Potential UKCS CO_2 retention capacity from IOR projects

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ABSTRACT

A key deliverable from the current DTI SHARP projects is an estimate of the overall UKCS potential for CO_2 injection, expressed in terms of additional oil production and the amount of CO_2 retained in the reservoir. The CO_2 capacity has been evaluated based on estimates of CO_2 IOR potential from an earlier systematic screening exercise of all UKCS fields.

The current UKCS IOR potential is in the region of 600 MMSTB (range 350-850 MMSTB) from WAG schemes and 1100 MMSTB (range 800-1400 MMSTB) for GSGI schemes. The potential decreases with increasing time as fewer fields remain on production. The net CO_2 retention capacity for the WAG schemes is currently around 150 million tonnes (2700 Bscf), whereas that for GSGI schemes is around 550 million tonnes (10000 Bscf). These results reflect the superior CO_2 utilisation efficiency in WAG schemes compared to GSGI projects.

There are currently around 60 potential WAG projects and significantly fewer GSGI opportunities. Despite this, the CO_2 retention potential from GSGI injection is approximately a factor of 3 larger than that for WAG injection, because the projects are generally bigger.

A WAG project could be implemented at any time between the present and the pre-COP deadline, because the well pattern for water-alternating-gas injection is consistent with that for water flooding. In contrast, the well pattern for GSGI is fundamentally different to that for water flooding. The 'window of opportunity' for the start of each GSGI project might, therefore, be taken as a limited period around the COP date. An example GSGI CO_2 usage profile based on this principle shows a peak capacity of approximately 35 million tonnes per year, corresponding to 7% of the total UK CO_2 emissions for 1999.

It may not be necessary to maintain miscibility in a GSGI project. Dropping the reservoir pressure before injection commences potentially improves gravity stability and the net gas utilisation efficiency. Several fields might benefit from this type of pressure management. If the CO_2 from a GSGI project had re-sale value for use in future IOR projects, the field could be depressurised or dump-flooded with water at the end of life and the CO_2 could be recovered via wells at the top of the structure.

WAG schemes typically end with a water post-flush, but it might be more attractive to leave as much CO_2 as possible in the formation if sequestration had commercial value. The overall CO_2 sequestration capacity of WAG projects might be increased by a factor of two if this strategy was adopted.

1 Introduction

A key deliverable from the current DTI SHARP projects is an estimate of the overall UKCS potential for CO_2 injection, expressed in terms of:

- Additional oil production (MMSTB)
- Amount of CO_2 retained in the reservoir.

The aim of this project is to generate an estimate of the UKCS IOR potential from CO_2, and the associated CO_2 retention, with uncertainty ranges. The potential for CO_2 sequestration has been evaluated separately in the JOULE2 project.

The evaluation is based on a simple model populated with data for each UKCS field. Fields are characterised as having either WAG or GSGI potential, or no CO_2 flooding IOR potential, based on the results of the DTI systematic Meteor screening programme from the early 1990s, revised in the light of any studies performed subsequently. Typical incremental oil recoveries are assigned to each case, depending on the IOR process, screening score and STOIIP. CO_2 consumption is estimated via simple volumetric algorithms, based on experience from UKCS field studies and reviews of CO_2 experience worldwide.

The timing of CO_2 injection projects will be related to the field COP dates, therefore a cut-off is applied when the window of opportunity becomes too short for a commercially viable project. A low STOIIP cut-off is also applied, to exclude fields that are too small to generate sufficient IOR to cover the minimum CAPEX costs associated with CO_2 injection.

The geological and petrophysical data for each field were taken from the original DTI Meteor screening exercise.

2 Cumulative remaining UKCS CO_2 and IOR potential

2.1 POTENTIAL ESTIMATED FOR CURRENT/ANTICIPATED RESERVOIR PRESSURES

The model details are described in the Appendix.

The cumulative IOR potential for CO_2 WAG projects on the UKCS is illustrated in Figure 1 and the corresponding CO_2 retention is shown in tonnes in Figure 2 and in Bscf in Figure 3. Analogous graphs for GSGI projects are presented in Figures 4-6. These results correspond to the input parameters shown in Figure 7. Maximum and minimum values are also shown on these figures. The terms ‘cumulative potential demand’ and ‘cumulative potential capacity’ mean the total volume of CO_2 required or stored if all the projects that are still technically feasible at a given time are eventually implemented.

The current UKCS IOR potential is in the region of 600 MMSTB from WAG schemes, with a range of 350-850 MMSTB (Figure 1) and 1100 MMSTB for GSGI schemes, with a range of 800-1400 MMSTB (Figure 4). The potential decreases with increasing time as fewer fields remain on production. The net CO_2 retention capacity for the WAG schemes is currently around 150 million tonnes (2500 Bscf), whereas that for GSGI schemes is around 550 million tonnes (10000 Bscf). These results reflect the superior CO_2 utilisation efficiency in WAG schemes compared to GSGI projects, although the IOR is higher for GSGI.

There are currently almost 60 potential WAG projects, but far fewer GSGI opportunities. Despite this, the CO_2 retention potential from GSGI injection is approximately a factor of 3 larger than that for WAG injection, because the projects are generally on a bigger scale and more CO_2 is required to produce a given increment (Figures 2 and 5).

The WAG cumulative profiles decrease relatively smoothly, because there are a large number of potential projects, whereas the GSGI potential decreases in discrete steps as the window of opportunity in individual fields closes. The GSGI potential is dominated by a few major fields.

The timescales for CO_2 demand could be stretched if COP is delayed, as discussed below. The retention of CO_2 in WAG projects has been re-evaluated assuming the window of opportunity closes at the nominal COP date, rather than 5 years earlier, to illustrate this possibility. The resulting profiles are illustrated in Figures 8-10. The current potential is larger for this calculation, because it includes fields that are due for COP within the next 5 years. This increases the current potential from 600 MMSTB (Figure 1) to nearly 800 MMSTB (Figure 8).

A WAG project could be implemented at any time between the present and the pre-COP deadline, because the well pattern for water-alternating-gas injection is consistent with that for water flooding. The well pattern for GSGI is fundamentally different to that for water flooding, however, requiring crestal injectors and downdip producers. The 'window of opportunity' for each GSGI project might, therefore, be taken as a limited period around the COP date, rather than any time between now and COP. If this outlook were adopted, the cumulative potential as plotted in Figures 5 and 6 would be misleading for GSGI.

An example CO_2 capacity profile has been constructed for all the GSGI projects, using the following simple method:

- Each GSGI project starts at the COP date, initially
- CO_2 injection occurs at a constant rate over a 10-year period, except for projects which require only a single injection well. The injection times for these fields were reduced, giving injection rates in the range 40-80 MMscf/well/d for all projects

The CO_2 profile was then constructed and reviewed. There was a large peak in demand over the period 2017-2019, owing to the relative timing of major projects. This was smoothed out by increasing the one of the project lifetimes from 10 to 12 years, and delaying its start by a few years. The resulting profile is illustrated in Figure 11. The peak potential demand of approximately 35 million tonnes per year corresponds to 7% of the total UK CO_2 emissions for 1999.

It is assumed that the 'window of opportunity' for CO_2 injection for IOR closes within a few years of COP. This is not the case for sequestration projects and is also a simplification for IOR schemes for the following reasons:

- COP dates are often delayed near the end of field life by the implementation of improved reservoir management schemes and OPEX reduction initiatives.
- If there was sufficient incentive for sequestration then GSGI schemes, in particular, might yield IOR beyond COP. CO_2 could be injected at the end of field life, when production ceases. The field could be abandoned at that time and re-entered after several years using, for example, an FPSO. The long time interval should allow formation of an oil rim at the OWC by gravity drainage. This could be produced via a small number of horizontal wells, avoiding the need to recomplete downwards periodically in an ongoing GSGI IOR

scheme. The discounted value of the oil would be small, due to the long delay before its recovery, therefore economic viability would depend on the incentive for sequestration.

- The CO_2 IOR and retention potentials may also decrease less rapidly than illustrated if significant new fields come onstream that are amenable to these processes.
- If a CO_2 pipeline or 'ring main' were built to supply a major project, this would significantly reduce the CAPEX for projects in nearby fields. In this case, CO_2 injection might become economically viable in fields that were excluded from the current evaluation because they were too small.

2.2 ADDITIONAL OPPORTUNITIES WITH PRESSURE MANAGEMENT

It may not be necessary to maintain miscibility to achieve an economically attractive increment in a GSGI project, because the recovery is improved by gravity drainage and compositional effects. Consequently, it may be possible to drop the reservoir pressure before injection commences, to reduce the CO_2 density in the formation, improving gravity stability and the net gas utilisation efficiency. Pressure management opportunities of this type were identified in five fields, which have little or no aquifer support.

2.3 CO_2 SEQUESTRATION/RE-SALE OPPORTUNITIES AT THE END OF PROJECTS

2.3.1 Sequestration or re-sale at the end of WAG flooding

Water alternating gas injection would normally be followed by a water post-flush, to maximise the incremental oil recovery for a given net volume of injected gas. It might be more attractive to leave as much CO_2 as possible in the formation, however, if CO_2 sequestration has a value and a trading permit system is in operation. Factors that might influence the decision on whether to perform a water post-flush are illustrated in Figure 12.

The gross gas utilisation is typically twice the net gas utilisation in onshore North American WAG flood. The mean potential UKCS CO_2 capacity would correspond to the 'Max' curve illustrated in Figure 2 if none of the projects was post-flushed with water. The current WAG CO_2 capacity is increased from 150 million tonnes to 300 million tonnes (or from 2700 Bscf to 5000 Bscf) in this scenario.

Alternatively, if a nearby field was also a candidate for a CO_2 IOR project, back-produced CO_2 could be sold on for re-use, towards the end of the project.

2.3.2 CO_2 re-sale at the end of GSGI

The CO_2 sequestration associated with a GSGI project might have commercial value if a trading permit system were in operation. Alternatively, the gas might have re-sale value for use in future CO_2 IOR projects. In this scenario, a field could be depressurised at the end of the GSGI project and the CO_2 could be recovered via wells at the top of the structure. Factors influencing the decision on whether to leave the CO_2 in the reservoir or back-produce it for re-sale are illustrated in Figure 13.

Evaluation of CO_2 recovery factors for this scenario is beyond the scope of this project. It seems probable, however, that between 50% and 75% of the CO_2 could be back-produced. Taking the mean UKCS CO_2 GSGI potential (Figures 5 and 6), a total of 5000-7500 Bscf, or 220-410 million tonnes, of the CO_2 used in GSGI projects could be recycled for other projects.

3 Conclusions

- The current UKCS IOR potential is in the region of 600 MMSTB (range 350-850 MMSTB) from WAG schemes and 1100 MMSTB (range 800-1400 MMSTB) for GSGI schemes. The potential decreases with increasing time as fewer fields remain on production. The net CO_2 retention capacity for the WAG schemes is currently around 150 million tonnes (2700 Bscf), whereas that for GSGI schemes is around 550 million tonnes (10000 Bscf). These results reflect the superior CO_2 utilisation efficiency in WAG schemes compared to GSGI projects.

- There are currently around 60 potential WAG projects, but far fewer GSGI opportunities. Despite this, the CO_2 retention potential from GSGI injection is approximately a factor of 3 larger than that for WAG injection, because the projects are generally on a bigger scale.

- The WAG cumulative profiles decrease relatively smoothly, because there are a large number of potential projects, whereas the GSGI potential decreases in discrete steps as the window of opportunity in individual fields closes.

- The well pattern for GSGI is fundamentally different to that for water flooding, therefore a GSGI project might be delayed until near the COP date. An example CO_2 capacity profile for all the GSGI projects has a peak capacity of approximately 35 million tonnes per year, corresponding to 7% of the total UK CO_2 emissions for 1999.

- It may not be necessary to maintain miscibility to achieve an economically attractive increment in a GSGI project. Dropping the reservoir pressure before injection commences potentially improves gravity stability and the net gas utilisation efficiency.

- Water alternating gas injection might be followed by a CO_2 post-flush, to leave as much CO_2 as possible in the formation, if CO_2 sequestration has commercial value. The overall CO_2 sequestration capacity of UKCS WAG projects might be increased by a factor of two if this strategy was adopted.

- If the CO_2 from a GSGI project had re-sale value for use in future IOR projects, the field could be depressurised or dump-flooded with water at the end of life to recover the CO_2. Between 50% and 75% of the CO_2 might be back-produced, corresponding to 5000-7500 Bscf, or 220-410 million tonnes, from all the potential GSGI projects.

Appendix: Model structure and mathematical algorithms

A 1 Algorithms for CO_2 requirements and IOR

A 1.1 WAG

The incremental oil recovery (IOR) produced by a CO_2 water alternating gas (WAG) project is estimated via the expression

$$\text{IOR} = (\text{WAG IOR efficiency}) * (\text{WAG score efficiency}) * \text{STOIIP}$$

The WAG IOR efficiency is input as the incremental recovery, expressed as a percentage of STOIIP within the project target area. The WAG score efficiency is a factor between 0 and 1 that increases as the Meteor technical score for the process increases. For example, if Meteor gave a technical score of 5 (the highest possible value, indicating that conditions were well suited to WAG CO_2 flooding), the WAG scheme is assumed to be fully implemented and efficient, with a WAG score efficiency of 1. In contrast, if Meteor gave a technical score of 1, the WAG scheme is assumed to be only 40% as efficient as a 'good' flood, therefore the WAG score efficiency is 0.4.

The net CO_2 retained at the end of the WAG scheme is given by the expression

$$\text{Net } CO_2 \text{ retained} = \text{IOR} * (\text{WAG } CO_2 \text{ factor alpha}) * \text{Bo} / \text{Bg}$$

The WAG CO_2 factor alpha varies between 1 and 2 and is related to the net CO_2 utilisation efficiency when expressed in reservoir volumes. The range 1-2 comes from the results of a CO_2 EOR Issues literature review. The potential capacity for gas may be higher than this during a project's lifetime, because more gas may be required than is finally retained in the reservoir. The factor Bo/Bg converts the retention to a surface volume.

A 1.2 GSGI

The incremental oil recovery (IOR) produced by a CO_2 gravity stable gas injection (GSGI) project is estimated via the expression

$$\text{IOR} = (\text{GSGI IOR efficiency}) * (\text{GSGI score IOR efficiency}) * \text{STOIIP}$$

This is directly analogous to the WAG expression.

The net CO_2 retained at the end of the GSGI scheme is given by the expression

$$\text{Net } CO_2 \text{ retained} = (\text{GSGI } CO_2 \text{ factor}) * \text{STOIIP} * (\text{GSGI score } CO_2 \text{ factor}) * 0.7 * \text{Bo} / \text{Bg}$$

This differs from the WAG CO_2 expression. For GSGI, the amount of CO_2 retained is proportional to the reservoir pore volume, rather than the process IOR, because of the fundamental difference in process geometries. The factor 'GSGI score CO_2 factor' allows the user to reduce the injected (i.e. retained) CO_2 volume compared to the potential target volume. This allows the possibility of early termination of a disappointing project. The factor of 0.7 accounts for the fraction of STOIIP left in the formation at the end of the gas flood and a small amount of mobile water also left in the gas swept region.

A 1.3 RANGES FOR RESULTS

Upsides and downsides are estimated by evaluating the IOR and retention deterministically for the 'P0' and 'P100' values shown in Figure 7.

A 2 Design of CO_2 capacity model

A 2.1 INTRODUCTION

The following principles have been adopted:

1. The CO_2 utilisations are all net values, i.e. the final amount of CO_2 retained in the formation at the end of the project.

2. Reservoir volumes are never counted twice. If a reservoir is a good candidate for WAG it will not also be counted for GSGI. If the technical screening scores for WAG and GSGI are identical, it is assumed that the WAG project is implemented, because this strategy generally has the lower risks and shorter payback times.

3. The COP dates are those currently nominated. It is noted, however, that COP deadlines have been extended for many fields in the past, therefore many of these dates may actually be too early. In this case, the 'window of opportunity' for CO_2 injection for IOR schemes would be stretched (Section 2.1).

A 2.2 EXPLANATION OF MODEL VARIABLES

The input values for the CO_2 capacity calculations are illustrated in Figure 7.

1. Terms in the expressions for IOR and CO_2 in Sections A1.1-A1.2 correspond to the headings in Figure 7.

2. The start and end years set the earliest and latest dates for which UK CO_2 capacities are calculated.

3. The number of realisations applies to the Monte Carlo sampling.

4. 'Target region' is used to specify the area within the UKCS to be included in the Monte Carlo calculation. The figures quoted in this report are for the entire UKCS.

5. 'WAG Min time before COP' specifies the number of years before the COP date that the 'window of opportunity' for a WAG process closes. This is set at 5 years for the results quoted, which implies that a WAG project over a shorter time would not be economically viable.

6. 'GSGI Min time before COP' specifies the date at which a potential GSGI candidate should be deleted from the list, i.e. the 'window of opportunity' closes. This has been set to 0 for the results quoted, because the well patterns required for a GSGI project are fundamentally different from those for a water flood, therefore it is assumed that GSGI would be performed at the end of field life. This is discussed further in Section 2.1.

A 2.3 DEFAULT VALUES OF PARAMETERS

The default values of variable parameters are based on experience from UKCS field studies and reviews of CO_2 experience worldwide.

WAG IOR efficiencies for proposed and existing projects are typically in the range 6-10% of STOIIP. The lower limit has been reduced to 4%, to account for some degree of under-performance in the field, relative to predictions, which may omit potential problems or underestimate uncertainties.

A second efficiency factor is applied in calculating the IOR from a WAG project, denoted the 'WAG score efficiency' (Section A1.1). This factor depends on the technical score assigned to CO_2 WAG flooding in the Meteor screening exercise. It is presented in the WAG table and illustrated in the graph in Figure 7. It is set to unity for projects with technical scores of ≥3, so that the overall IOR efficiency is in the range 4-10%, in line with field studies and worldwide experience. It falls off rapidly for projects with technical scores of 2 and 1, to reflect poorer than average performance for these potentially more marginal schemes. Fields that have not been screened are treated as WAG projects, with a WAG score efficiency (denoted 'default') of 0.5. This equates to a technical score of just over 1 for screened projects (Figure 7).

There are fewer examples of GSGI IOR projects, therefore it is harder to estimate typical ranges for IOR recovery factors for this process. GSGI IOR efficiencies are generally expected to be lower than WAG efficiencies, but the incremental oil volumes are larger, because the volumetric sweep is higher. The uncertainty in the amount of recoverable oil is reduced in miscible GSGI, compared to immiscible GSGI, because the value of S_{org} is very low. Consequently, the default efficiency range for GSGI floods has been set to 9-15% of STOIIP.

A second efficiency factor is applied in calculating the IOR from a GSGI project, denoted the 'GSGI score IOR efficiency' (Section A1.2). This is analogous to the factor 'WAG score efficiency' for WAG projects. It is presented in the GSGI table and illustrated in the graph in Figure 7. The default values decrease from unity more rapidly as the technical score decreases for GSGI projects than for WAG schemes. This reflects potentially greater technical complexity in capturing mobilised oil in a GSGI flood, which involves recompleting the producers downwards and extracting oil from a thin oil rim. The efficiencies may be increased for scenarios in which capture of the oil bank is straightforward. Recent advances in well technology are reducing the cost and increasing the reliability of these operations.

The WAG CO_2 factor 'alpha' is related to the net CO_2 utilisation efficiency when expressed in reservoir volumes. The projects reviewed had values in the range 1-2, therefore this range is adopted as the default. The GSGI CO_2 factor relates the volume of CO_2 retained in the reservoir to the volume initially occupied by the oil, therefore it differs fundamentally from the WAG CO_2 factor and is unlikely to be greater than unity, from geometrical considerations. A range of 0.5-0.9 has been supplied as the default. The additional GSGI CO_2 parameter, 'GSGI score CO_2 factor' (Section A1.2), is shown in the GSGI table and illustrated in the graph (Figure 7). The default value is set to unity for projects with technical scores of 4 and 5, therefore it causes no reduction in CO_2 retention for these projects. The value decreases linearly for lower technical scores, representing the early termination of projects that perform below expectation.

Another scenario in which the amount of CO_2 finally retained in the reservoir might be reduced would be if the gas were re-used in another field. In this case, the first field would be dump-flooded with water, or depressurised at the end of a GSGI scheme, recovering the gas for transport to the second field and use in another CO_2 injection project. More generally, whether the CO_2 were recovered at the end of a project would depend on the value of the gas at that time. Conversely, if there were an incentive to sequester CO_2, a WAG scheme might finish with injection of a large gas slug before COP. Thus overall, the amount of CO_2 ultimately retained might be smaller than that required for IOR in a GSGI scheme or larger than the IOR requirement for a WAG scheme.

The choice of default values for the parameters 'WAG min time before COP' and 'GSGI min time before COP' are explained in Section A2.2.

A 3 Population of model with data

Producing oil fields with STOIIPs greater than 100 MMSTB were included in the database. Fields with lower STOIIPs were considered too small to generate sufficient IOR to cover the minimum CAPEX costs associated with CO_2 injection for IOR. Reports from the Meteor UKCS screening exercise were used as the primary source of input data for this project. Fields were split into separate reservoir units if they were screened separately. A total of 105 reservoir units were included in the dataset.

Only the STOIIP allocated to the UKCS is included if a field straddles the median line . The STOIIP was also reduced if only a fraction of the reservoir or unit was considered amenable to CO_2 injection, or if some form of gas injection scheme has already been implemented in the reservoir.

The COP time was estimated for fields for which it is uncertain.

Acknowledgements

This project was performed by AEA Technology as part of the UK Department of Trade and Industry's SHARP contract.

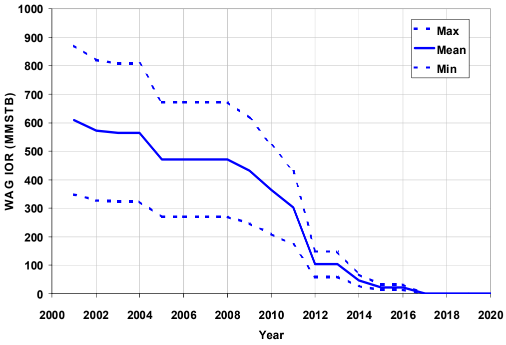


Figure 1 Cumulative WAG IOR potential for parameter values illustrated in Figure 7

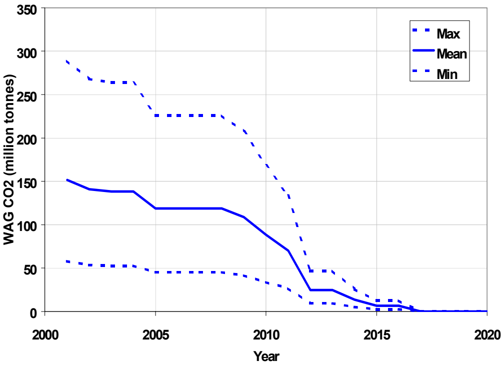


Figure 2 Cumulative WAG CO_2 potential retention (in tonnes) for parameter values illustrated in Figure 7

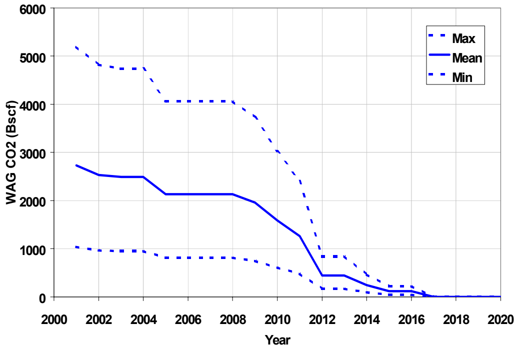


Figure 3 Cumulative WAG CO_2 potential retention for parameter values illustrated in Figure 7

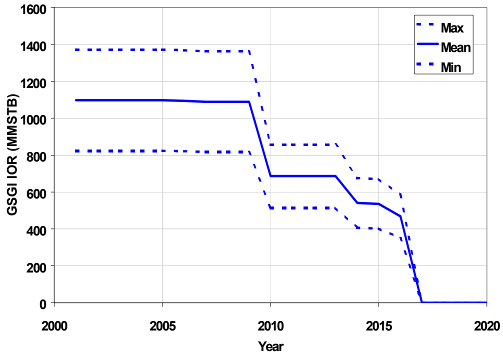


Figure 4 Cumulative GSGI IOR potential for parameter values illustrated in Figure 7

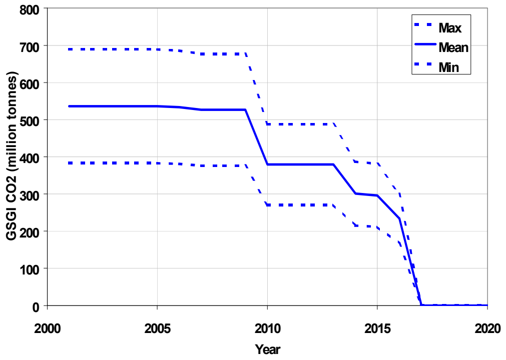


Figure 5 Cumulative GSGI CO_2 potential demand (in tonnes) for parameter values illustrated in Figure 7

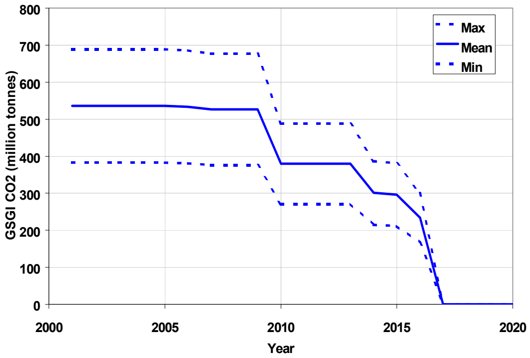


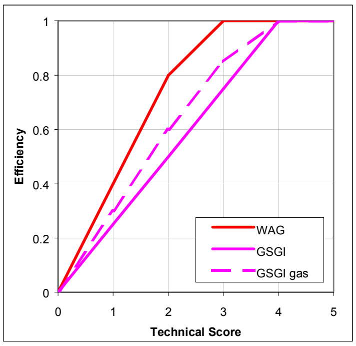
Figure 6 Cumulative GSGI CO_2 potential demand for parameter values illustrated in Figure 7

VARIABLE PARAMETERS

	P0	P50	P100	
WAG Max IOR Efficiency	4%	7%	10%	
GSGI Max IOR Efficiency	9%	12%	15%	
WAG CO2 factor (alpha)	1	1.5	2	(in range 1 to 2)
GSGI CO2 factor	0.5	0.7	0.9	
WAG Min time before COP		5		years
GSGI Min time before COP		0		years

WAG Score	IOR Efficiency
0	0
1	0.4
2	0.8
3	1
4	1
5	1

GSGI Score	IOR Efficiency	CO2 Factor
0	0	0
1	0.25	0.3
2	0.5	0.6
3	0.75	0.85
4	1	1
5	1	1



Start year	2001
End year	2020
Number of realisations	1000

Target region	ALL	(CNS,NNS,WOS,LAND or ALL)

Figure 7 Parameter input values used for results illustrated in Figures 1-6

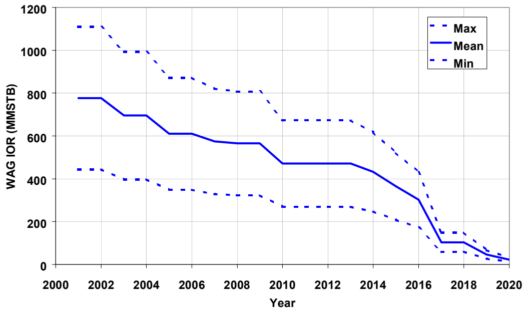


Figure 8 Cumulative WAG IOR potential assuming window of opportunity closes at COP date

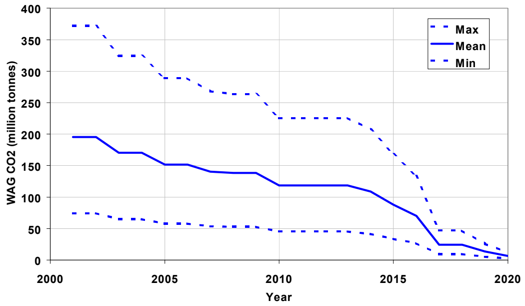


Figure 9 Cumulative WAG CO_2 potential retention (in tonnes) assuming window of opportunity closes at COP date

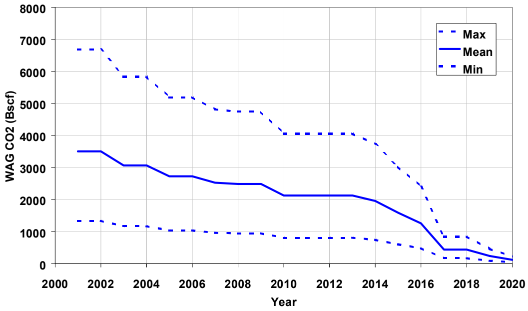


Figure 10 Cumulative WAG CO_2 potential retention assuming window of opportunity closes at COP date

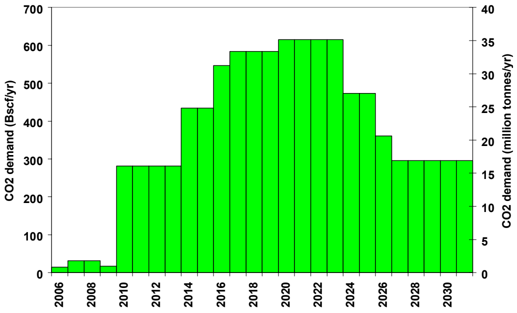


Figure 11 Illustrative CO_2 requirement profile for all potential GSGI projects

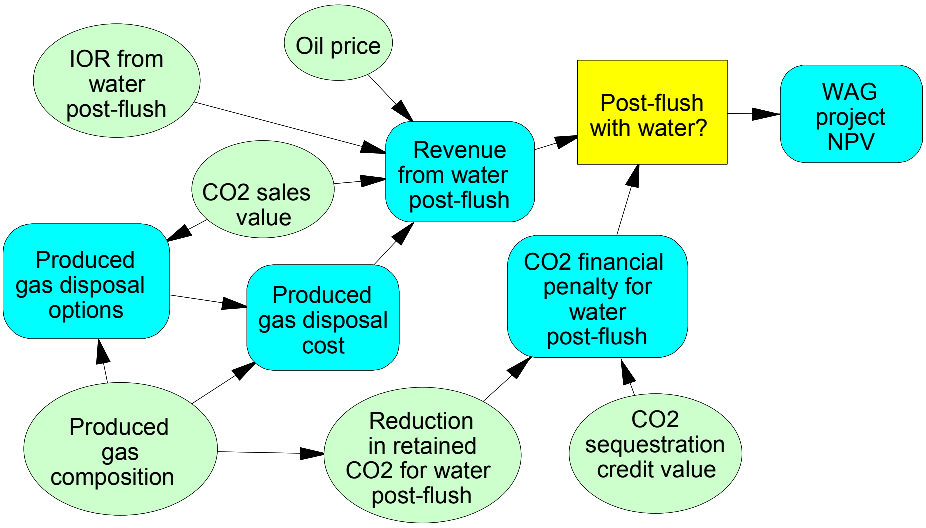


Figure 12 Factors influencing whether to perform water post-flush after CO_2 WAG project

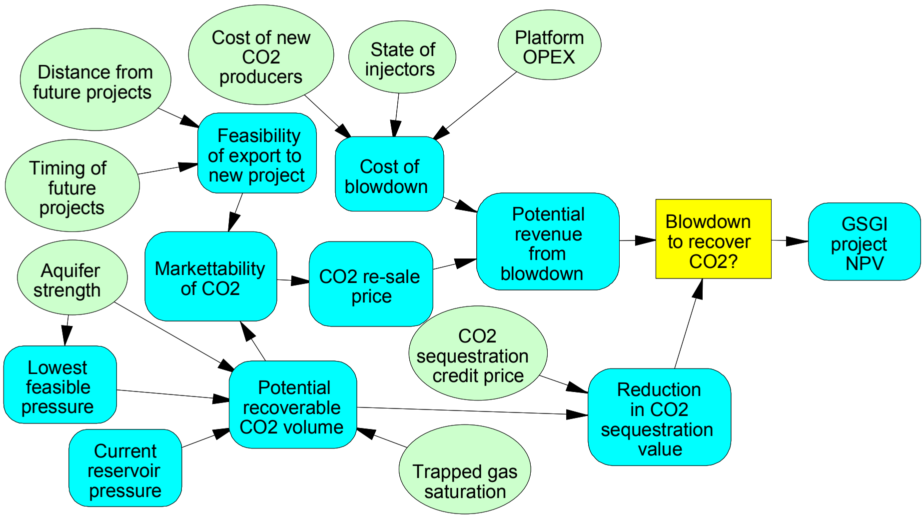


Figure 13 Factors influencing whether to blow down field and recover CO_2 after CO_2 GSGI project