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2008 Worldwide Survey of Subsea Processing: Separation, Compression, and Pumping Systems

STATUS OF THE TECHNOLOGY

MARCH 2008

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Information Accuracy: We have attempted to use correct and current, as of press time, information for the subsea processing systems and equipment described herein. No installed, sanctioned, nor pending application was intentionally excluded. We have summarized the capability and operating experience by acting as a neutral party and integrator of information. Information has been collected from public sources, company brochures, personal interviews, phone interviews, press releases, industry magazines, vendor-supplied information, and web sites. No guarantee is made that information is accurate or all-inclusive. Neither **INTEC Engineering** nor **Offshore Magazine** assumes any responsibility or liability for any party's use of the information presented. If any information is found to be incorrect, not current, or has been omitted, please send comments to ssp@intec.com.

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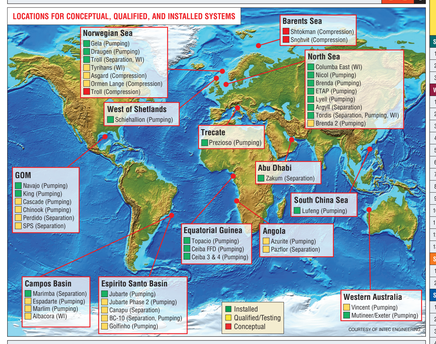
LOCATIONS FOR CONCEPTUAL, QUALIFIED, AND INSTALLED SYSTEMS



COURTESY OF INTEC ENGINEERING

TABLE 3 – DRIVERS FOR:

1.0 SUBSEA COMPRESSION
- 1.1 Increase subsea tieback distance
- 1.2 Improve flow assurance issues

2.0 SUBSEA BOOSTING
- **2.1 RESERVOIR ADVANTAGES**
  - 2.1.1 Increase ultimate recovery by lowering abandonment pressure
  - 2.1.2 Enable oil recovery from low pressure reservoirs
  - 2.1.3 Enable oil recovery for low quality fluids
- **2.2 PRODUCTION ADVANTAGES**
  - 2.2.1 Increase production rate by reducing the flowing wellhead pressure
  - 2.2.2 Reduce opex by reducing recovery time (shorten life of field)
  - 2.2.3 Offset friction or elevation pressure loss
- **2.3 FACILITIES ADVANTAGES**
  - 2.3.1 Longer subsea tiebacks

3.0 SUBSEA WATER INJECTION
- 3.1 Eliminate topsides water injection handling equipment
- 3.2 Eliminate water injection flowlines

4.0 SUBSEA SEPARATION
- 4.1 Minimize topsides water handling
- 4.2 Remove liquids from gas stream
- 4.3 Increase hydrocarbon production volume
- 4.4 Decrease total boost system power requirements

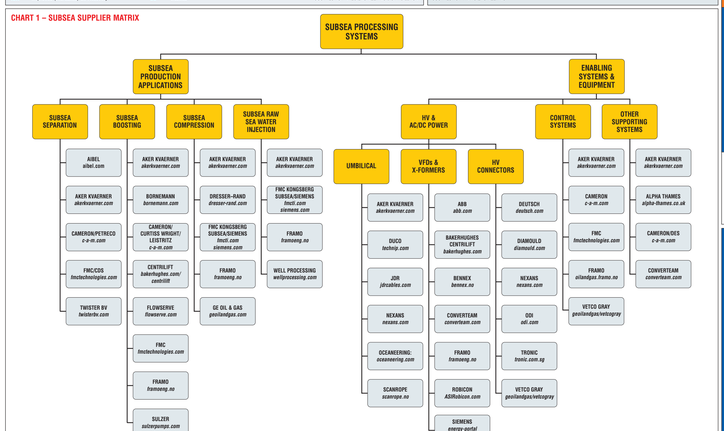
COURTESY OF INTEC ENGINEERING & BHP BILLITON

TABLE 4 – INDUSTRY ACRONYMS & ABBREVIATIONS

ACSS	Centrifugal Subsea Submersible Pump
BLPD	Barrels of Liquid per Day
BPD	Barrels per Day
BOPD	Barrels of Oil per Day
CAPEX	Capital Expenditures
CTCU	Cable Traction Control Unit
ESP	Electrical Submersible Pump
FFD	Full Field Development
FPS	Floating Production System
FPSO	Floating, Production, Storage, & Offloading Vessel
GOWSP	Gas-Oil-Water Separation Platform
GVF	Gas Volume Fraction
Hp	Horsepower
ICS	Integrated Compressor System
IOR	Improved (Increased) Oil Recovery
kW	Kilowatt
LDDM	Long Distance Delivery Management
LDDS	Long Distance Delivery System
MBLPD	Thousand Barrels of Liquid per Day
MPP	Multiphase Pump
MW	Megawatts
OPEX	Operational Expenditures
PCM	Power Control Module
PCDM	Power and Communication Distribution Module
PLIM	Pipeline Inline Manifold
ROV	Remote Operated Vehicle
RPM	Revolutions Per Minute
RWI	Raw Water Injection
SCM	Subsea Control Module
SIORS	Subsea Increased Oil Recovery System
SMUBS	Subsea Multiphase Booster Station
SS	Subsea
SSBI	Subsea Separation Boosting Injection
SUBSIS	Subsea Separation and Injection System
SWIT	Subsea Water Injection and Treatment System
VASPS	Vertical Annular Separation and Pumping System
VSD	Variable Speed Drive
WD	Water Depth
WGC	Wet Gas Compressor
WI	Water Injection
WIP	Water Injection Pump

SUBSEA SEPARATION TYPES
- 2-Phase (Gas/Liquid)
- 2-Phase (Oil/Water)
- 3-Phase (Gas/Oil/Water)
- 4-Phase (3-Phase with solids removal & disposal)

CHART 1 – SUBSEA SUPPLIER MATRIX



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SUBSEA PUMP TYPES

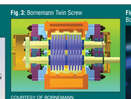
Fig. 1: Leistritz Twin Screw

COURTESY OF LEISTRITZ

Fig. 2: Leistritz Twin Screw Pump & Motor

COURTESY OF LEISTRITZ

Fig. 3: Bornemann Twin Screw



COURTESY OF BORNEMANN

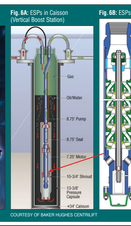
Fig. 4: Bornemann Twin Screw Pump & Motor

COURTESY OF BORNEMANN

Fig. 5: Framo Helico - Axial SS Booster Pump

COURTESY OF FRAMO ENGINEERING

Fig. 6A: ESPs in Caisson (Vertical Boost Station)



COURTESY OF BAKER HUGHES CENTRILIFT

Fig. 6B: ESPs

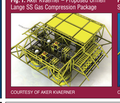
COURTESY OF BAKER HUGHES CENTRILIFT

Fig. 6C: Centrilift MVP Multiphase Pump Stage

COURTESY OF BAKER HUGHES CENTRILIFT

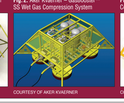
SUBSEA GAS COMPRESSION SYSTEMS & PRODUCTS

Fig. 1: Aker Kvaerner – Proposed Ormen Lange SS Gas Compression Package



COURTESY OF AKER KVÆRNER

Fig. 2: Aker Kvaerner - GasBooster™ SS Wet Gas Compression System



COURTESY OF AKER KVÆRNER

Fig. 3: FMC Technologies SS Gas Compression Station

COURTESY OF FMC TECHNOLOGIES

Fig. 4: FMC & Siemens Technology – SS Wet Gas Compressor

COURTESY OF SIEMAG

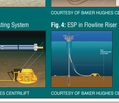
Fig. 5: Kvaerner Booster Station (KBS) for SS Gas Compression

COURTESY OF GE OIL & GAS

Fig. 6: FRAMO Wet Gas Compression System

COURTESY OF FRAMO ENGINEERING

Fig. 7: FRAMO SS Wet Gas Compression System



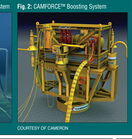
COURTESY OF FRAMO ENGINEERING

SUBSEA MULTIPHASE PUMPING SYSTEMS

Fig. 1: Aker Kvaerner – MultiBooster™ System

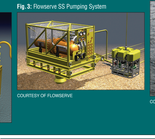
COURTESY OF AKER KVÆRNER

Fig. 2: CAMFORCE™ Boosting System



COURTESY OF CAMERON

Fig. 3: Flowserve SS Pumping System



COURTESY OF FLOWSERVE

Fig. 4: Framo SS Multiphase Pump Station, Ceiba Field

COURTESY OF FRAMO ENGINEERING

Fig. 5: Framo SS MultiManifold

Incorporates Multiphase Boosting, Multiphase Metering, Multiport Selector Manifold for up to 8 wells and with Fiber optics and Hydraulics Control system. Two systems delivered to Olinco.

COURTESY OF FRAMO ENGINEERING

Fig. 6: FMC Technologies SS Multiphase Pump

COURTESY OF FMC TECHNOLOGIES

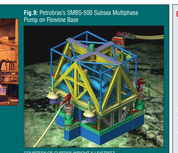
Fig. 7: SBMS-500 System in Transit from Petrobras Qualification Test Site

COURTESY OF CURTISS-WRIGHT & LEISTRITZ

Fig. 8: SBMS-500 Motor/Pump Module

COURTESY OF CURTISS-WRIGHT & LEISTRITZ

Fig. 9: Petrobras's SMBS-500 Subsea Multiphase Pump on Flowline Base



COURTESY OF CURTISS-WRIGHT & LEISTRITZ

SUBSEA BOOSTING METHODS USING ESPs

Fig. 1: Horizontal ESP Boosting Station

COURTESY OF TECHRIP

Fig. 2: ESP in Caisson Boosting System

COURTESY OF BAKER HUGHES CENTRILIFT

Fig. 3: ESP Jumper Boosting System

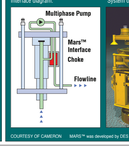
COURTESY OF BAKER HUGHES CENTRILIFT

Fig. 4: ESP in Flowline Riser

COURTESY OF BAKER HUGHES CENTRILIFT

SUBSEA PROCESSING ENABLER – MARS™ (Multiple Application Re-injection System)

Fig. 1: MARS™ Subsea Tree Interface diagram



COURTESY OF CAMERON

Fig. 2: Cameron's MARS™ System on SS Tree

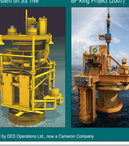


Fig. 3: MARS™ First Application: BP King Project (2007)

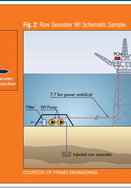
MARS™ was developed by DES Operations Ltd., now a Cameron Company

SS WATER INJECTION SYSTEMS

Fig. 1: Raw Seawater WI Schematic

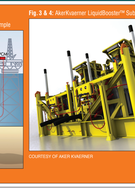
COURTESY OF AKER KVÆRNER

Fig. 2: Raw Seawater WI Schematic Sample



COURTESY OF FRAMO ENGINEERING

Fig. 3 & 4: AkerKvaerner LiquidBooster™ Subsea Raw Seawater Injection System (Photo: StatoilHydro Tyrihans SS Raw Seawater Injection (SRSWI) System)



COURTESY OF AKER KVÆRNER

COURTESY OF AKER KVÆRNER

Fig. 5: Framo Raw Seawater Injection System (Columba E Project).

COURTESY OF FRAMO ENGINEERING

Fig. 6: Well Processing SWIT System As A Template.

COURTESY OF WELL PROCESSING

Fig. 7: Well Processing's new Sea Water Injection and Treatment System (SWIT) now in development in Norway.

COURTESY OF WELL PROCESSING

TABLE 2 – METHODS/CONFIGURATIONS

	METHOD/CONFIGURATION	TECHNOLOGY STATUS: CONCEPTUAL	QUALIFIED	INSTALLED OR SANCTIONED	SAMPLE PROJECTS Where systems have progressed the furthest
	SUBSEA COMPRESSION METHODS/CONFIGURATIONS				
1	Centrifugal (AKS, Siemens/FMC)		Q		Ormen Lange, Asgard
2	Contra-Rotating Axial (Framo WGC)		Q		
3	Twin-Screw Multiphase Pump	C			
	WELL PRODUCTION FLOW BOOSTING METHODS/CONFIGURATIONS				
1	MPP Per Well			Q	Ceiba C3 & C4, King
2	MPP at SS Manifold			Q	Ceiba
3	MPPs Incorporated within SS Manifold			I	Brenda, Exeter + Multineer
4	MPP at Flowline Inlet			I	Ceiba, Shiehallion, Vincent, Azurite
5	MPP at Riser Base		Q		
6	ESP Downhole in SS Well			Q	Otter, Gannet, Lihua
7	ESP Downhole + MPP			Q	Multineer/Exeter
8	ESP Downhole + Caisson ESP			Q	Jubarte
9	ESP Downhole + ESP Horiz. Boost Station		Q		
10	ESP Vertical Boost Station (Caisson ESP)		Q		Golfinho
11	ESP Horizontal Seafloor Boost Station		Q		Cascade/Chinook
12	ESP in Flowline Riser			Q	Navajo
13	ESP in Flowline Jumper (Note 1)	C			
	SUBSEA WATER INJECTION METHODS/CONFIGURATIONS				
1	Produced WI System (with SS Separation)			Q	Troll C Pilot
2	Raw Sea Water SS Injection System			I	Colombia E
	SUBSEA SEPARATION METHODS/CONFIGURATIONS				
1	In-line Supersonic - Twister Technology		Q		Canapu Field
2	ESP Downhole Oil/Water Separation		Q		
3	ESP Downhole Gas/Liquid Separation		Q		
4	ESP Caisson Separation			Q	Marimba (VASPS)
5	2-Phase - Gas/Liquid			Q	Pazflor
6	2-Phase - Water/Oil with Water Reinjection			Q	Troll C Pilot
7	3-Phase - Gas, then Oil/Water			I	Tordis

GRAPH 9 – Subsea Pumping Operation Experience by Project

COURTESY OF FRAMO ENGINEERING

TABLE 1 – WORLDWIDE SURVEY OF SUBSEA GAS COMPRESSION, BOOSTING, WATER INJECTION, AND SEPARATION (1)

PROCESSING DISCIPLINE	COUNT	FIELD OR PROJECT	STATUS	COMMENTS	YEAR	OWNER/ FIELD OPERATOR	REGION	WATER DEPTH		TIEBACK DISTANCE		SYSTEM LIQUID THROUGHPUT		DIFFERENTIAL PRESSURE		POWER	GAS VOLUME FRACTION	SYSTEM PACKAGER	NO. OF PUMPS	PUMP TYPE	PUMP MANUFACTURER
					Yr. (11)	COMPANY		Meters	Feet	Km	Miles	M3/Hr.	MBOPD MBWPD	BAR (3)	PSI (3)	MW (2)	% OF VOL.	COMPANY	PUMPS	TYPE	COMPANY
SUBSEA GAS COMPRESSION	1	**DEMO 2000**	Q	Statoil K-Lab Test	2001	Statoil	Norway									3.60		Framo Engineering			Framo
	2	**Ormen Lange (4)**	Q		2011	Hydro	Norway	850	2,789	120	193	520	79	60	870	60		Aker Kvaerner	4		Aker Kvaerner/GE
	3	**Asgard**	Q		2012	StatoilHydro	Norway	250	820	53	85					16		TBA	2		TBA
	4	**Troll**	C		2016	StatoilHydro	Norway	340	1,116	4	6							TBA			TBA
	5	**Shtokman**	C		2020	Gazprom	Barents Sea	350	1,148	565	909					240		TBA			TBA
	6	**Snohvit**	C		2020	Statoil	Barents Sea	345	1,132	143	230					60		TBA			TBA
FULL WELLSTREAM SUBSEA BOOSTING	1	★ **Prezioso (20)**	I	MPP @ Base of Platform	1994	AGIP	Italy	50	164	0	0	65	10	40	580	0.15	30-90%	Nuovo Pignone (8)	1	Twin-Screw	GE Oil & Gas
	2	**Draugen Field**	I	SMUBS Project	1994	A/S Norske Shell	Norway	270	886	6	3.7	193	29	53	773	0.75	42%	Framo Engineering	1	Helico-Axial	Framo
	3	**Gela Field**	I		1994	AGIP															
	4	★ **Lufeng 22/1 Field (9)(19)**	Q	Tieback to FPSO	1998	StatoilHydro	South China Sea	330	1,083	1	0.6	860	130	35	508	0.40	3%	FMC Technologies	5+2 Spare	Centrifugal (1P)	Framo
	5	**Machar Field (ETAP Project)**	I		1999	BP Amoco	North Sea	85	277	35.2	21.9	555	84	22	319	0.90	64%	Framo Engineering	2+1 Spare	Helico-Axial	Framo
	6	**Topacio Field**	Q	Tieback to Zafiro FPSO	2000	ExxonMobil	Equatorial Guinea	500	1,641	9	5.6	470	71	35	508	0.86	75%		2+1 Spare	Helico-Axial	Framo
	7	**Ceiba C3 and C4**	Q		2002	Triton E.G.	Equatorial Guinea	750	2,461	7.5	4.7	450	68	45	653	0.84	50%	Framo Engineering	2+1 Spare	Helico-Axial	Framo
	8	**Ceiba Field (FFD)**	Q	Full Field Development	2003	Triton E.G.	Equatorial Guinea	700	2,297	7.5	4.7	1,800	272	40	580	0.85	75%	Framo Engineering	4+1 Spare	Helico-Axial	Framo
	9	**Mutineer/Exeter**	Q	Well ESPs+MPP on seafloor	2004	Santos	W. Australia	140	459	7	4.3	600	91	30	435	1.10	0-40%	Framo Engineering	2+1 Spare	Helico-Axial	(16)
	10	**Brenda Field**	Q	For Framo MultiManifold	2005	OILEXCO N.S.	North Sea	145	476	8.5	5.3	750	113	35	508	1.10	40-65%	Framo Engineering	1+1 Spare	Helico-Axial	Framo
	11	**Lyell**	Q	SS Tieback to Ninian South	2005	CNR	North Sea	140	459	11	6.8	200	30	20	290	1.10	0-90%	Aker Kvaerner	1	Twin-Screw	Bornemann
	12	**Jubarte Field**	Q	Uses BCSS (14)	2007	Petrobras	Espirito Santo Basin	1,350	4,429	4	2.5	146	22	138	2,002	1.10	10-40%	FMC Technologies	4	ESP	BH Centrilift
	13	**Schiehallion**	I	2 Systems	2006	BP	West of Shetlands	400	1,312	3	1.9	2x1,350	2x204	26	377	1.80	74%	Framo Engineering	4	Helico-Axial	Framo
	14	★ **King (7)**	Q	SS Tieback to Marlin TLP	2007	BP	GOM, MC Blks	1,700	5,578	29	18	550	83	50	725	1.00	0-95%	Aker Kvaerner	2+1 Spare	Twin-Screw	Bornemann
	15	**Nicol Field**	I		2007	OILEXCO N.S.	North Sea	145	476	18.5	11.5	338	51					Framo Engineering	1	Helico-Axial	Framo
	16	**Navajo Field (17)**	Q	ESP in Flowline Riser	2007	Anadarko	GOM	1,169	3,834	6.7	4.2	24	4	40	583	0.75	57%	Centilift	1	ESP	BH Centrilift
	17	**Vincent**	I		2008	Woodside	W. Australia	475	1,558	3	1.9	1,250	189	42	609	1.80	25-70%	Framo Engineering	2+2 Spare	Helico-Axial	Framo
	18	**Marlim**	Q	SBMS-500 SS Field Test	2008	Petrobras	Campos Basin	640	2,100	3.1	1.9	500	75	60	870	1.20	0-100%	Curtiss-Wright/Kvaerner	1	Twin-Screw	Leistritz
	19	**Brenda #2**	Q		2008	OILEXCO N.S.	North Sea	145	476	8.5	5.3	750	113	35	508	1.10	40-65%	Framo Engineering	1	Helico-Axial	Framo
	20	**Argonauta (BC-10)**	Q	Caisson /Artificial Lift Manifold	2009	Shell	Brazil	1,900	6,234	9	5.6	64	9.7	165	2,393	1.10	30%	FMC Technologies	2	ESP	BH Centrilift
	21	**Golfinho Field**	Q	ESP in Caisson (BCSS)	2009	Petrobras	Espirito Santo Basin	1,350	4,429			146	22	138	2,002	1.10	10-40%	FMC Technologies	4	ESP	
	22	**Azurite Field**	Q		2009	Murphy Oil	Congo, W. Africa	1,338	4,390					40	580	1.20		Framo Engineering	2+1 Spare	Helico-Axial	Framo
	23	**Cascade**	Q	Horizontal ESP on Skid	2009	Petrobras	GOM	2,484	8,150	8	5	135	20	163	2,357	1.50	20%	FMC Technologies	4	ESP	BH Centrilift
	24	**Chinook**	Q	Horizontal ESP on Skid	2009	Petrobras	GOM	2,682	8,800	19.3	12	135	20	160	2,326	1.80	0%	FMC Technologies	4	ESP	BH Centrilift
	25	**Espadarte**	Q	Horizontal ESP on Skid	2009	Petrobras	Brazil	1,400	4,593			83	13	120	1,740	0.90	10-40%		1	ESP	
	26	**Jubarte Field**	Q	Phase 2 - Uses BCSS (14)	2010	Petrobras	Espirito Santo Basin	1,193	3,914			145	22				30-40%	Aker Kvaerner	8	ESP	
SUBSEA WATER INJECTION	1	★ **Troll C Pilot (15)**	Q	SUBSIS (SS Sep.& WI Sys.)	2000	NorskHydro AS	Norway	340	1,116	4	2.5	250	38	151	2,190	1.60		ABB/Framo	1+1 Spare	Helico-Axial	Framo
	2	★ **Tordis Field (13)**	I	SS Sep. + MPP + WI	2007	StatoilHydro	North Sea	200	656	11	6.8	650	98	100	1,450	2.30		FMC Technologies	(12)	Helico-Axial	Framo/FMC
	3	**Columba E.**	I	SS Water Injection	2007	CNR	North Sea	145	476			331	50	305	4,424	2.30		Framo Engineering	2	Centrifugal	Framo
	4	**Albacora Leste Field**	Q	Raw Water Injection	2009	Petrobras	Brazil	1,240	4,068			375	57	80	1,160	.5-1.2		Framo Engineering	3+1 Spare	Helico-Axial	Framo
	5	**Tyrihans**	Q	SS Raw Sea WI System	2009	StatoilHydro	Norway	300	984	31	19.3	710	107	190	2,756	2.50		Aker Kvaerner	2+1 Spare	Centrifugal	Aker Kvaerner
SUBSEA SEPARATION	1	**SPS Project**	Q		1968	Exxon	GOM	610	2,001			80	12								
	2	**Zakum**	I		1970	BP	Abu Dhabi	22	72	0	0										
	3	**Argyll**	I		1989	BOET (6)	North Sea	75	246												
	4	★ **Troll C Pilot (15)**	Q	SUBSIS (SS Sep.& WI Sys.)	2000	NorskHydro AS	Norway	340	1,116	4	2.5	250	38	15-25	218-363	1.60		ABB/Framo	1+1 Spare	Helico-Axial	Framo
	5	**Marimba Field**	Q	VASPS Field Test	2000	Petrobras	Campos Basin	395	1,296	1.1	0.7	46	7	10	145	0.08		Cameron	1	ESP	Reda
	6	★ **Tordis Field (13)**	I	SS Sep. + MPP + WI	2007	StatoilHydro	North Sea	200	656	11	6.8	596	120	16	232	2.30		FMC Technologies	(12)	Helico-Axial	Framo/FMC
	7	**Perdido**	Q	Caisson Sep. & Boosting	2010	Shell	GOM	2,438	7,999				20-40	159	2,303	1.00	15%	FMC Technologies	5	ESP	BH Centrilift
	8	**Ostra/Abalone (BC 10)**	Q	Caisson/Artificial Lift Manifold	2010	Shell	Brazil	1,900	6,234	9	6	185	28	152	2,205	1.10	5%	FMC Technologies	4	ESP	BH Centrilift
	9	**Pazflor (5)**	Q	Gas/Liq. Sep.	2011	Total	Angola, Blk 17	800	2,625	4	3			100	1,450	2.30	<16%	FMC Technologies	6+2 Spare		
	10	**Canapu Field**	Q	Twister Separation Technology		Petrobras	Espirito Santo Basin	1,700	5,578	21	13.1							TwisterBV	none		

LEGEND ("Stop Light")
- C – Conceptual Project
- Q – Qualified/Testing
- I – Installed & Currently Operating
- ★ – Indicates a World Record

NOTES:
1. See information accuracy statement below title block.
2. Power for gas compression is for the entire compression station. All other power listed is for an individual pump motor.
3. DP values are for individual pumps.
4. Ormen Lange is pumping low volumes of condensate
5. According to Total the Pazflor development will utilize seabed gas/liquid separation next to the production well, which will be the world's first application of this approach.
6. British Offshore Engineering Technology
7. King project utilizes the world's first umbilical to combine with HV cables with the service umbilical.
8. Nuovo Pignone is now part