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CO_2 Pipeline infrastructure – lessons learnt

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Abstract

Some 6,500 km of CO_2 pipelines have been operating for years for Enhanced Oil Recovery (EOR) operations, primarily in the United States. Moreover, there are a number of CO_2 pipelines that are in use for CO_2 utilization (CCU) or Carbon Capture and Storage (CCS) operations in Europe and the Americas. Valuable experience and lessons learned are available from these projects relevant for all phases of CO_2 pipeline projects: from early identification to execution and operation. A comprehensive set of information has been collected, evaluated and made accessible with the aim to benefit the development of future CO_2 pipelines. The resulting database shows a wide variety of characteristics among existing CO_2 pipeline projects. In addition, a Reference Manual document adds an overview of results and lessons learned and it can serve as a guide to enable access to the full set of information in the database.

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Keywords: CO_2 Pipelines; Lessons Learned;

1. Introduction

Currently, there are over 6,500 km of CO_2 pipeline in North-America, Europe, the Middle East, Africa and Australia. Some of these pipelines have been operating for many years, mostly to transport CO_2 for enhanced oil recovery (EOR) operations in the Americas. Some pipelines are linked to Carbon Capture and Storage (CCS) projects

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and a number of new pipelines associated with CCS are under development at the time of publication. Valuable lessons learned were gained during these projects that can benefit current and future CO_2 pipeline projects.

2. Goal and Scope of the study

The aim of the study was to capture key learnings from the design, construction, operation and regulation of existing CO_2 pipelines and to make these available to project developers, decision makers and regulators working on current and future CO_2 pipeline projects. The results have led to a reference manual that consists of (a) an overview of lessons learned based on existing CO_2 pipeline projects and (b) guidelines for the development of new CO_2 pipeline projects [1].

Table 1 summarizes the key content topics of interest and corresponding data elements. Information was gathered for over 100 properties for each selected project.

Table 1 Categories and elements of the database

Category	Sub-categories and Data elements
Pipeline infrastructure	Pipeline: E.g. Route, length, depth of lay, material, diameter, wall thickness
	Auxiliary equipment: Compression and dehydration
	Costs: Design and construction
Operation & maintenance, risk and safety	Operational characteristics: E.g. Volume, source, destination, purity, pressure, flow
	Monitoring: Inspections and monitoring
	Safety: Procedures, corridors and valves
Regulatory regime	Realization process: Spatial planning, environmental impact assessment and permits/concessions
	Restrictions: E.g. Spatial planning and location
Public concern	Public communication: Media, publications and health
	Decision process: Environmental Impact Assessment

3. Approach

There are over eighty CO_2 pipeline projects around the world. A carefully selected subset of twenty-nine CO_2 pipelines was prepared out of these eighty projects with the aim to cover all key regions and conditions in a balanced way. In this process the following criteria were considered, in addition to the availability of public information:

- Geographical coverage;
- Onshore and offshore;
- Time of construction covering both recent and older projects;
- EOR and storage projects;
- Existing and planned;
- Conventional and new concepts;
- New-built and reuse of pre-existing pipelines.

Table 2 lists the selected pipeline projects.

Table 2. CO_2 pipeline projects included in the assessment

	Project name	Country code[a]	Status[b]	Length (km)	Capacity (Mton/y)	Onshore / Offshore	Sink[c]
	North-America						
1	CO_2 Slurry	CA	P	Unknown	Unknown	Onshore	EOR
2	Quest	CA	P	84	1.2	Onshore	Saline aquifer
3	Alberta Trunk Line	CA	P	240	15	Onshore	Unknown
4	Weyburn	CA	O	330	2	Onshore	EOR
5	Saskpower Boundary Dam	CA	P	66	1.2	Onshore	EOR
6	Beaver Creek	US	O	76	Unknown	Onshore	EOR
7	Monell	US	O	52.6	1.6	Onshore	EOR
8	Bairoil	US	O	258	23	Onshore	Unknown
9	Salt Creek	US	O	201	4.3	Onshore	EOR
10	Sheep Mountain	US	O	656	11	Onshore	CO_2 hub
11	Slaughter	US	O	56	2.6	Onshore	EOR
12	Cortez	US	O	808	24	Onshore	CO_2 hub
13	Central Basin	US	O	231.75	27	Onshore	CO_2 hub
14	Canyon Reef Carriers	US	O	354	Unknown	Onshore	Unknown
15	Choctaw (NEJD)	US	O	294	7	Onshore	EOR
16	Decatur	US	O	1.9	1.1	Onshore	Saline aquifer
	Europe						
17	Snøhvit	NO	O	153	0.7	Both	Porous Sandstone formation
18	Peterhead	UK	P	116	10	Both	Depleted oil/gas field
19	Longannet	UK	C	380	2	Both	Depleted oil/gas field
20	White Rose	UK	P	165	20	Both	Saline aquifer
21	Kingsnorth	UK	C	270	10	Both	Depleted oil/gas field
22	ROAD	NL	P	25	5	Both	Depleted oil/gas field
23	Barendrecht	NL	C	20	0.9	Onshore	Depleted oil/gas field
24	OCAP	NL	O	97	0.4	Onshore	Greenhouses
25	Jänschwalde	DE	C	52	2	Onshore	Sandstone formation
26	Lacq	FR	O	27	0.06	Onshore	Depleted oil/gas field
	Rest of the World						
27	Rhourde Nouss-Quartzites	DZ	P	30	0.5	Onshore	Depleted oil/gas field
28	Qinshui	CN	P	116	0.5	Onshore	ECBMR
29	Gorgon	AU	P	8.4	4	Onshore	Sandstone formation

[a] Country codes: AU=Australia, CA=Canada, CN=China, DE=Germany, DZ=Algeria, FR=France NL=Netherlands, NO=Norway, UK=United Kingdom, US=United States

[b] Legend status: P=Planned, O=Operational and C=Cancelled

[c] EOR=Enhanced Oil Recovery, ECBMR=Enhanced Coal Bed Methane Recovery

The resulting list includes sixteen projects in North America, ten in Europe, one in Africa, one Asia and one Australia. To maximize the value of the content presented in the study, the project team decided to include four CO_2 pipelines that have been cancelled. For these projects (Barendrecht (the Netherlands), Jänschwalde (Germany), Kingsnorth (England) and Longannet (Scotland)), FEED-studies were available, containing detailed information that is valuable for the purpose of this study.

For each of these pipelines a database was populated. A checklist was prepared for this purpose covering all data elements sought. The first step in data gathering was to carry out a literature survey of the selected CO_2 pipeline projects. The following sources were consulted:

- Project websites;
- Environmental Impact Assessments or Environmental Statements;
- Reports on pipeline routes (sometimes as part of a permit application);
- FEED-studies;
- Journal articles, including scientific articles.

Next, pipeline owners were contacted to seek additional information. Contacts were established by telephone, e-mail and face-to-face meetings at offices and conferences. A large number of interviews were conducted and supplemental information was obtained that could not be retrieved from literature.

4. Data Availability

The quality, accessibility and level of detail of the data presented in the following sections varied for a number of different reasons:

- Confidentiality and commercial constraints;
- Change of pipeline owner;
- Lost or inaccessible data;
- Lack of digitalization;
- Language.

5. Findings Design

5.1. Drivers and Characteristics of CO_2 Pipelines

CO_2 pipelines connect a variety of sinks and sources with each other. The most common CO_2 sources are gas processing plants, fossil-fuelled power stations and natural sources of CO_2. The latter source is commonly used in the United States. These natural sources were developed in the 1970s to provide CO_2 for EOR in Texan oil fields located in the Permian Basin.

Common sinks are oil fields for EOR, but also depleted oil and gas fields are used. The benefit of these storage sites is that there is existing infrastructure in place that may be reused for CO_2 transportation and injection. In some of the European projects (OCAP, Barendrecht, Lacq, Peterhead and Longannet) existing infrastructure has been re-used or this is being considered.

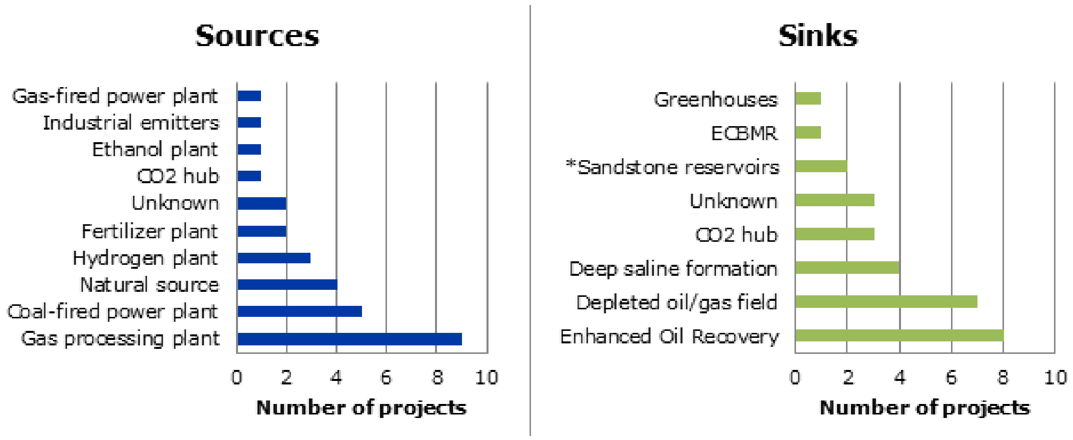

Figure 1 Sources and sinks of the twenty-nine CO_2 pipeline projects studied.

The purity of the CO_2 stream depends on the CO_2 source and, if appropriate, the CO_2 capture technology. In all 29 pipeline projects the purity exceeds 95% and ⅓ of the projects deliver a purity greater than 99%. The most relevant impurities in the CO_2 stream are H_2O, N_2, O_2, H_2S and CO.

Where multiple CO_2 sources and sinks exist, a transmission and distribution network and possibly a hub may develop. Currently operating hubs are almost all located in the USA; examples are the Denver City Hub and the McCamey Hub. We learned that CO_2 hubs have no specific set of rules because they are usually developed ad-hoc when CO_2 sources are available and/or a viable market exists. Each hub has its own standards for CO_2 purity, acceptable impurities, pressure and temperature.

The physical characteristics of the CO_2 pipelines investigated in this study vary greatly. For example, the range in length lies between 1.9 and 808 km. Table 3 shows the spread including other characteristics such as diameter and wall thickness.

The inclusion of short-distance demonstration projects as well as commercial, long-distance EOR projects is the main reason for the large variation. The longest pipelines are located in North America and the average length of CO_2 pipelines there is longer than in Europe. Another interesting point is a positive correlation between length and capacity of the pipelines; longer pipelines have to transport larger volumes of CO_2 to be economically viable.

Table 3 - Physical characteristics of CO_2 pipelines

Parameter	Range
Length (km)	1.9 - 808
External diameter (mm)	152 – 921
Wall thickness (mm)	5.2 – 27
Capacity designed (Mt/y)	0.06 – 28
Pressure min (bar)	3 – 151
Pressure max (bar)	21 – 200
Compressor capacity (MW)	0.2 - 68

5.2. Design and construction of CO_2 pipelines

In many respects, CO_2 pipelines are comparable to natural gas pipelines but there are the following key differences:

- The properties of CO_2 lead to different design parameters.
- In many places CO_2 pipeline projects are first-of-a-kind.
- CO_2 pipelines do not transport a product that people see as directly beneficial.
- Risks associated with geological storage and the Lake Nyos incident influence the public perception of CO_2 pipelines.

In contrast to natural gas, high-pressure CO_2 pipelines are not self-arresting in terms of longitudinal failure and thus require the installation of crack arrestors. Crack arrestors can simply be occasional joints of pipe with greater wall thickness and improved hoop-stress properties. An alternative is the periodic wrapping with non-metallic materials.

The following dedicated design standards for CO_2 pipelines currently exist:

- Unites States: CFR part 195
- Canada: CSA Z662
- Europe: DNV-RP-J202
- ISO/TC 265 (currently under development)

CO_2 pipeline projects generally go through the same cycle as other gas pipeline projects. The project cycle typically takes between 3 to 6 years from concept stage to the final investment decision. The actual construction time usually lies typically between 1 and 4 years depending on the length and complexity of the pipeline.

5.3. Re-use of gas pipelines

Pipelines commonly have service lifetimes that exceed their primary reason for existence. Re-purposing a pipeline for CO_2 use can drastically reduce overall CCS project costs and in fact may make the difference between success and failure of a CCS project. Usually but not always, use of an existing pipeline for CO_2 transport involves reversal of flow. As long as the initial design (as modified to take into account any loss of pressure rating over the life of the line in its initial service) can support the pressures, volumes, compositions and design operating parameters required in CO_2 service, there is every reason to re-use the line. Two areas commonly where existing pipeline are commonly re-used are offshore where pipeline costs are high and in onshore acid gas re-injection (a mixture of CO_2 and H_2S is injected into an aquifer or into a depleted gas reservoir).

5.4. Corrosion protection

Corrosion of the pipeline steel (which is usually carbon steel due to economic reasons) is a serious concern related to leakage and needs to be addressed during the whole project. Most CO_2 pipelines are buried under the ground, so they need both internal and external corrosion protection. The most commonly used method to prevent external corrosion is cathodic protection, sometimes in combination with coating. Water is the main risk factor for internal corrosion.

For the projects analyzed in this study the water content in the CO_2 stream covers a wide range: between <50 ppmv (e.g. OCAP, Snøhvit, Kingsnorth, Lacq and Weyburn) up to 630 ppmv (e.g. Central Basin, Sheep Mountain, Monell, Slaughter, Bairoil and Salt Creek).

To prevent corrosion, the pipeline operator aims to keep the water content as low as possible, based on what is technically and economically practicable. Typically, a dehydration system is used to control the water content in the CO_2 stream. CO_2 streams from sources that produce a dry CO_2 gas (e.g. hydrogen plants, gas-processing plants) may not need additional dehydration.

5.5. Compressors and auxiliary equipment

The number and capacity of the booster stations or compressors depend on the pipeline dimensions, transported volume and phase of the CO_2 stream. The majority of the studied pipelines transport the CO_2 in supercritical phase. To avoid phase change in practice the operators stay clear of the phase transition boundaries.

During operation, a sudden unexpected pressure drop in the pipeline can indicate a leak. For such a case, pipelines are equipped with Emergency Shutdown (ESD) valves to isolate the affected pipeline section. The distance between these ESD valves varies over the pipeline and depends on factors like population density and regulations. The selected CO_2 pipelines in this study have an average ESD valves distance of 10-20 km.

Flow meters are another important piece of equipment. They provide both a means of accurate billing and early detection of leaks.

5.6. Operation, inspection and maintenance of CO_2 pipelines

Regulations require that the responsible operator prepares and follows a manual for each pipeline system. It consists of written procedures for conducting normal operations and maintenance activities but also handling abnormal operations and emergencies. In the USA, this manual needs to be reviewed at least once a year.

Limited data was available on the control systems used for CO_2 pipelines. Typically, a SCADA (Supervisory Control and Data Acquisition) system monitors the key operational parameters: pressure, temperature, water content and flow rate. Very small leaks may be hard to detect with this system. The Weyburn project uses a special Leak Detection System (LDS), which monitors for leaks every 5 seconds and displays the related data on a computer screen. In combination with proprietary software, the LDS can determine the size and location of a potential leak. The flow meters integrated into SCADA and LDS help with checking the CO_2 mass balance for contract obligations.

To minimize external influences, most pipelines are buried underground but this makes inspection more difficult. Most countries prohibit building activities within a certain range of the pipeline corridor, typically some 5 m. In addition, visual corridor inspections by foot, car or helicopter take place frequently.

Most operators use so-called "pig runs" to inspect the inside of their pipelines. A pig can clean the pipeline, measure wall thickness and detect leakage and corrosion. With around EUR 1 million (USD 1.4 million) for pipelines with a length between 25 - 270 km, pig runs are very costly. One reason for this is the low lubricity of CO_2, which poses a great challenge.

Besides the pipeline, inspection of auxiliary equipment takes places on a regular basis as well. This includes compressors, dehydration units, valves, cathodic protection system, monitoring systems and emergency systems.

5.7. Decommissioning and abandonment

Pipeline decommissioning is the permanent deactivation of a pipeline to leave the pipeline in a permanently safe condition, as prescribed by a regulatory body.

The main reason for decommissioning of a pipeline is that it no longer has a commercial use. Otherwise, well-constructed and well-maintained pipelines often have a lifetime in excess of the design lifetime. CO_2 pipelines are expected to perform as well or even better than other gas pipelines if the operator carefully addresses corrosion issues.

Because the existing CO_2 pipeline projects are relatively young (40 years), there is hardly any information available about large-scale decommissioning activities.

6. Findings regulatory regime

6.1. Permitting

Depending on the location of the project and the related regulatory framework, an assessment of environmental impacts might be necessary. The approaches and requirements for this vary from country to country. In general, such an assessment for a CO_2 pipeline is not fundamentally different from that for another gas pipeline.

North American regulations require an Environmental Impact Statement (EIS) when the project is complex in nature and needs consideration and analysis of environmental effects, for example under the National Environmental Policy Act (NEPA) in the USA. Opinions of stakeholders and public participation play an important role in North American EISs. According to Directive 2011/92/EU, in Europe an Environmental Impact Assessment (EIA) is required for pipeline sections with a diameter of more than 800 mm and a length of more than 40 km. Most European CO_2 pipeline projects carried out an EIA because the capture and storage facilities triggered it, not the pipeline itself. Not many EIAs or EISs have been carried out that focus specifically on the pipeline.

In the investigated jurisdictions, CO_2 pipelines are within the regulatory framework of all pipelines that transport gaseous or liquid substances. In the USA, CFR 49 Part 195 applies, which was amended in 1989 to include CO_2 in the former “Hazardous Liquid” category. Before this, CO_2 pipelines had to meet codes for natural gas pipelines. Canada has its own regulation for CO_2 pipelines, CSA standard Z662. In Europe, Directive 2099/31/EC on geological CO_2 storage states that the framework used for natural gas pipelines is adequate to regulate CO_2 as well.

The permitting and approval process plays a key role in the timeline realisation of pipeline projects. Securing permits and performing EISs/EIAs usually takes much longer than actual construction. An example for this is the 808 km Cortez pipeline in the US, which took 8 years to complete with only 2 years of construction time. Reason for the long timeline was the requirement for state-by-state approval of the pipeline routing.

The acquisition of necessary permits and right-of-way may be more time consuming than the actual construction of the pipeline, so they have to be done in a timely manner. In the USA, CFR Section 195.248 prescribes a minimum pipeline burial depth of 1.2 m. After construction, regulations require a test of pipeline integrity. CO_2 pipelines that have passed hydrostatic testing are cleaned and dried to prevent corrosion or premature failure on start-up.

6.2. Safety statistics

For the US, the PHMSA (Pipeline and Hazardous Materials Safety Administration) provides statistics on pipeline incidents. According to PHMSA, there have been 46 incidents involving CO_2 pipelines between 1972 and 2012. The main reasons for these incidents were:

- Relief valve failure
- Weld, gasket or valve packing failure
- Corrosion
- Outside force

Most of these incidents occurred in areas with low population density, so they did not cause any reported casualties or fatalities. In contrast, natural gas pipeline accidents injured 217 and killed 58 people over the period 1986 – 2001. However, it is difficult to make effective comparisons between CO_2 and natural gas pipelines yet because of the huge discrepancy in the number of km of pipeline (550,000 km for gas pipelines vs. 6,500 km for CO_2 pipelines in the USA).

In Europe, no incident reporting or analysis system exists for CO_2 pipelines, so industry gathers statistics and reports incidents on a voluntary basis. The OCAP project reported three incidents with small leakages during operation of the pipeline. Again, no human injuries or fatalities occurred.

7. Findings public concern

It is important to understand the key drivers of public concern because it can become a serious threat to a project if not handled in time and in a careful manner. During interviews many pipeline operators made clear that the CO_2 pipeline is usually not the focal point of public opposition. Most concerns relate to either the capture (building of a power plant or production plant) or the storage part of the project. In general, there is less public concern over offshore transport and storage than over onshore projects.

The Barendrecht CCS project in the Netherlands is an example where public concern led to the cancellation of a project. The developers of the nearby ROAD project directly used the lessons learned from Barendrecht by training staff to communicate simply and clearly and to address concerns from local residents adequately.

Most projects investigated in this study used websites, public meetings and telephone helplines as means of communication. The range of available information on the websites vary from project to project. Some projects (e.g. Saskpower Boundary Dam, OCAP and Lacq) have dedicated websites while others (e.g. Kinder Morgan, Jänschwalde and Kingsnorth) just provide simple generic information. The participation in public meetings varies as well. Most North American pipeline projects have seen only limited interest in public meetings. Reasons for this are the difference in population density and the long-standing oil and gas operations that both lead to a higher acceptance of pipelines compared to Europe.

8. Findings CO_2 pipeline costs

Key costs drivers for pipelines are:

- Piping (type and grade of material)
- Equipment (such as compressors, booster stations, valves, crack arrestors, etc.)
- Trenching (i.e. earthworks, excavation, backfilling)
- Distance
- Diameter
- Terrain
- Labour
- Engineering (e.g. design, project management, regulatory/permitting activities)

For some projects, cost data is publicly available and can be used as a reference to estimate future project costs. Due to commercial reasons, engineering companies sometimes keep the design and construction costs confidential. Table 4 presents actual costs for selected CO_2 pipeline projects that were available from public documents.

If data is not readily available, then it is possible to estimate pipeline capital costs using credible sources, such as the NETL guidelines (*Carbon Dioxide Transport and Storage Costs in NETL Studies – Quality Guidelines for Energy Systems Studies*) [3]. The related formulas reflect US dollars as of 2011 and require diameter and length as input parameters. The results of the estimation can give a first impression of possible CO_2 pipeline costs but are in no way an accurate estimate. In any case, terrain has the strongest influence on pipeline costs and accounts for the largest uncertainty in cost estimation.

Table 4 Costs for selected CO_2 pipelines

Pipeline	Costs for pipeline	Currency	Year	Onshore/ Offshore	International units
Canyon Reef Carriers (SACROC)	46 million	USD	1971	Onshore	D= 324 – 420 mm L= 354 km
Cortez	700 million	USD	1982	Onshore	D= 762 mm L= 808 km
Weyburn CO_2 pipeline	51 million	USD	2008	Onshore	D= 305 – 356 mm L= 330 km
Quest	140 million	USD[b]	2012	Onshore	D= 324 mm L= 84 km
Qinshui	39.35 million	USD	2006	Onshore	D= 152 mm L= 116 km
Longannet	160 million	GBP	2011	On: 100 km Off: 270 km	D= 500 to 900 mm L= 380 km
ROAD	90 million	EUR	2010	On: 5 km Off: 20 km	D= 450 mm L= 25 km
Gorgon	9 million	AUD	2011	Onshore	D= 269 – 319 mm L= 8.4 km

[a] For pipeline and associated compression stations
[b] Initial estimate in CAD (Canadian dollars). Assumed exchange rate USD 1.00 = CAD 1.00

Operation and maintenance costs are not readily available from the investigated CO_2 pipeline projects but again can be estimated by using the following guidelines:

- Fixed O&M costs of USD 8,454 per mile and year based on experience in North America [3];
- 1.5% of initial capital costs per year excluding costs for compression [2]; although another source (confidential interview) mentions examples where cost are in the range of 3-8% of capital costs.
- EUR 1 million (USD 1.4 million) per pig run for a pipeline of some 10s km length [4].

A number of factors differentiate CO_2 pipelines from other gas pipelines when it comes to costing. Some examples are:

- The CO_2 depressurization characteristics dictate the use of crack arrestors.
- The carbon steel grade needs to be resistant towards brittle fracture because CO_2 can reach very low temperatures when expanded.
- Specific purity and water content specs for the CO_2 suppliers to meet.
- Temperature and pressure according to single dense phase transport.
- Installation of ESD valves to limit CO_2 release in case of leakage.
- Venting procedures need to include provisions for lofting and dispersing released CO_2.
- Gaskets and other non-ferrous materials must be resistant to deterioration in presence of CO_2.

Usually the CO_2 supplier(s) or the CO_2 capture project part is responsible for accounting the costs related to separation, clean-up, compression and dehydration of the raw CO_2 stream.

9. CO_2 pipeline database and reference manual

The results of the study have been captured in a CO_2 pipeline database and accompanying reference manual document. To enable convenient access to the collated information an interactive web tool was prepared based on Google Maps. It shows the location and routing of the 29 CO_2 pipeline projects investigated in this study and allows users to zoom in and access a summary of information from the database (see screenshot in Figure 2).

Figure 2 Interactive map tool for accessing CO_2 pipeline database. (demo version available at http://www.globalccsinstitute.com/publications/CO2-pipeline-infrastructure)

The Reference Manual complements the database. On the one hand it serves as a summary of the information in the database to assist project developers, decision makers and regulators. On the other hand it is intended as a guide to accessing the database, pointing to relevant examples in the database where further information can be found. This Reference Manual highlights key design, construction, operational and regulatory learnings from existing work on CO_2 pipeline infrastructure.

This reference manual was written primarily for project developers that are planning to build a CO_2 pipeline but who are not specialist in detailed engineering calculations or cost estimates. Secondly, the reference manual provides valuable information for governments and regulators, addressing different phases of a CO_2 pipeline project, including permitting and regulations.

10. Conclusion

The purpose of this study was to collect non-confidential information on CO_2 pipelines and make it available to project developers, decision makers, regulators and interested public. The findings of the study are easily accessible in three different ways: through a reference manual, a database and an interactive web tool.

With the exception of the USA, most countries have little experience with CO_2 pipelines or CO_2-EOR operations. Even for many of the operational projects certain information is not accessible due to commercial or other reasons.

This applies especially to costs and auxiliary equipment that belongs to other parts of the process chain, like compressors and dehydration units.

A main result of the study is that CO_2 pipelines are both similar and different compared to other gas pipelines, natural gas in particular. They are similar to some extent, so that the regulations and standards used for CO_2 originate in natural gas pipeline codes. But they are different in terms of the physical properties of CO_2, which results in different design parameters, and the risk perception, which the public usually associates with geological storage of CO_2.

Secondly, both the database and the reference manual show that CO_2 pipeline projects come in a wide variety and that there is no single established blue-print for a CO_2 pipeline design. Every project is distinct with respect to length, terrain crossed, type of CO_2 source and sink, environment, public views, and complexity of network. This influences design parameters such as material selection, insulation, pipeline diameter, wall thickness, corrosion protection, compression, dehydration, operating temperature, purity of CO_2 stream, and maintenance regimes.

The permitting and approval processes play a major role in the overall project timeline. This can take much longer than expected and exceed the construction time by far. Thee CO_2 pipelines in the USA have a good safety track record with 40-year history of operation with no known civilian injuries or fatalities.

11. Acknowledgements

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