experts (at operators, service companies, research institutes, regulatory bodies).
- Only 9 responses from different regions (North America, Europe, Australia)
- Questionnaire subjects comprise:
  - Drilling & completion operations
  - Abandonment regulations
  - Abandonment practices
  - Data availability

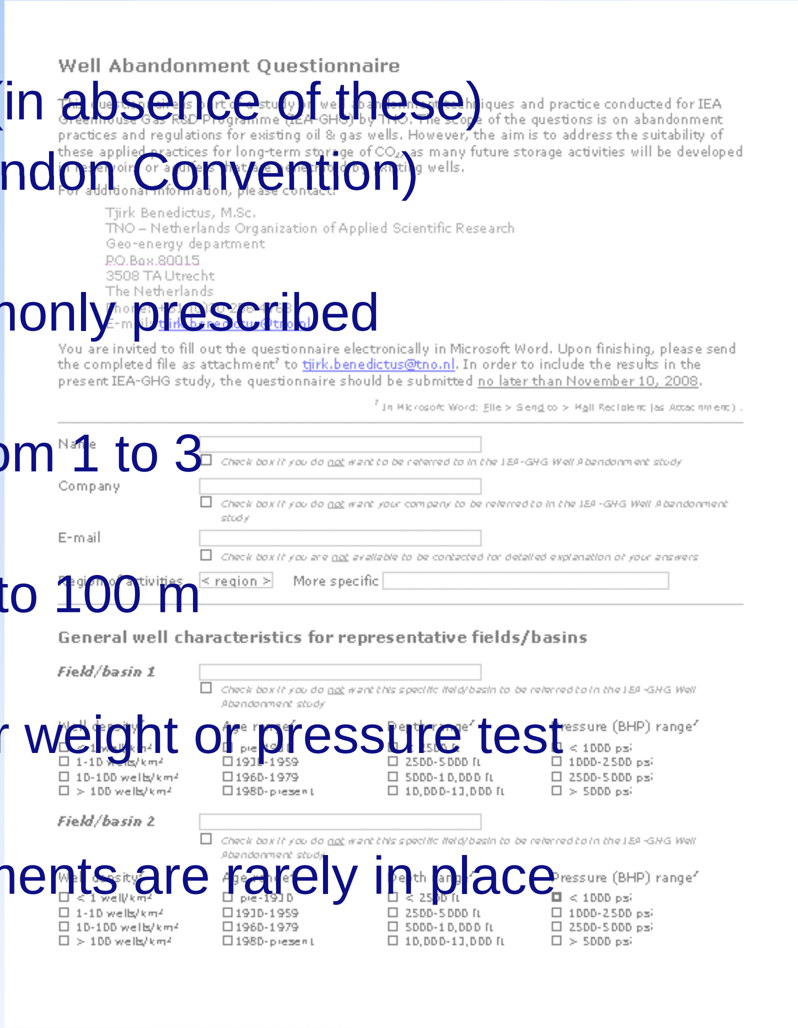
Questionnaire: Drilling and completion

- Various steel grades used for casing (e.g. J55, K55, L80, N80, C95, P110, Q125), generally following (API) guidelines on H_2S content, temperature and pressure.
- Common practice to use Cr-13 type steel in corrosive environments
- Primary cement sheath typically present along 30-70% to 70-90% of the wellbore
- 0-10% to 10-30% of wells show initial leakage (i.e. SCP, gas migration), due to casing corrosion/wear, poor cement coverage, improper slurry design, or overpressurization



Questionnaire: Abandonment regulations

- Regional or national regulations, or (in absence of these) international guidelines (OSPAR, London Convention)
- Balanced plug method is most commonly prescribed
- Minimum number of plugs ranges from 1 to 3
- Minimum plug length ranges from 8 to 100 m
- Plug testing generally involves either weight or pressure test
- Requirements for corrosive environments are rarely in place



Well Abandonment Questionnaire

practices and regulations for existing oil & gas wells. However, the aim is to address the suitability of these applied practices for long-term storage of CO_2, as many future storage activities will be developed

Tjirk Benedictus, M.Sc.
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The Netherlands

You are invited to fill out the questionnaire electronically in Microsoft Word. Upon finishing, please send the completed file as attachment[1] to tjirk.benedictus@tno.nl. In order to include the results in the present IEA-GHG study, the questionnaire should be submitted no later than November 10, 2008.

Company
☐ Check box if you do not want your company to be referred to in the IEA-GHG Well Abandonment study

E-mail
☐ Check box if you are not available to be contacted for detailed explanation of your answers

< region > More specific

General well characteristics for representative fields/basins

Field/basin 1
☐ Check box if you do not want this specific field/basin to be referred to in the IEA-GHG Well Abandonment study

Pressure (BHP) range

☐ 1-10 wells/km²	☐ 1930-1959	☐ 2500-5000 ft	☐ 1000-2500 psi
☐ 10-100 wells/km²	☐ 1960-1979	☐ 5000-10,000 ft	☐ 2500-5000 psi
☐ > 100 wells/km²	☐ 1980-present	☐ 10,000-13,000 ft	☐ > 5000 psi

Field/basin 2
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Pressure (BHP) range

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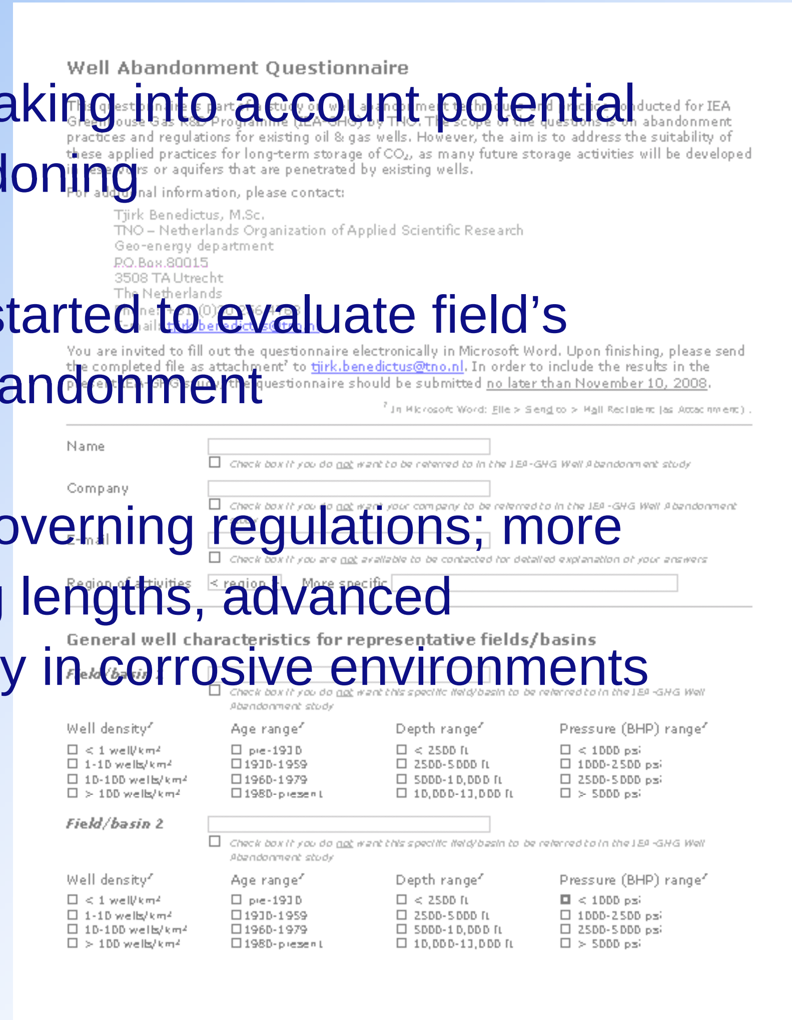
Questionnaire: Abandonment practice

- Majority of operators has not been taking into account potential second life applications when abandoning
- However, some operators recently started to evaluate field's value for future purposes prior to abandonment
- Company practices closely reflect governing regulations; more stringent measures (e.g. longer plug lengths, advanced materials) may be applied, especially in corrosive environments


Well Abandonment Questionnaire

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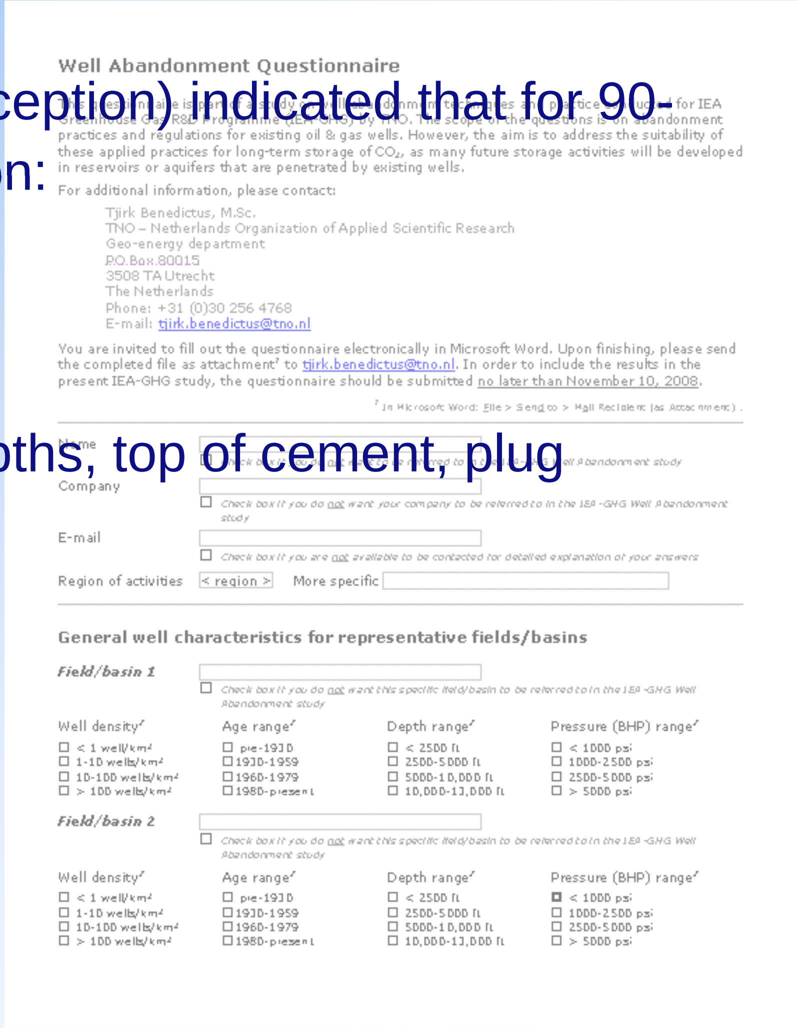
Questionnaire: Data availability

- Majority of respondents (a single exception) indicated that for 90-100% of the wells data is available on:
  - Well location (coordinates)
  - Present well status
  - Well configuration (i.e. cased depths, top of cement, plug lengths, materials applied)



Well Abandonment Questionnaire

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[1] In Microsoft Word: File > Send to > Mail Recipient (as Attachment).

Well Abandonment Regulations

- Literature research of well abandonment requirements in international regulations and a selected number of countries/states with petroleum history, including;
  - Australia
  - Canada
  - China
  - Europe (e.g. Denmark, Netherlands, Norway, UK)
  - Japan
  - USA (Alaska, California, Texas)

- Data obtained of plug lengths and position requirements used in;
  - the transition zone from uncased to cased sections
  - reservoir (uncased) section
  - perforated cased sections

Selection of minimum plug requirements

- Transition zone from uncased to cased sections;
  - Europe; 50-100 m, except UK; 30 m
  - International; 30-60 m, except Canada; 15 m depending on formation

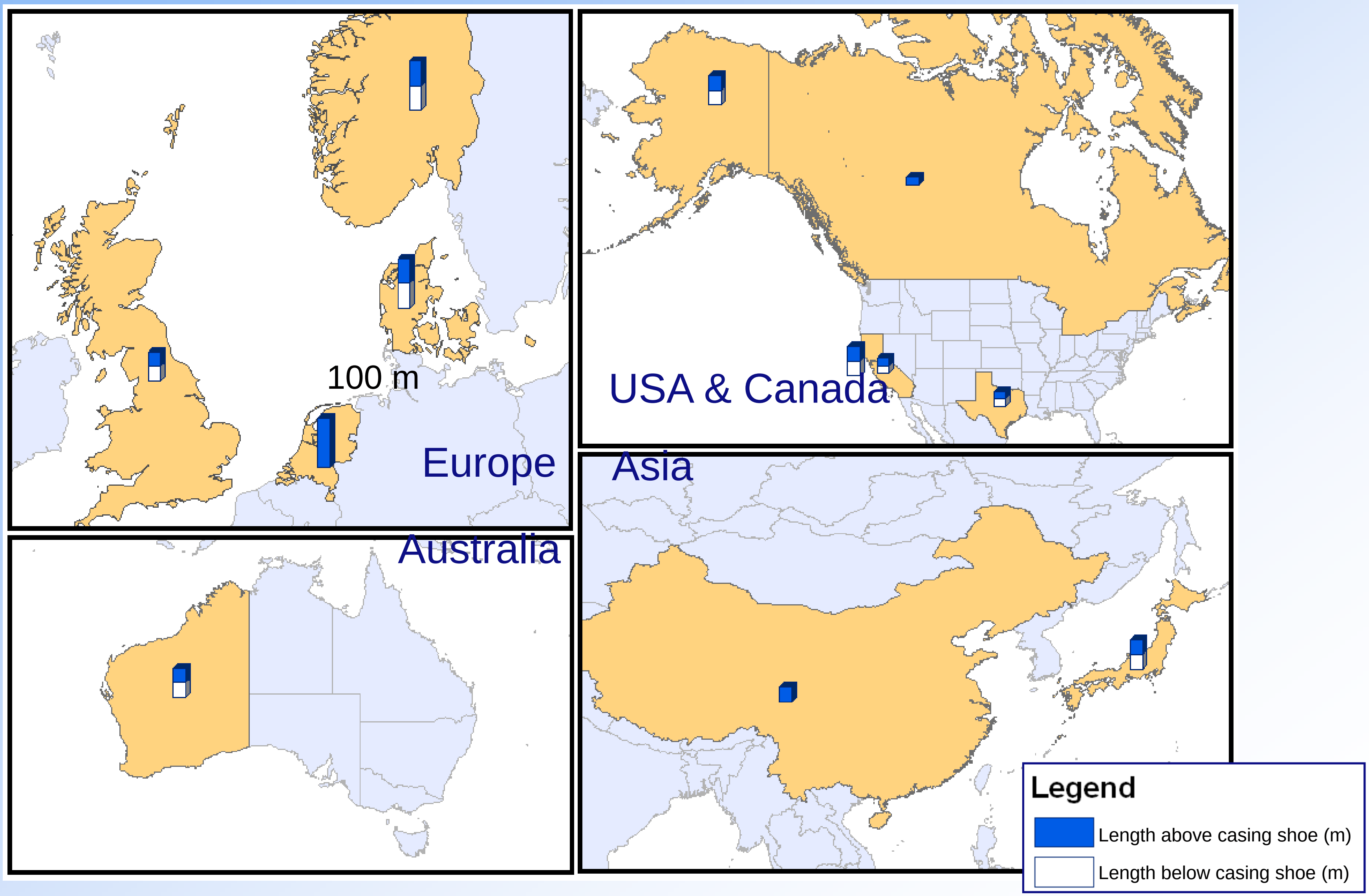
- Reservoir (uncased) section
  - Europe and International; 50-100 m, except UK and Canada; 30 m

- Perforated cased sections
  - Europe; 50-100 m, except UK; 30 m
  - International; 30-60 m, except Canada; 80 m

Note: plug lengths in feet have been converted into meters and rounded off

Minimum plug lengths per country/state

Transition zone from uncased to cased sections



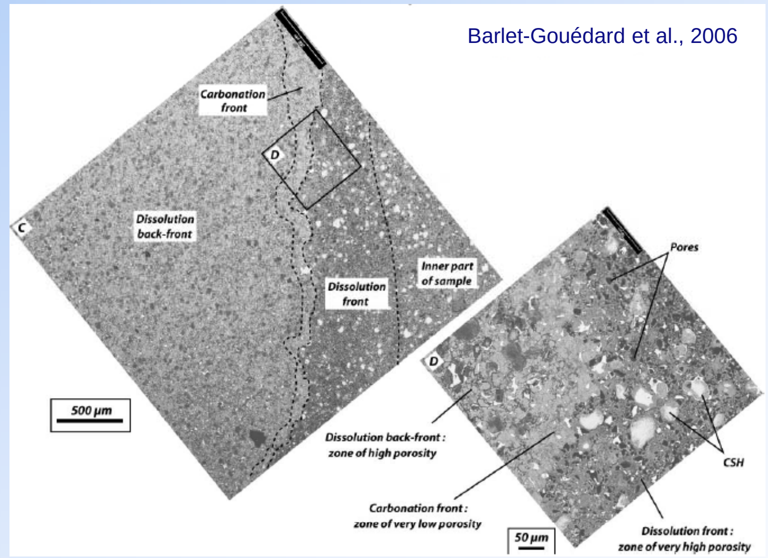
Remarks on review of abandonment regulations

- Assessment of the regulatory framework provides a first order proxy for initial identification of abandonment practices only
- Cement plug is compulsory in all evaluated regulatory documents
- Main differences involve plug requirements (lengths) at the level of the deepest casing shoe
- The application of mechanical plugs often require additional cementing (exact requirements differ significantly among regulations)

Note that reviewed documents often involve unofficial translations of the original documents from the native languages to English

Impact of CO_2 on wellbore integrity: an overview

- Cement degradation is considered to be diffusion-controlled
- Function of e.g. pH, T, P and salinity, but also on curing conditions, experimental setup (static vs. flowing, supercritical vs. dissolved CO_2)

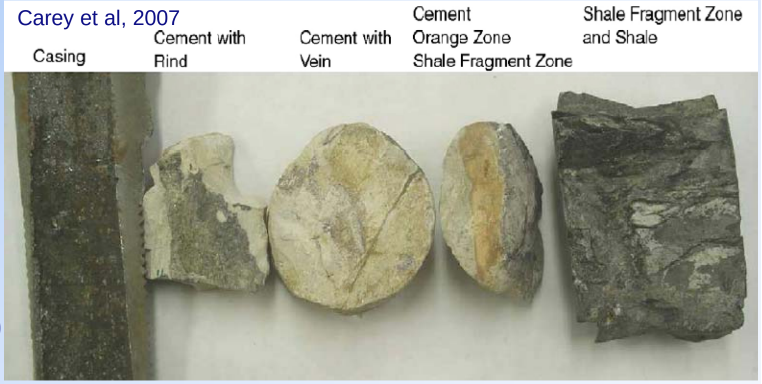


Barlet-Gouédard et al., 2006

- Extrapolating published experimental data according to Fick's Law of diffusion ($d = C \cdot t^{½}$), shows divergent results: Time (t) required to degrade d = 25 mm of cement, ranges from 15 days to over 724,000 year (under different conditions)

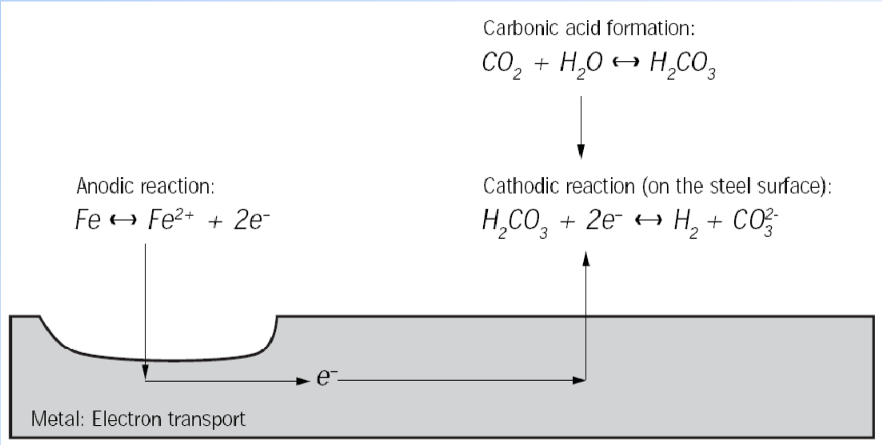
Impact of CO_2 on wellbore integrity: an overview

- Limiting factors apply translating experimental results to field cases, e.g.:
  - Limited reaction surface in the field (taken into account by some authors)
  - Limited availability of free water (especially for some depleted gas fields)
  - High salinity (especially abundance of Ca^{2+}) may reduce degradation or even lead to self-healing through calcite precipitation



Impact of CO_2 on wellbore integrity: an overview

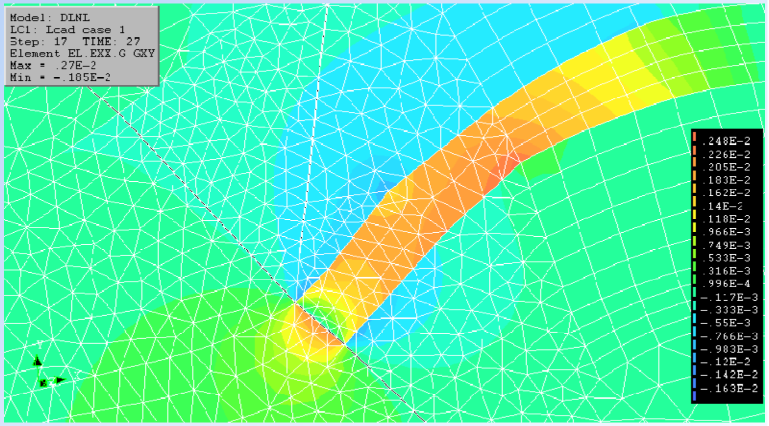
- Steel corrosion is a linear process
- Function of pH, temperature, salinity and partial CO_2 pressure
- Published experimental results show corrosion rates in the order of mm's per year



- Under favorable conditions (T>60-100ºC; pH>5) siderite ($FeCO_3$) precipitation can retard corrosion, forming a (partially) protective layer
- In general, higher grade steel is more susceptible to corrosion

Impact of CO_2 on wellbore integrity: an overview

- Mechanical deformation
  - Reservoir decompaction due to CO_2 injection: strain incompatibility at cement-steel interface may cause debonding, and tensile cracks in the cement sheath



  - Shear deformation at the interface between reservoir and cap rock may damage the wellbore
  - Micro-fractures and micro-annuli may arise from:
    - Poor cement job (incl. cement shrinkage)
    - Temperature and/or pressure changes or cycles

Impact of CO_2 on wellbore integrity: an overview

- Interaction of casing corrosion and cement degradation along micro annuli

- Experimental work on a cement-steel sample in CO_2-brine (incl. Ca^{2+}) by Carey et al. (2008) shows:

  - No significant loss of mass of both steel and cement

  - Precipitation of siderite ($FeCO_3$) on the steel surface

  - Limited penetration of CO_2 in cement consistent with 1-D diffusion

Impact of CO_2 on wellbore integrity: an overview

- Interaction of chemical, mechanical and physical processes
  - Huerta et al. (2008) and Lécolier et al. (2008) report self-healing at cement-casing interface in lab experiments
  - At increasing confining stress, mechanical weakening results in rapid closure of fractures
  - Lécolier et al. (2008) report decreasing permeability and flow rates

Recommended best practice

- Future wells can be designed, drilled completed and abandoned taking into account any CO_2 storage reservoirs
- Suitability of existing wells for CO_2 storage needs to be evaluated
  - Accessible wells may require workover operations to be able to adequately isolate CO_2 storage reservoirs; techno-economical considerations determine the feasibility
  - Abandoned wells generally are not accessible. Especially older wells may pose threats to CO_2storage. Furthermore, timing and stringency of global abandonment regulations varies considerably

Managing previously abandoned wells

- Lab experiments show cement degradation rates extrapolating to a maximum of 12.4 m in 10,000 years under severe T conditions, i.e. 204ºC, 69 bar (in practice penetration is likely to be less)

- Prescribed cement plug lengths range from 15 to 100 m

- Quality and mechanical integrity of cement plug and sheath seems to be of more significance than chemical degradation:
  - Fractures or annular pathways in or along the cement will likely govern the permeability of the wellbore system

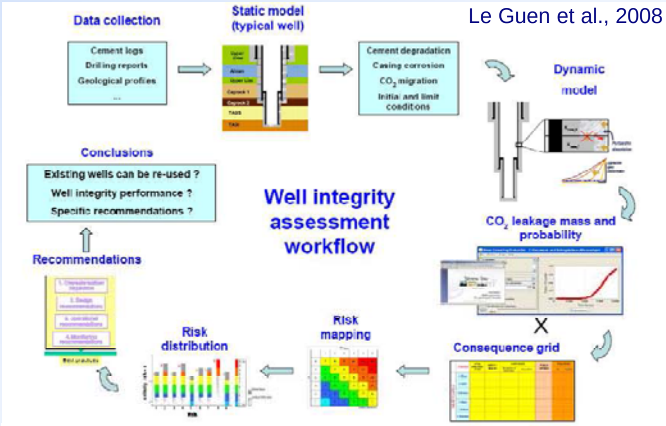
- Supported by investigations of downhole cement samples by Carey et al. (2007) and Crow et al. (2008):
  - Diffusion-based degradation of cement is limited
  - CO_2 migration was observed along cement-steel and cement-formation interfaces

Risk Management: assessment

- When considering long-term CO_2 storage, the current state of wells involved needs to be confidently assessed, including previously abandoned wells
  - Evaluation of abandonment configuration with respect to second life application
  - Evaluation of current state of materials and placement, extrapolating from data gathered prior to abandonment

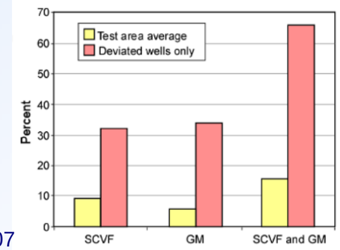
Risk assessment methodologies

- Qualitative RA ⟶ FEP (Feature, Event, Process) analysis to identify site-specific CO_2 storage related hazards (e.g. TNO CASSIF, Quintessa)
- Quantitative RA ⟵
  - Deterministic (applicable to small numbers of wells)
  - Probabilistic (applicable to large sets of wells; e.g. OXAND methodology ⟶)



Le Guen et al., 2008

- Semi-quantitative: e.g. data mining



Watson and Bachu, 2007

Risk Management: monitoring

- Monitoring well integrity as part of the entire suite of monitoring techniques employed on a storage site

- Monitoring abandoned (inaccessible) wells will be limited

- Potential techniques involve:
  - (near-)surface measurements (soil gas/fluxes, groundwater chemistry)
  - remote sensing
  - geophysical methods (e.g. seismic)

- In order to enhance discrimination between natural and injected CO_2, tracers could be added to the injected CO_2

Risk Management: remediation

- Remediation of abandoned wells requires re-entering and re-abandonment and is extremely costly and generally unfeasible
- The ultimate measure to mitigate leaking storage reservoirs would be releasing pressure by venting CO_2 into the atmosphere

- Obviously costly remediation or venting CO_2 should be prevented, initially by performing a comprehensive assessment of the wells involved prior to CO_2 injection

Thank you!

Any suggestions, comments or input regarding the Well Abandonment report would be appreciated.

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