Zero discharge measures – overview of technology

Production – produced water, drainage water, well clean-up, sand cleaning, etc.

Principle 1 - Reduce water production

Technologies	Effect on other discharges /emissions	Reduction potential (water quantity %)	Technology status	References	Application/limitations
Better reservoir management - ***4D seismology*** - ***Smart wells*** - ***Underbalanced drilling*** - ***Recompletion of old wells***		0 - 40 on the field	The technology is available/being developed		Smart wells and underbalanced drilling are most relevant for new wells.
Blocking of water zones/ water cut-off ***- Reperforation, side tracking***	May lead to both increased and reduced discharge of chemicals. Reduced water production and reduced need for gas lift lead to reduced gas compression and reduced emissions to air. Water cut-off may give a longer production time and increased total water production.	0 - 40 per well	The technology is available/being developed	Ongoing activities in the industry.	Some of the technologies may be influenced by changes in reservoir conditions, a limited life-span, reservoir mobility and the capacity of the seal between the reservoir zones. *Water cut-off* Some of the technologies cannot be used in old wells due to high temperature, scaling, types of completion, cracks in the formation and the flow behind the casing.

- Mechanical • **Mechanical plug,** • **Straddle packer,** • **Sliding sleeve,** • **Patch flex** • **Inflatable plugs**				In use on Statfjord, Norne, Gyda, Heidrun, Åsgard, Yme, Sleipner, Patch flex: tested on Velsefrikk Being considered for Oseberg	*Mechanical plug*: only suitable for completions of the ”monodrill” type. *Straddle packer*: only suitable if there is no flow behind the casings. *Inflatable plugs*: Not permanent, sensitive to changes in pressure and temperature.
- Chemical **(cement, gel, resin, foam cement, carbonate, microbial)**				In use on Ula, the Ekofisk area, Statfjord Being considered for Oseberg C	
- Remote operated • **SCRAMS (Surface controlled reservoir analysis and management system)** • **DIACS (Downhole instrumentation and control system)** • **Smart wells (surface-operated equipment down in the well, such as valves, zone isolation packers)**					*SCRAMS*: limitations related to sand control Microbial: not suitable for a high temperature?

Downhole separation		70 - 90 per well under normal conditions	Further testing required		The potential is greatest for new installations/ satellites. Challenges regarding maintenance, well interventions, level gauging, difficult to implement in existing wells.
- Vertical (hydrocyclone)				Vertical separation being developed by Baker Hughes, Framo.	Can be used for water cut-off > 50 % and a low gas/liquid ratio. One limitation is that the production wells often are too small. Used abroad.
- Horizontal	Energy-saving, can reduce emissions to air			Horizontal separation, tests being done by Hydro on Ullrigg. Considered on Brage	Can be used for water cut-off 0-100 %, should be usable both in new and old wells, but may be difficult to install in old wells. Problems with sand and chalk particles. Requires a suitable geological formation for injection.
Seabed separation	Can reduce the consumption of chemicals Can reduce the need for energy and emissions to air	0 - 95 per separation	The technology is available/being developed.	Troll Pilot – Troll C, separates oil and water on three wells Being considered for satellites up towards Norne.	High potential on new installations/ satellites. Little potential on existing installations.

Principle 2 - Reuse

Technologies	Effect on other discharges	Reduction potential (water quantity %)	Technology status	References	Application/limitations
Reinjection of produced water (PWRI) **(pressure support)**	May lead to increase emissions to air due to reduced re-injectability later	80 - 95	The technology is available	Balder and Ringhorne, Frigg, Ekofisk, Glitne, Brage, Grane, Gyda, Heimdal, Heidrun (in part), Jotun, Norne (in part), Oseberg Sør, Oseberg Øst (> 90%), Snorre B, Tambar, Tor, Ula (91%), Valhall (2003), Veslefrikk, Visund, Brage (>70%) Planned on Skirne/Byggve, Statfjord C – the pilot injection is completed, expanded injection to 18 000 m^3/day autumn 2003. Being considered for Oseberg Field Center, Oseberg C , the West Flank and Draugen	Costs and energy requirements will be field-specific. Risk of acidification – and scaling if mixed with sea water. Can only be tested after water breakthrough. Can lead to acidification of reservoir / H2S production Need for nitrate injection? Can cause wear and tear on water inj. pumps due to sand and deposits and loss of injectability due to oil content and high temperatures in produced water.

Principle 3 - Disposal (cf. Utsira injection, last page of Appendix 5)

Technologies	Effect on other discharges/ emissions	Reduction potential (water quantity %)	Technology status	References	Application/limitations
Injection of produced water **a) in the reservoir**	Increases the emissions of CO_2 and NOx			Heimdal	
b) in other formation or aquifer	May increase emissions of CO_2 and NOx	80 - 95	The technology is available	Kvitebjørn Being investigated for Oseberg Field Center and Oseberg C	Requires waste wells, suitable formations.
Injection of produced sand	May increase emissions of CO_2 and NOx	50 - 100	The technology is available	Snorre B, Valhall, Visund, Oseberg Sør	
Injection of drainage water	May increase emissions of CO_2 and NOx	80 - 95	The technology is available	Valhall, Balder, Jotun, Oseberg C, Kvitebjørn, Heidrun, Brage, Oseberg Field Center, Oseberg Sør and Oseberg Øst, Njord, Visund, Snorre B	
Injection of well fluids • **Well clean-up /testing (avoid burning above flare boom)** • **Well treatment**	Reduces emissions of CO_2 and NOx	50 - 100 % of the oil volume that otherwise would have been discharged to sea with produced water	The technology is available	Gullfaks, Statfjord, Veslefrikk, Sleipner, Åsgard Gyda, Ula and Valhall	

				Brage, Troll B, Troll C, Oseberg Sør, Oseberg Øst, Snorre B, Snorre TLP	

Principle 4 a) – Cleaning produced water

Technologies	Cleans what	Cleaning effect (given as % and/or mg/l)	Technology status	References	Application/limitations
C-Tour *(placed upstream of hydrocyclones)* ***1) Extraction with condensate without fractionating***	Dispersed oils and dissolved aromatic hydrocarbons (PAH, phenols)	Effective removal in lab. Potential for reduction of dissolved comp. and dispersed with 80-90%.	The technology is available, expected to be qualified?? in 2003.	Tested on Statfjord B in 2002 with promising results, long-term test in 2003. Has been tested out by Hydro in Porsgrunn and ”qualified ” in relation to Hydro's platforms.	The BTEX level increases (doubling Statfjord B) if a fractionating column is not installed. Can be used on large quantities of water. Needs little room and no extra source of energy. Requires a certain pressure and temperature and condensate quality. Particles in the well stream may be limiting. Most effective with condensate qualities in the area C3/C4, with a tail that is as light as possible.
2) Extraction with condensate with fractionating	Dispersed oils and dissolved aromatic hydrocarbons (BTEX, PAH, phenols)				
3) Extraction with pure propane	Dispersed oils and dissolved aromatic hydrocarbons (BTEX, PAH, phenols)				
EPCON ***1) Mechanical ”soft cyclone” stage - CFU (Compact Flotation Unit)***	Dispersed oil, particles > 1 micron	Down towards?? 10 – 15 mg/l	The technology is available	CFU has been tested on Oseberg C and the Field Center, Brage and Ekofisk, plus tested on slop water on Åsgard . Will be installed on Brage and Snorre TLP, Ekofisk and Oseberg	Capacity: 10 – 300 m^3/hour Several small units are more effective than one large unit. Doesn't require much in terms of weight and room, little maintenance needed This process is very useful for severely polluted sub-streams. Can handle small water volumes like drainage water,

				Field Center. Drainage water from Troll C is cleaned in EPCON.	sandy water (being tested), well-cleaning, etc. Can replace degassing drum and hydrocyclones or produced water separators and flocculation units. There may be a need for flotation gas and flocculent.
2) ***Filtration Unit***	Dissolved components incl. PAH and the heavier alkyl phenols.	5 mg/l	The technology is being developed	CFU and FU have been tested on Gullfaks B and Oseberg C.	Critical concerning scale, particles and droplets of oil.
CETCO **CrudeSep – Vertical compact unit**	Dispersed oils, particles and some dissolved organic material plus exhaust gases.		Tests in progress	I used e.g. on Ekofisk in connection with PWRI-pilot.	Takes up a lot of space if the water volumes are large.
CrudeSorb – Filter technology	Removes dispersed oil, PAH, phenols and alkyl phenols, and reduces the heavy metal content		The technology is available/being used	Used for well clean-up; Heidrun, Sleipner, Gullfaks satellites, Jotun and internationally, Kristin	Filter mass with a long lifetime which can be reinjected or burnt. (Being tested.) Still questions concerning maintenance? May generate special waste
Flotation cells ***Technology for meeting the requirement of 40 mg/l*** ***Flotation***	Dispersed oil	20 – 60 mg/l	The technology is available	In use on several installations	High capacity, but needs a relatively high retention time and takes up much space
hydrocyclones ***Technology for meeting the 40 mg/l requirement***	Dispersed oil	Removes approx. 50-95% depending on liquid characteristics 20-50 mg/l With the effect from a degassing	The technology is available	In use	May be connected in series New hydrocyclones have a higher efficiency due to new design, a lower rate per cyclone and a higher reject ratio. Variable efficiency and capacity.

		drum, the oil content in the water may in favorable conditions get as low as 10 – 15 mg/l			Inefficient for small-sized droplets, which are often found in water from condensate fields. The cleaning effect depends on chemicals being added during the process.
MPPE (Macro Porous Polymer Extraction) ***Liquid – liquid extraction and steam stripping with a fixed matrix***	Dissolved components (PAH, BTEX) and volatile part of dispersed oil	Possible to remove 90% of dissolved components and 20 to 30% of dispersed oil	The technology is available	Tested on Åsgard A in 2001 with a good result, removed approx. 50% of dispersed oil in an overdimensioned test facility (decided not to install). Being considered on Troll Used in the Netherlands	May be used on gas platforms Can only handle small volumes Requires a lot of space Energy-demanding
Droplet growth technologies ***A fiber material that increases the size of the oil droplets in the hydrocyclones*** **PECT-F**	Reduces oil in water	20 - 40% reduction of oil after cleaning in hydrocyclones	The technology is available	Installed on Draugen in 2001, shows less efficiency than during testing. Tested on Ekofisk, Eldfisk and Jotun. Installed on Heidrun in 2001 – improved efficiency towards 60%, but the hydrocyclones became clogged with naphthenes after a week.	The technologies have the greatest potential when the droplet size is such that moderate droplet growth leads to a great improvement in the efficiency of the hydrocyclones. According to the supplier, this is the case for condensate fields May be used in existing and new hydrocyclones. Capacity depends on the hydrocyclone. Problems with clogging of particles. Similar technology to Mares Tail. Needs no control system, requires little space, weight and maintenance.

Mares Tail ***Corresponding technology to PECT-F.***				The technology is considered for testing on Sleipner.	Must be placed upstream of the hydrocyclones. This makes it possible to install two units in parallel, where replacing the fiber spool can take place much faster than replacing the matrix in PECT-F, which has this one in the inlet chamber on the hydrocyclone vessel.
Hydroflock and **G-Floc**				Tested on Draugen	Technologies which through moderate stirring within the chamber, where small amounts of coagulant and flocculent may also be added, achieve a cleaning effect corresponding to PECT-F and Mares Tail.
Centrifuges ***Gravitation***	Dispersed oil and dispersed condensate	Effective for dispersed oil 5-25 mg/l	The technology is available	Troll A? and C. Used to clean drainage water on most of Hydro's installations	Application limited to moderate volumes of water. Used on drainage water and gas fields. *Advantages* Compact, no additives needed, handles variable water flows, the return flow is clean *Disadvantages* High investment, operation and maintenance costs, energy-demanding

Principle 4 b) – Cleaning of produced sand

Technologies	Cleans what	Cleaning effect	Technology status	References	Application/limitations
Sand cyclones	Oily sand	< 1% adherence	The technology is available	Approved for installation on Gullfaks	
More robust hydrocyclones	Oily sand	< 1% adherence	The technology is available	Pre-project on Statfjord, under consideration on Vigdis	
Washing plant	Oily sand	< 1% adherence	The technology is available	Snorre B	In order to function optimally, the implementation of the technology should be planned in the design phase. Modifications on existing installations are expensive.

Chemicals – Production

Principle	Method	Reduces what /Effect on use and other discharges	Chemicals status	References	Applications/limitations
Avoid use of chemicals	**Choice of materials** **Mechanical operations**	Replaces wax inhibitors	Available	Used in several places on the Norwegian Shelf Nitrate injection in the water injection system is used full-scale on Veslefrikk and Gullfaks in order to eliminate use of biocides.	Use of chromium steel in pipelines and production equipment in order to avoid injection of corrosion inhibitor Use of nitrate in order to reduce the need for other chemicals (H2S) Increased pigging frequency as a replacement for wax inhibitors
Substitution/ Reduction of chemicals	**Development and replacement of chemicals**		Available	In process on all installations on the Norwegian Shelf	
	Optimization - ***”Online meter” for oil in water*** - ***Move injection point***		Available	Continuous work on all fields Online-meter on Oseberg C	Gives early warning of problems.
	”Sko-flo” ***Better control of chemicals***		Available	Troll C, Oseberg Field Center, Oseberg C, Oseberg Sør, Oseberg Øst. Study carried out on Brage	

	Framo contactor *(mixes chemicals)*	Framo-contactor reduces 30-35% of H_2S scavenger consumption	Available	Åsgard B, being considered on Gullfaks, Veslefrikk	
	Reuse of H_2S remover **Recycling of MEG/TEG**	Approx. 50% reuse when the H_2S remover is recycled	Installed on Ekofisk 1998 Recycling of MEG/TEG through gas dehydration and addition to prevent the formation of hydrates.	Ekofisk 2/4-J Planned on Skirne/Byggve E.g. Heimdal	
Reuse	**Washing chemicals etc.**		Available		
Disposal (injection)	**Amino plant** ***Removal of H_2S***			Åsgard	
Discharge	Absorbs dissolved components and PAH		Available	Being tested on Statfjord B and C, Draugen	Degree of separation increases with increasing temperature and salinity. Rest product in the form of mud.
Nature ***Flocculent that is added upstream of the crude oil, i.e. before degassing drums***					

Drilling and well

Principle 1 – Reduce the amount of drilling waste

Technologies	Effect on other emissions/ discharges	Reduction potential (drilling waste %)	Technology status	References	Applications/limitations
Reduce well diameter **Replace 26"pipes with 17 ½"**		50% reduction in discharge of drilling fluids, cement and cuttings in the top hole section	The technology is available	Gullfaks, Norne, Draugen	
Slim hole drilling **Changing well design, casings**	Reduces emissions to air	80% reduction in discharge of drilling fluids, cement and cuttings	The technology is available	Statfjord, Sleipner	
Branch drilling	Reduces emissions to air Reduces amounts of drill cuttings, drilling fluid and chemicals		The technology is available	Troll B, Troll C, etc	
Monodiameter well design Thomas – Rife Gas Unit	Reduces emissions to air	Reduction of drill cuttings up to 50%.	Tested by Shell onshore in Texas. Planned used offshore in the Gulf of Mexico in 2003 (SepCo)	Well no. 15 Stan County, Texas.	Replaces conventional well design from top hole to bottom

Principle 2 - Reuse

Technologies/methods	Effect on other emissions/ discharges	Reduction potential %	Technology status	References	Applications/limitations
Water-based drilling fluids	Increased emissions to air (during transport)	30% reduction in discharges of drilling fluids		Gullfaks, Statfjord, Veslefrikk, Huldra, Norne, Heidrun, Draugen, being planned on Mikkel On average, 88%of water-based drilling fluids are reused on all of Hydro's drilling installations. A base for reuse has been established at Mongstad.	Can limit the choice of drilling fluids. Reuse of drilling fluids reduces the use of chemicals, but may lead to a somewhat more uncertain data collection (geology/petrophysics).
Oil-based drilling fluids	Increased emissions to air (during transport)	Reduction in total consumption		Ula and Gyda, Valhall Oseberg B, Oseberg Sør, Brage	Reuse of drilling fluids reduces the use of chemicals, but may lead to a somewhat more uncertain data collection (geology/petrophysics). Requires drill cutting injection /transport to land – zero discharge to sea
Synthetic drilling fluids	Increased emissions to air (during transport)	Reduction in total consumption		Planned on Skirne/Byggve Hydro: All OBM or POBM are reused. A bank for reuse has been established at Mongstad.	
Completion fluid/chemicals		30 % reduction in discharge of chemicals		Gullfaks, Statfjord, Huldra, Norne, Heidrun, all Hydro's fields	
NeoDrills "Preconduct"					

Pre-installation of conductor pipes for subsea wells	No discharge, cuttings reduced by 30-50 m^3 cuttings per well		The technology has been partially tested.	Studies in process or completed for Glitne, Tampen and Goliat.	
Riserless Mud Return System - RMR			The technology is under assessment		Possibility of safeguarding drilling fluids and drilled-out mass from the top hole section.

Principle 3 – Disposal

Technologies	Effect on other emissions/ discharges	Reduction potential %	Technology status	References	Applications/limitations
Injection of drill cuttings	Lower emissions to air than with transport/ processing on land.		The technology is available	Brage, Ekofisk, Eldfisk, Ringhorne, Gullfaks, Statfjord (A+B+C), Gyda, Valhall, Jotun, Oseberg B (Field Center), Oseberg C, Oseberg Sør and Øst, Sleipner Vest, Varg, Snorre B (being considered for Snorre TLP), being considered for Heidrun Tambar, Visund, Veslefrikk, Ula, Grane and Kvitebjørn (planning cuttings)	Applicable to oil-based drilling fluids. Alternative to transport to land for processing.
Injection of slop (residue of oil and chemicals)				All installations that have injection of cuttings	
Injection of used drilling fluids				All installations that have injection of cuttings	
Injection of cementing chemicals (mixing water)	Increases emissions of CO_2 and NOx	95 % reduction in emission		Gyda, Ula, Valhall, Norne, Oseberg C, Oseberg Field Center, Brage	
Injection of completion chemicals	Increases emissions of CO_2 and NOx	95 % reduction in emission		Gyda, Ula, Valhall, Jotun, Oseberg C, Oseberg Field Center, Brage	

Principle 4 – Emissions/discharges

Methods/materials/ chemicals	Effects on other emissions /discharges	Reduction potential %	Technology status	References	Applications/limitations
Ilmenite ***(alternative weight material – black color)***	Increased consumption of washing chemicals	Reduced emission/ discharge of heavy metals	Further tests will be conducted	Is used on Hod, Norne, Ekofisk, Eldfisk, Gyda, Ula, Draugen Considered for use on Heidrun, Valhall, Åsgard, Kristin	Leak tests have been conducted, these do not document whether they are biologically available. Functions operationally. More dust is formed (visual impression), which leads to increased need for cleaning/painting.
Hematite ***(alternative weight material – red color due to iron)***			Available	Hydro has conducted tests, used by Agip in the Barents Sea. Will be tested on a Hydro well in 2003.	Functions operationally. Iron may affect the drilling stability in directional drilling.
Heavy salt solutions			Available	Considered for use on Kristin (must have oil-based as a backup) Tune	
Water-based drilling fluids in all sections	Reduced emissions to air Increased discharge of chemicals	Reduced consumption of oil-based drilling fluids	Available	Heidrun, Draugen, Troll A, Troll B and C pre-drilling, Grane exploration drilling Being considered for Mikkel	Limited to simple well paths. The current technology is not good enough to replace oil-based drilling fluids. On Troll, Hydro uses this with up to three branches.

New procedures for reduced consumption of chemicals - ***Washing chemicals*** - ***Cement chemicals***			Available	Statfjord Norne	

Pipelines

Principle	Method	Reduces what/ Effect on other emissions/ discharges	Chemical status	References	Applications/limitations
Avoid use of chemicals	**Choice of materials** **Use of fresh water when laying pipelines**	Reduces use of oxygen scavenger/ biocide	Available Available	Grane	When landing – fresh water from land Also possible in connection with short pipeline stretches offshore, tie-ins of satellites, etc. Depends of the fresh water resources offshore.
Substitution/ Reduction of chemicals	**Start-up** - ***reduce the use of dyes*** - ***reduce the use of biocide*** - ***reduce the use of corrosion inhibitor*** - ***use of fresh water and NaOH***	Reduces the use of corrosion inhibitor	Available Available	Draugen Draugen activity planned without use OTS to Sture	Dye as pellet – to be placed at the joint Preventive treatment to avoid growth of bacteria Run the cleaning pig regularly to avoid deposits which prevents the corrosion inhibitor from working properly and encourage bacteria growth.

	Start-up/operation - ***Electrical heating***	Reduced the use of hydrate inhibitor and gives less flaring, but increases consumption of energy		Åsgard	Less MeOH in the gas export pipeline

Utsira injection

Utsira is a shallow sandstone formation containing approximately 40% salty water.
The salinity in the Utsira water is more or less the same as the salinity in produced water from Statfjord B. The Utsira formation stretches across large sections of the North Sea, encompassing an area of approximately 26 000 km2 and a volume of around 550 billion m3.

Utsira is a shallow formation, about 1000 meters under the seabed, with low pressure. The formation has good injectivity. Even though the pressure is low, a considerable increase in emissions to air of CO_2 and NOx may occur when large quantities of water are injected.

Oily drill cuttings have been injected via the annulus into Utsira from several fields over the last eight to ten years. Associated gas from Glitne is injected into Utsira. Produced water from Kvitebjørn will be injected into Utsira. Brage uses sulfate-free Utsira water as injection water. Separated CO_2 from the Sleipner Vest gas is injected into Utsira.

A layer of shale above Utsira makes the formation leak-proof. The EU-sponsored research project SACS (”Saline Aquifer CO2 Storage”) has monitored the storage of CO_2 in the Utsira formation. The conclusion is that no CO_2 is leaking out from the Utsira formation.

A study has been conducted in the Statfjord late phase project with regard to produced water injection into Utsira/Hordaland. The study concludes that Utsira/Hordaland has the potential to receive the entire or parts of the produced water flow from Statfjord. The costs of an injection solution are calculated to be high, since most of the water must be injected from seabed wells that first have to be drilled. Any effects on other fields’ exploitation of Utsira are expected to be marginal.