



# Offshore offloading of CO<sub>2</sub>

Review of single point mooring types and suitability

May 2015

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# Offshore offloading of CO<sub>2</sub> – Review of single point mooring types and suitability

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## 1 Introduction

There are many types of single point mooring (SPM) and loading systems that have been developed in the offshore Oil and Gas sector for the transfer of hydrocarbon and other fluids from production wells, platforms or floating storages to tankers. Several of them can probably be adapted for transfer, in the opposite direction, of carbon dioxide (CO<sub>2</sub>) transported by ship as a refrigerated liquid, to injection wells for enhanced oil recovery (EOR) or geological storage. However, no clearly favoured offloading system for CO<sub>2</sub> has emerged yet (Brownsort, 2015).

This brief, desk-based study, carried out by Scottish Carbon Capture & Storage (SCCS) as part of the CATO-TKI project *Transportation and unloading of CO<sub>2</sub> by ship – a comparative assessment*, looked at the types of SPM available, their key characteristics and potential suitability for CO<sub>2</sub> offloading. The study developed a flow-chart based selection guide for a CO<sub>2</sub> offloading mooring taking account of some constraints of location, material and equipment characteristics and operations. It also considered the fit of potential mooring systems to the outline process route options developed earlier in the project. However, recommendations of mooring systems are not possible at the current stage of the project, as case study data has not yet been finalised.

## 2 Single point mooring types

An up-to-date commercial database (Infield Systems Ltd, 2015) lists over 35 named mooring systems in use globally. While many of these are fairly close variants of each other, or different suppliers' names for essentially the same system, there are seven clearly separate categories that can be identified. These include one conventional system and six single point systems; an eighth category is added from other literature (Omata, 2011). These are distinguished in Table 1<sup>1</sup>, together with their listed variants (there may be others) and a brief description. Note that single point loading systems that do not provide an actual mooring connection to the ship, but rely on the ship having a dynamic positioning (DP) system are included in this review.

Some examples from each of the main categories of SPM are pictured in Appendix 1.

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<sup>1</sup> Sources for information in Table 1 include: Infield Systems Ltd (2015), SBM Offshore (2013), Stella (2012), Oil Spill Solutions (2015), Subsea 7 (2014), Bluewater Energy Services (2009), Wichers (2013), Omata (2011).

**Table 1. Categorisation of single point mooring and loading systems**

Category	System names	Abbreviations	Brief description	Underwater flexibles?
Articulated	Single anchor leg mooring Single anchor leg rigid arm mooring Single anchor leg mooring rigid arm Single anchor leg storage Articulated loading column Articulated loading platform	SALM SALRAM SALMRA SALS ALC/ARTC ALP	<ul style="list-style-type: none"> <li>Articulated, buoyant column allowing rotation.</li> <li>Single seabed attachment, gravity or piled.</li> <li>Mooring by hawser or rigid arm/yoke.</li> <li>Surface flowline connections by floating hoses, or within rigid arm, or aerial hoses from raised platform (ALC/ALP).</li> <li>Seabed connections by flexible or by universal joint in flowline.</li> </ul>	Yes, in most cases.  ALC, ALP and possibly some SAL designs use universal joints rather than flexibles underwater.
Buoy	Catenary anchor leg mooring Catenary anchor leg mooring – soft yoke Catenary anchor leg – rigid arm Rigid mooring buoy Single buoy mooring Unmanned production buoy Vertical anchor leg mooring	CALM CALM-SY CALRAM RMB SBM UPB VALM	<ul style="list-style-type: none"> <li>Buoy usually with turntable section, or swivel.</li> <li>Seabed fixing by one or more catenary lines or tension legs from varied anchor options.</li> <li>Mooring by hawser or rigid arm/yoke.</li> <li>Surface flowline connections by floating hoses, or within rigid arm.</li> <li>Seabed connections by flexible.</li> </ul>	Yes
Fixed tower	Fixed tower single point mooring Jacket soft yoke	FTSPM JSY	<ul style="list-style-type: none"> <li>Rigid tower/jacket fixed to seabed with above-water rotating section.</li> <li>Mooring by hawser or articulated yoke.</li> <li>Above-water flowline connections by aerial hoses or within articulated yoke</li> <li>Rigid riser with above-water swivel joint.</li> </ul>	No

**Table 1. Continued**

Floating tower	Exposed location single buoy mooring Floating loading platform Floating cylinder facility	ELSBM FLP SPAR	<ul style="list-style-type: none"> <li>• Large floating tower/spar structure with above-water rotating section</li> <li>• Seabed fixing by multiple catenary lines or tension legs from varied anchor options.</li> <li>• Mooring by hawser.</li> <li>• Above-water flowline connections by aerial hoses.</li> <li>• Seabed connections by flexible.</li> </ul>	Yes
Spread	Conventional (or catenary) buoy mooring	CBM	<ul style="list-style-type: none"> <li>• Usually four catenary-anchored mooring buoys, with hawsers holding ship steady (not weathervaning).</li> <li>• Flexible risers and surface hose connections.</li> </ul>	Yes
Submerged flexible	Single anchor loading (1) Submerged loading system	SAL SLS	<ul style="list-style-type: none"> <li>• Flexible riser with pick-up buoy and wire, stored on seabed when not in use, SAL has catenary mooring connection, SLS has none, requiring DP ship.</li> </ul>	Yes
Submerged buoy	Hybrid riser tower Single anchor loading (2) Single leg hybrid riser Submerged tethered buoy Tripod catenary mooring and loading system Ugland Kongsberg offshore loading system	HRT SAL SLHR STB TCMS UKOLS	<ul style="list-style-type: none"> <li>• Submerged buoy at depth clear of shipping, tethered by one or more catenary lines or tension legs from varied anchor options.</li> <li>• Either mooring hawser with pick-up buoy from main buoy, or no mooring connection, requiring DP ship.</li> <li>• Flexible or part-rigid (hybrid) riser and flowline connection from seabed, via main buoy to ship, with pick-up buoy and wire.</li> <li>• Main buoy usually has swivel/turntable to allow weathervaning.</li> </ul>	Yes
Turret	Bottom mounted internal turret Buoyant turret mooring Riser turret mooring system Single point turret Submerged turret loading Submerged turret production Turret riser mooring system	BMIT BTM RTMS SPT STL STP TRMS	<ul style="list-style-type: none"> <li>• Turret concept involves swivelling manifold integrated with internal well through ship, or external support structure, at bow to allow weathervaning.</li> <li>• Turret may be fixed or disconnectable.</li> <li>• Disconnectable turrets may be submerged with pick-up buoy or on surface.</li> <li>• Turret tethered by multiple catenary lines from varied anchor options.</li> <li>• Flexible riser from seabed, connection through turret.</li> </ul>	Yes

### 3 Selection of offloading system

The choice of single point system for CO<sub>2</sub> offloading will depend on a number of factors including:

- Location – sea conditions, water depth.
- CO<sub>2</sub> condition – refrigerated liquid or warmed fluid<sup>2</sup>; temperature, pressure (T, P).
- Flexible hose suitability – for CO<sub>2</sub> condition and exposure environment (subsea, surface, aerial).
- Ship design – existing or new, space for processing equipment, DP system.

Some general observations follow against each of these factors.

#### 3.1 Location

Locations for CO<sub>2</sub>-EOR being considered by the project are likely to be offshore in the North Sea. This will rule out conventional buoy mooring systems (spread moorings), as these are only suitable for sheltered locations; ships cannot weathervane when using such systems and the strains on moorings would be too great in exposed locations. All the other SPM systems listed are designed to let the ship weathervane, that is, to point head-to-wind, or to current/waves if these create the dominant forces.

The sea conditions (wave heights and frequencies) under which offloading systems can operate differ between designs; this is a critical factor affecting the operational availability (“up-time”) of the system. The assessment of suitability of design for average sea state at a particular location is a specialist matter, beyond the scope of this review. However, most of the systems described here have been designed for offshore use.

Water depth varies from 50m or less in the Southern North Sea, through 1-200m in the Central North Sea to 2-400m in Northern North Sea, west of Shetland area and further north off Norway. Fixed tower mooring systems are only likely to be considered in shallower depths areas, perhaps <80m depth (Vermeulen, 2011) while catenary anchor or tension leg mooring systems are suitable for much greater depths. Indeed several such systems have been developed for much deeper waters, such as offshore Brazil with water depths around 2,000m (Malone, Kuuskraa, DiPietro, 2014). Articulated systems (articulated loading platforms, single anchor leg systems) were developed for intermediate depths, such as for the Statfjord field with around 150m depths (Sandberg, 2012).

#### 3.2 CO<sub>2</sub> condition

The condition of CO<sub>2</sub> at transfer from ship to offloading facility, whether as refrigerated liquid or warmed fluid, strongly affects the choice of SPM system through use of flexible hoses in the design and the limitations of such hoses, discussed in the following section.

The condition of CO<sub>2</sub> at transfer depends on a fundamental decision for the overall process design: whether buffer storage is needed between ship transport and CO<sub>2</sub> injection. This in turn depends on the injection profile required at the well, which depends on the nature of the EOR (or storage) operation and the reservoir properties.

If, after evaluating the match between supply profile (ship size and frequency) and the required injection profile, it is determined that offshore buffer storage is needed, then offloading of CO<sub>2</sub> as a

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<sup>2</sup> The term “warmed (or warm) fluid” is used in this report to describe CO<sub>2</sub> at conditions near or above 0°C, including supercritical conditions; the CO<sub>2</sub> having been warmed from refrigerated transport conditions.

refrigerated liquid will be required. It is assumed that buffer storage will be of refrigerated liquid CO<sub>2</sub> as storage of warmed CO<sub>2</sub> is likely to be impractical or costly due to the higher pressures or volumes involved.

The design of CO<sub>2</sub> transport ship may also lead to a need to transfer CO<sub>2</sub> as refrigerated liquid, if the ship does not have the process equipment necessary to re-condition CO<sub>2</sub> to a warm fluid.

In either case, it is assumed for this review that transfer of refrigerated liquid CO<sub>2</sub> will require a SPM design using above-water flexible or articulated connections. This limits the SPM to the fixed tower designs, or possibly to floating towers if the buffer storage and processing equipment can be sited on the tower. An alternative option would be refrigerated liquid CO<sub>2</sub> transfer to a floating storage and processing barge using tandem, in-line astern, systems developed for liquefied natural gas (LNG) transfers from floating LNG production units; an example is shown in Appendix 1.

### 3.3 Flexible hose suitability

After ship transport liquid CO<sub>2</sub> will be at conditions around 7 bara and -50°C (Vermeulen, 2011). Transfer of refrigerated liquid CO<sub>2</sub> by flexible hose is commonplace onshore (e.g. road tanker offloading) and may be used for quayside ship loading, however, this is considered higher risk than using articulated marine loading arms for ship loading (Vermeulen, 2011). There is no experience to date of offshore transfer of liquid CO<sub>2</sub> by flexible hose.

For LNG, hoses have been developed for offshore transfers at more extreme conditions than needed for refrigerated liquid CO<sub>2</sub> (hoses rated to 20 bara and -196°C, e.g. BPP-TECH, 2015). However, in most cases use of such hoses is limited to above-water (aerial) environments. A few examples of floating LNG hoses have emerged recently (Trelleborg, 2013; Technip, 2013) but the degree of experience with these is unknown and they may be limited to moderate sea conditions.

Flexible hoses suitable for refrigerated or cryogenic liquid transfers in submerged applications had not been developed by 2009 (Bluewater, 2009), but recent patents claim to have developed such hoses (Pollack *et al*, 2011; Menardo & Queau, 2013). These are designed for transfers between a floating production/liquefaction unit and a LNG carrier ship, and are intended to be easily exchanged.

Floating or submersible flexible hoses suitable for LNG may extend the range of SPM options suitable for refrigerated liquid CO<sub>2</sub> transfer in future, but, as stated above this is not assumed for this review.

For permanently submerged flexible lines there seems to be no option suitable for refrigerated or cryogenic liquids currently available. This limits offloading system options, if buffer storage of refrigerated liquid CO<sub>2</sub> is required, to fixed towers or floating storage and processing units where onward transfer is of warmed CO<sub>2</sub>; all other SPM options require a flexible flowline connection to the seabed. In contrast, rigid pipe-in-pipe systems suitable for submerged transfer of LNG are available (Technip, 2013), although possibly limited to near-shore applications.

Flexible hoses for the transfer of CO<sub>2</sub> after warming, either between ship and SPM, or from SPM to seabed, would seem to be more straightforward. Temperatures for transfer suggested in the literature are generally above 0°C with pressures ranging 60 – 400 bar (Brownsort, 2015). These are well within the range of established high-pressure hose technology used in the Oil and Gas sector (Dunlop, 2015). Although materials of construction will need to be selected for CO<sub>2</sub> use, it appears unlikely that flexible hose suitability will be a constraint on SPM type for warm CO<sub>2</sub> offloading.



### 3.4 Ship design

There are a small number of existing CO<sub>2</sub> carrier ships operating in European waters to service international trade in pure CO<sub>2</sub> for the industrial gases and food and drinks markets (Brownsort, 2015). These are designed for refrigerated liquid CO<sub>2</sub> discharge, so if they were to be used to service offshore CO<sub>2</sub> injection facilities they would be limited to SPM types suitable for refrigerated liquid transfer, as described in the sections above, even if buffer storage were not required. However, it is unlikely that such ships would be available, or suitable due to their small capacities.

It is more likely that CO<sub>2</sub> carriers for EOR or geological storage would be newly built or converted and so could have process equipment installed to recondition the CO<sub>2</sub> cargo to a warm fluid if the downstream process requires this. So it is unlikely that ship design would be a technical constraint on the choice of SPM offloading system, provided that ship and SPM are designed for compatibility.

An exception to this would be that if a ship is being converted to a CO<sub>2</sub> carrier and does not already have a DP system installed, it might not be technically possible or financially viable to retrofit. This would then exclude selection of the SPM systems without a physical mooring connection that require DP to keep the ship on station.

Clearly the ship would preferably be designed or converted to be fully compatible with the SPM offloading system. For many of the systems listed this will require hawser mooring equipment and a flexible coupling station, usually in the bow of the vessel. For the turret mooring systems more extensive adaptations are required to house the swivel turret manifold, either in a well within the hull or using an external support structure at the bow. While it is possible to have such turrets disconnectable, they are not designed for rapid turnaround such as needed for a CO<sub>2</sub> shuttle service; they are designed as stable, semi-permanent moorings for floating production, storage and offloading (FPSO) vessels.

### 3.5 System selection guide

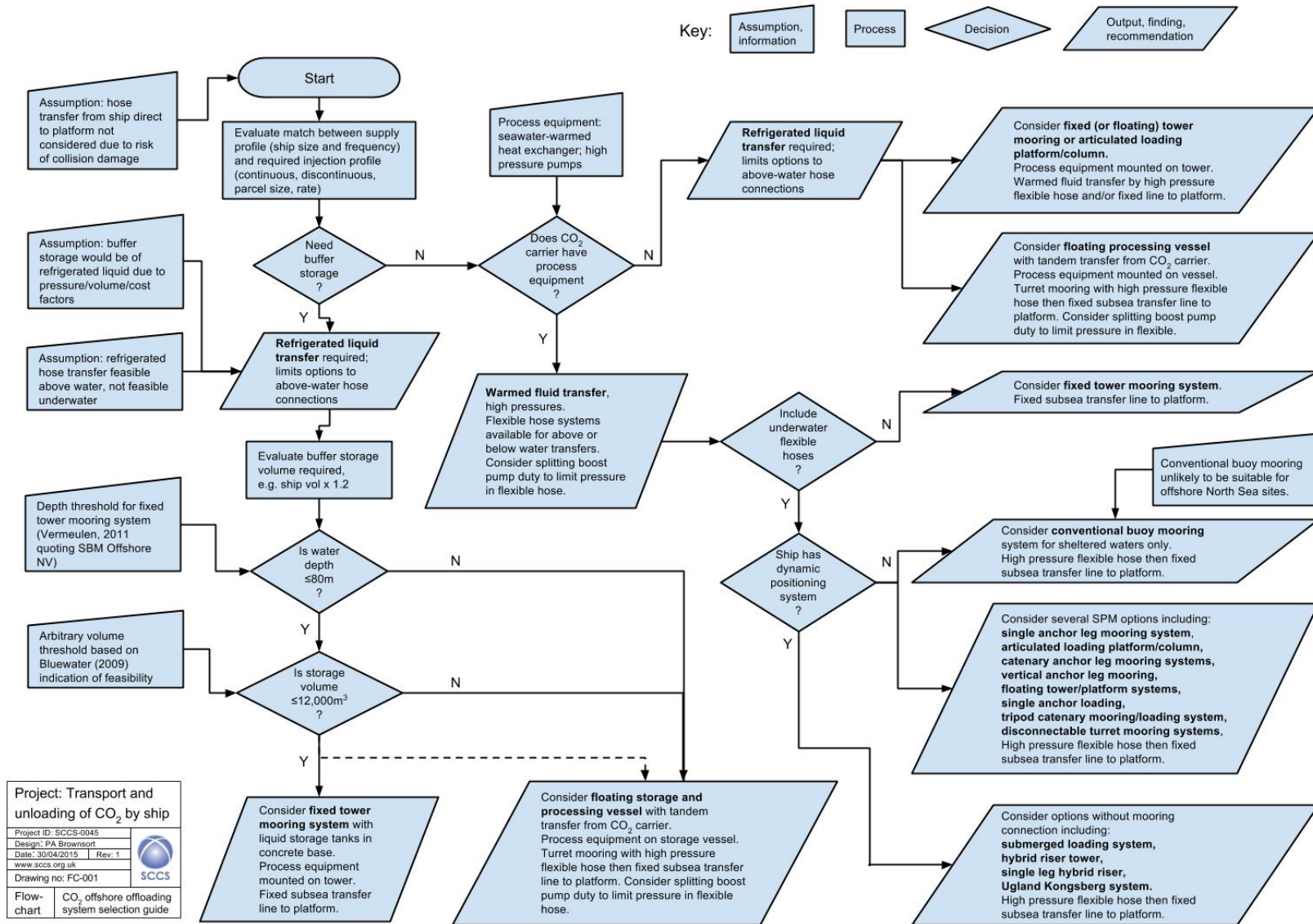
This review has been made solely on the basis of publicly available information with no expert consultation and so should be treated with some caution. However, by making some assumptions and applying simple logic to the information obtained, it is possible to offer a tentative flow-chart for selection of an offshore offloading system for CO<sub>2</sub>. This is presented in Fig 1.

The key questions for selection of an offshore mooring and offloading system for CO<sub>2</sub> can be summarised as:

- Is buffer storage required at the offloading point?
- Does the carrier ship have process equipment for re-conditioning CO<sub>2</sub> from refrigerated liquid to a warmed fluid?
- Are permanently submerged flexible hoses for warmed, pressurised CO<sub>2</sub> acceptable?
- Does the ship have a DP system?

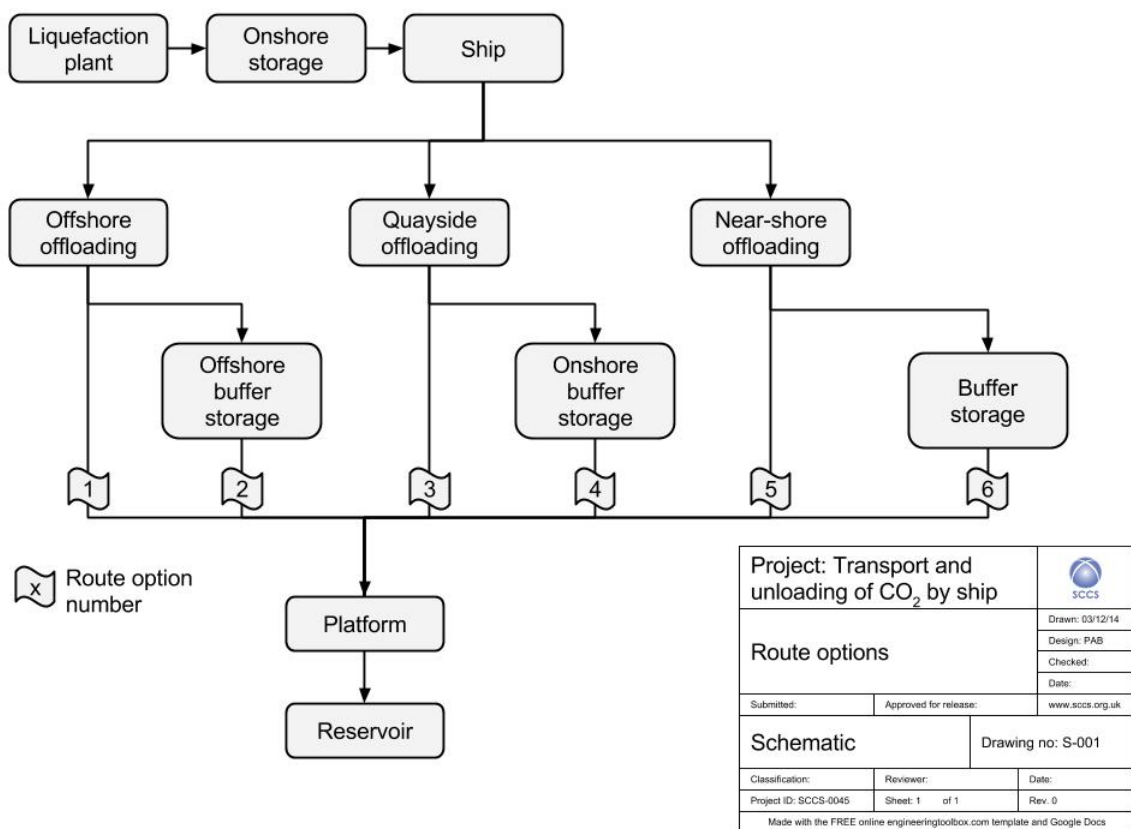
Some additional questions on water depth and storage volume affect the selection in some cases. An underlying assumption, discussed above, is that flexible hoses will only be used for refrigerated liquid CO<sub>2</sub> transfer in above-water connections.

Figure 1. CO<sub>2</sub> offshore offloading system selection guide



## 4 Potential mooring systems for process route options

The six process route options outlined earlier in the project (Brownsort, 2014) are shown in Figure 2. Options 3 and 4 involve quayside offloading, which would preferably employ conventional articulated marine loading arms; they are not considered here. Options 1, 2 and 5, 6 involve offshore and near-shore offloading respectively and would require a suitable mooring system. These have been subjected to an exercise using the selection guide described above to identify potentially suitable SPM offloading systems, as far as possible. A simplifying assumption has been made that if buffer storage is not required, carriers would have process equipment aboard for re-conditioning CO<sub>2</sub>. It is also assumed that the near-shore options have relatively shallow water depths. The outcomes are summarised in Table 2.



**Figure 2. Schematic of process route options**

**Table 2. Offloading system selection for project process route options**

Option	Route description	Offloading system selection outcomes	Comments
1	Offshore offloading with no buffer storage	Fixed tower mooring systems.	No requirement for submerged flexibles.
		For ships without DP: Single anchor leg mooring system, Articulated loading platform/column, Catenary anchor leg mooring systems, Vertical anchor leg mooring, Floating tower/platform systems, Single anchor loading, Tripod catenary mooring/loading system, Disconnectable turret mooring systems.	All require permanently submerged high-pressure flexibles or universal flowline joints. DP vessels could also use all these.
		For ships with DP systems: Submerged loading system, Hybrid riser tower, Single leg hybrid riser, Ugland Kongsberg offshore offloading system.	All require permanently submerged high-pressure flexibles or universal flowline joints.
2	Offshore offloading with buffer storage (reconditioning on storage facility)	Fixed tower mooring systems with storage tanks integrated into base.	Practical storage volume may be limited.
		Floating storage and processing vessel.	Permanently moored, weathervaning storage vessel with tandem transfer.
5	Near-shore offloading to pipeline terminal with no buffer storage	Fixed tower mooring systems.	No requirement for submerged flexibles.
		For all ships: Single anchor leg mooring system, Catenary anchor leg mooring systems, Vertical anchor leg mooring, Single anchor loading, Tripod catenary mooring/loading system.	All require permanently submerged high-pressure flexibles. Systems for DP vessels listed for Option 1 unlikely to have sufficient water depth.
		Conventional buoy mooring.	Only suitable for sheltered waters. Requires permanently submerged high-pressure flexibles.
6	Near-shore offloading to pipeline terminal with buffer storage	Fixed tower mooring systems with storage tanks integrated into base, (reconditioning on storage facility).	Practical storage volume may be limited.
		Fixed tower mooring systems with buffer storage onshore, (reconditioning onshore).	Using rigid pipe-in-pipe for refrigerated liquid transfer to shore storage.
		Floating storage and processing vessel, (reconditioning on storage facility).	Permanently moored, weathervaning storage vessel with tandem transfer.

Going through this exercise highlights that there are a wide variety of mooring options that may be feasible for some scenarios even when a number of constraints are imposed, while for others there are limited options. The exercise shows that it is difficult to generalise this selection process and that more specific information will need to be developed for case studies before offloading systems can be shortlisted for detailed design. However, there are some observations that can be made at this stage.

Fixed tower single point mooring/offloading systems would seem to be a versatile option, being feasible in all cases considered in the exercise. They are the only systems that avoid the need for any submerged flexible hoses, suggesting greater robustness and lower maintenance costs. This aligns with findings of studies reported by Vermeulen (2011) that could only recommend such systems for the Southern North Sea case study involved. However, they would not be suitable for water depths for the Central North Sea or further north or west. Also they are known to have significantly higher capital costs than buoy-based offloading systems (Bluewater, 2009).

For scenarios where buffer storage of CO<sub>2</sub> is required there are limited choices for suitable offloading systems, due to the need to transfer refrigerated liquid through flexible hoses. For offshore locations the use of a (semi)-permanently moored floating storage and processing vessel would appear most viable. For near-shore locations siting the storage onshore may lead to savings offsetting the costs of a fixed offloading tower and rigid pipe-in-pipe transfer line; however, if suitable port facilities are available, quayside offloading would be expected to have much lower costs.

Where carrier ships can re-condition CO<sub>2</sub> to a warm fluid before offloading, and assuming flexible hoses for such conditions are available, the choice of SPM offloading system is much wider. The buoy and submerged-buoy based designs would appear to be most versatile with many options that could be tailored to the specific design case and offering a balance between lower capital cost (Bluewater, 2009) and operability.

## 5 Conclusions and recommendations

There are many different single point mooring and loading systems in use for hydrocarbons, several of which are likely to be adaptable for offloading CO<sub>2</sub> at an offshore location.

The selection of a single point system for CO<sub>2</sub> offloading depends on a number of factors including location of offloading point, CO<sub>2</sub> condition at transfer, availability of suitable flexible hoses and the ship design. Most of these factors are dependent on the individual case involved and it is, therefore, not possible to give a general recommendation of offloading system.

- Detailed knowledge of the downstream process design (CO<sub>2</sub> injection profile and rate, injection temperature and pressure, reservoir properties, platform capabilities) is needed before selecting a suitable offloading system.
- Specialist advice on mooring and offloading design is needed to define a suitable system.

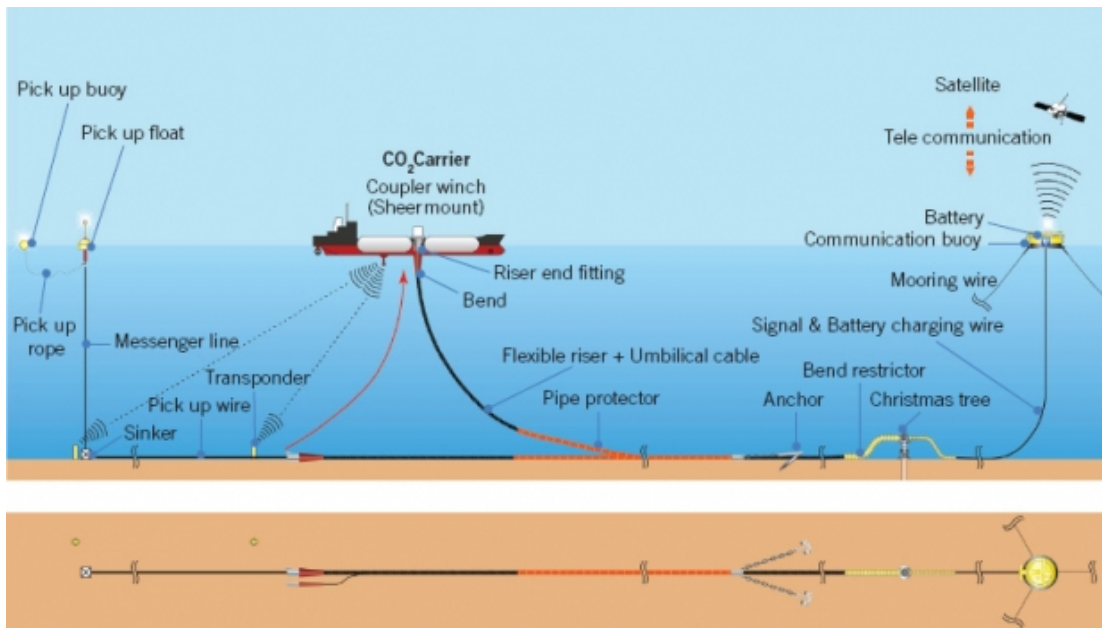
However, using available information a tentative logic flow-chart has been proposed to narrow down options for single point offloading systems. Four key questions relate to (i) the need for buffer storage at the offloading point; (ii) process equipment available on the ship; (iii) acceptability of permanently submerged flexible hoses for warm CO<sub>2</sub> transfer; and (iv) dynamic positioning capability of the ship. An assumption was made that flexible hoses suitable for refrigerated liquid CO<sub>2</sub> transfer in, or under seawater are not available.

- Improved understanding of the suitability of flexible hoses for CO<sub>2</sub> transfers would be beneficial, particularly for permanently submerged situations and for refrigerated liquid transfer.

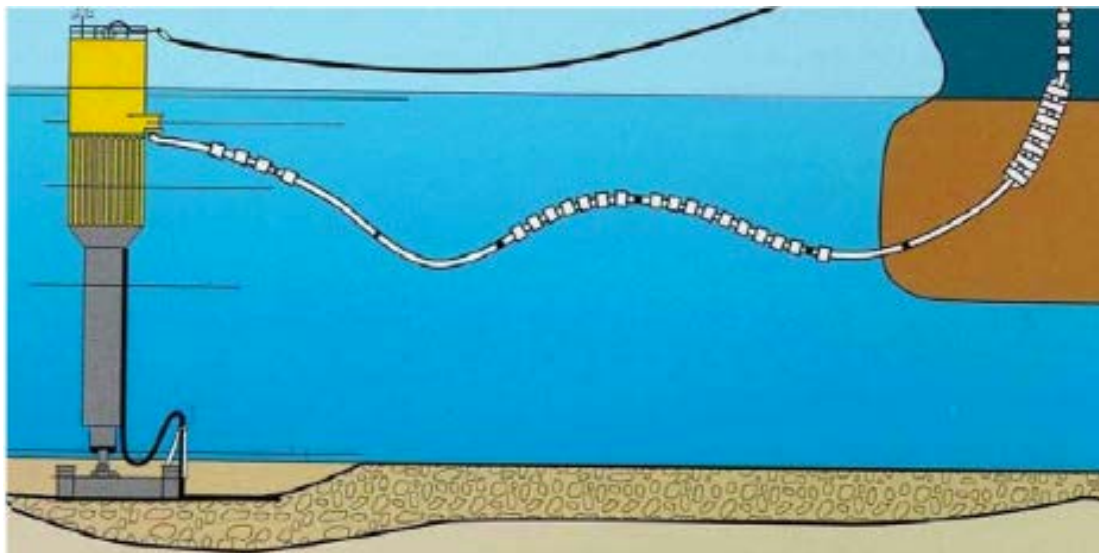
Using the flow-chart, four route options outlined for the CATO-TKI project were tested to give an initial screening of potential CO<sub>2</sub> offloading systems. For each route a number of possible systems were identified. However, the routes involving refrigerated liquid CO<sub>2</sub> offload to buffer storage have more limited options.

- The need for buffer storage after offloading is a key question that depends on design of the injection operation; the project should assess this factor critically before progressing with transport chain design.

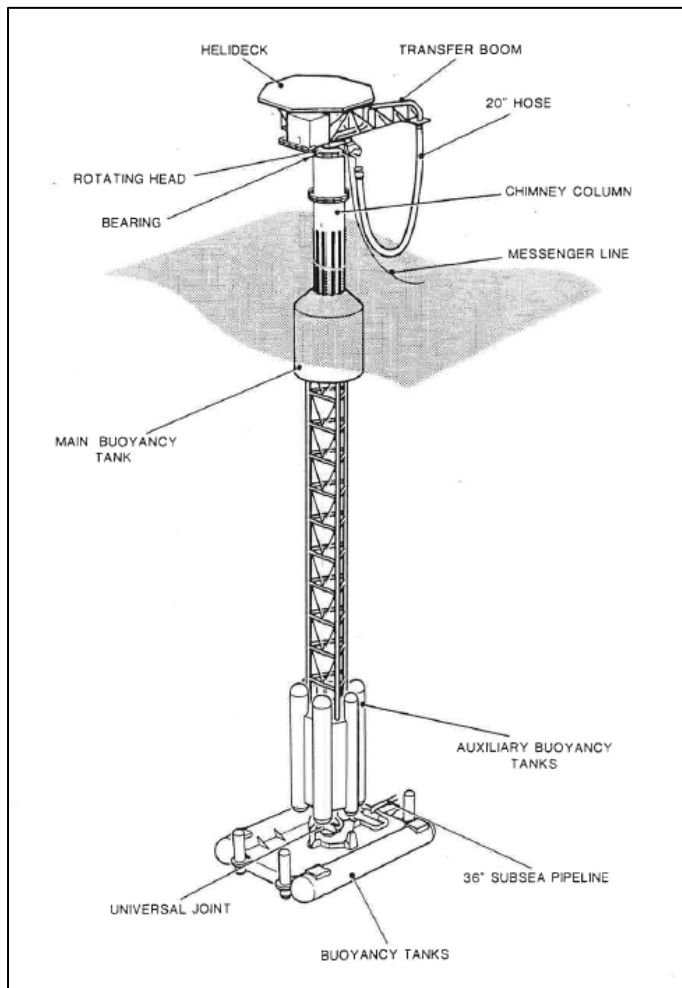
## 6 Appendix 1



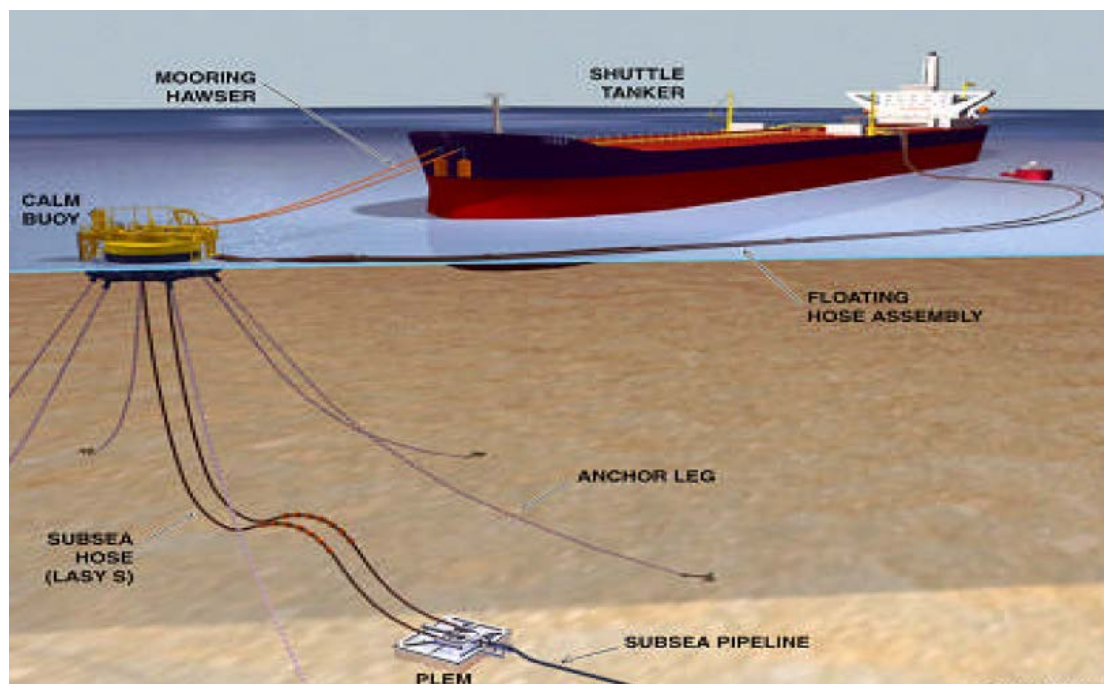
**Figure A. Submerged loading system (SLS). Source: Omata 2011**



**Figure B. Single anchor leg mooring (SALM). Source: Stella (2012)**



**Figure C. Articulated loading platform (ALP). Source: Sandberg (2012)**

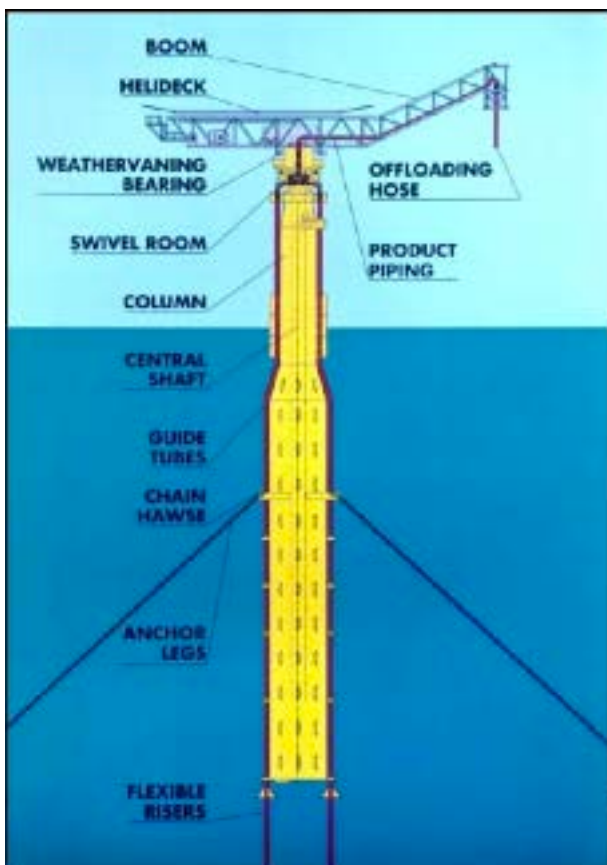


**Figure D. Catenary anchor leg mooring (CALM). Source: Sandberg (2012)**

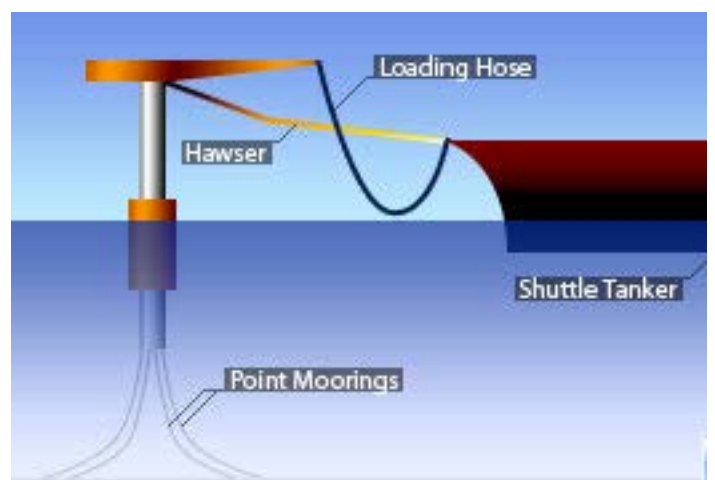




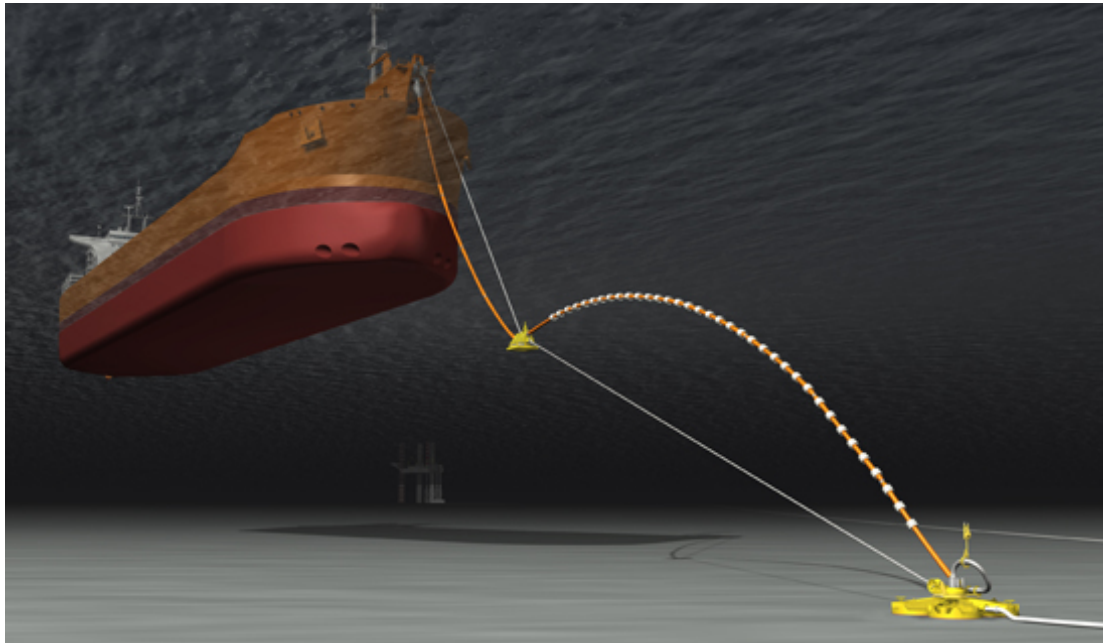
**Figure E. Fixed tower single point mooring (FTSPM). Source: SBM Offshore, reproduced in Vermeulen (2011)**



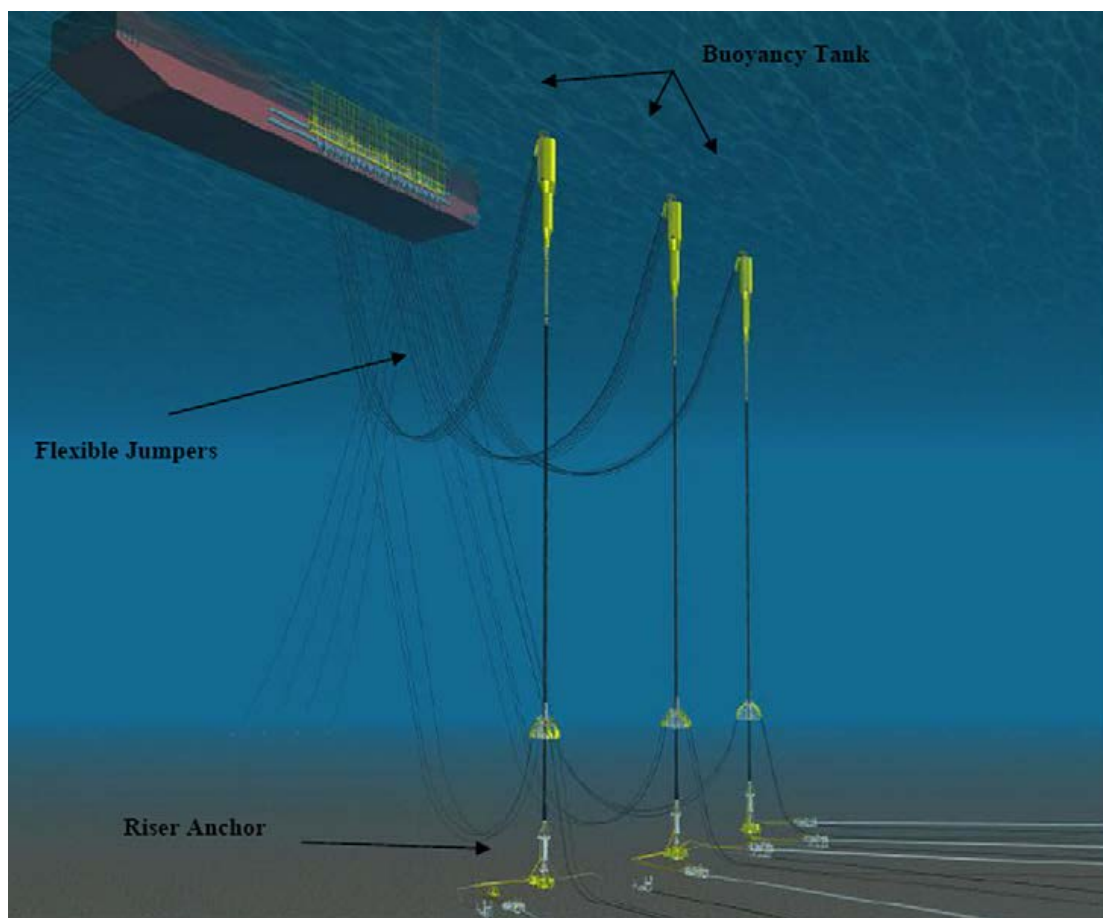
**Figure F. Floating loading platform (FLP). Source: Stella (2012)**



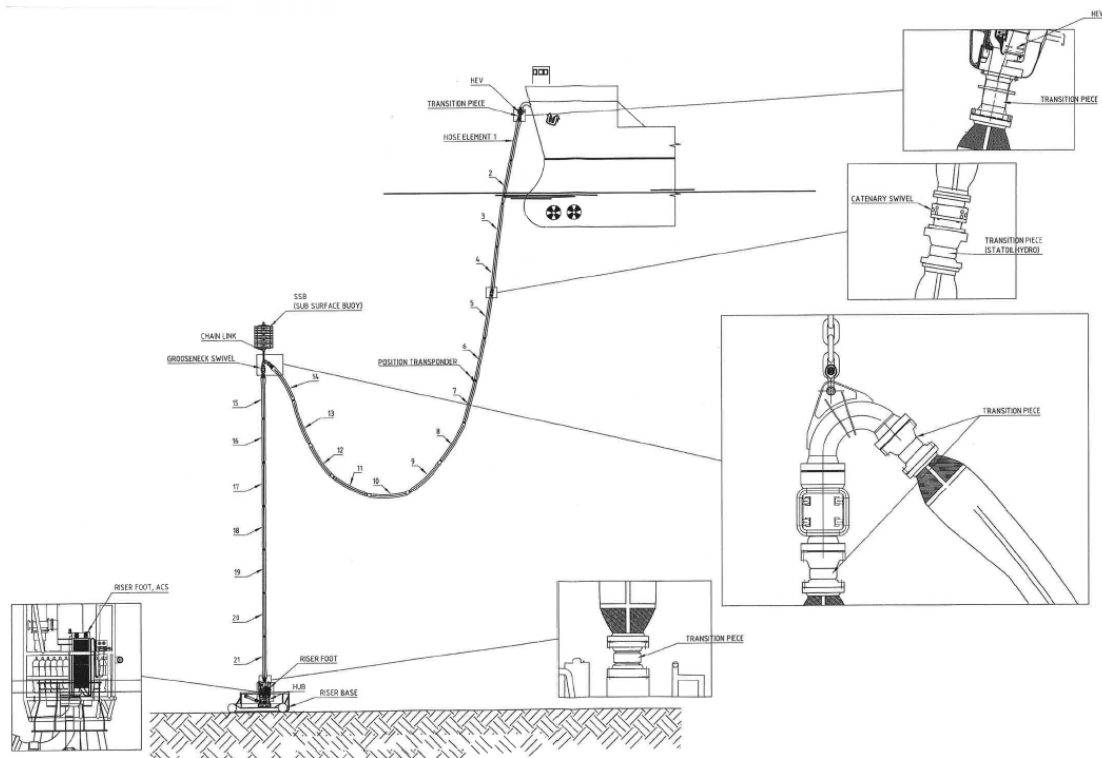
**Figure G. Floating loading platform (FLP). Source: Oil Spill Solutions (2012)**



**Figure H. Single anchor loading (SAL). Source: NOV (2014)**



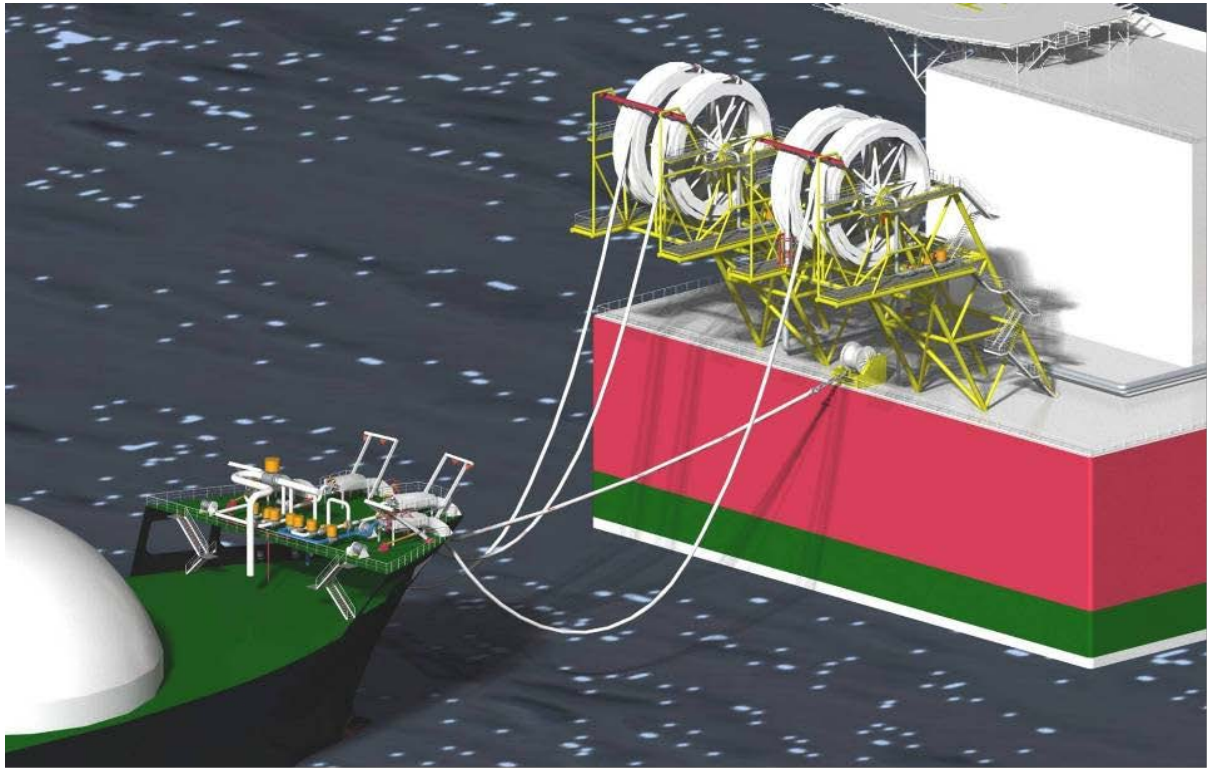
**Figure I. Single leg hybrid risers (SLHR). Source: Hachana (2012); original image from Subsea 7.**



**Figure J. Uglad Kongsberg offshore loading system (UKOLS). Source: Sandberg, 2012**



**Figure K. Disconnectable external turret mooring. Source: Smith (2009)**



**Figure L. Tandem offloading system for LNG. Source: Bluewater (2015)**

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