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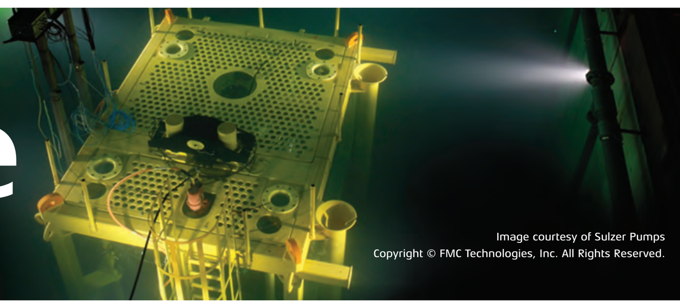

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2013 WORLDWIDE SURVEY OF SUBSEA PROCESSING: SEPARATION, COMPRESSION, AND PUMPING SYSTEMS

STATUS OF THE TECHNOLOGY

MARCH 2013

Prepared By: Mac McKee, Larry Forster, Richard Voight, Spiridon Ionescu, John Allen, Thiago Mesquita Paes, and RJ Baker of INTECSEA, E. Kurt Albaugh of Repsol E & P USA, Peter Batho of Chevron Energy Technology Company, and David Davis of Offshore Magazine

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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, or 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 INTECSEA nor *Offshore Magazine* guarantees or 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@intecsea.com.

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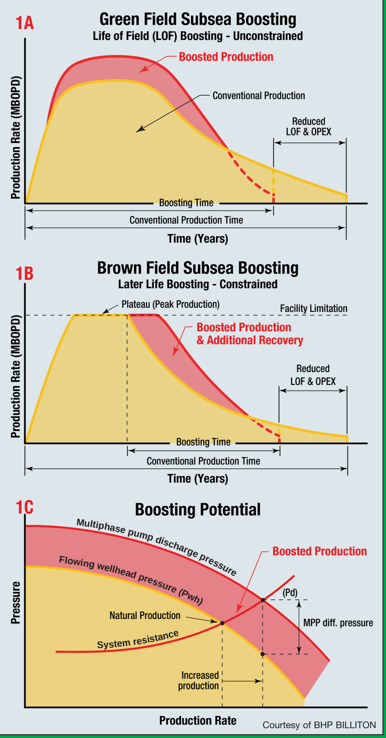
GRAPHS 1A, 1B, 1C – SUBSEA BOOSTING POTENTIAL



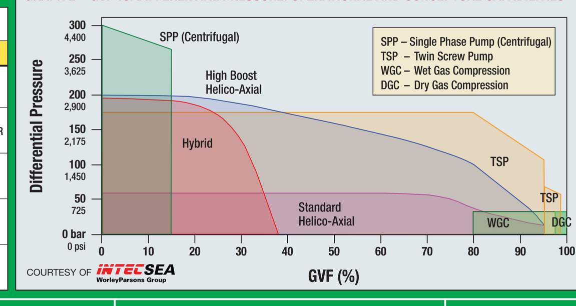
Courtesy of BHP BILLITON

SUBSEA BOOSTING PUMP TYPES

TABLE 2 – PUMP TYPES & APPLICATIONS

	TYPE	NORMAL CONFIG.	APPLICABILITY FOR SUBSEA BOOSTING
1	CENTRIFUGAL	HORIZONTAL OR VERTICAL	● Highest differential pressure capability among pump types. ● Handles low Gas Volume Fraction (GVF) < 15% at suction conditions.
2	HYBRID (CENTRIFUGAL & HELICO-AXIAL)	VERTICAL	● Combination of helico-axial and centrifugal impeller stages. ● Primary application is for use downstream of separator or in low GOR applications where GVF is consistently < 30% at suction conditions.
3	ESP	HORIZONTAL OR VERTICAL	● Widely deployed technology used for boosting in wells, caissons, flowline risers, and mudline horizontal boosting applications. ● Applicable for GVF < 50%.
4	HELICO-AXIAL	VERTICAL	● Applicable for higher GVF boosting applications – typical range of 30-95% GVF at suction conditions. ● Moderate particulate tolerance.
5	TWIN SCREW	HORIZONTAL OR VERTICAL	● Good for handling high GVF – up to 98% GVF at suction conditions. ● Preferred technology for high viscosity fluids.

GRAPH 2 – GVF vs. DIFFERENTIAL PRESSURE: OPERATIONAL AND CONCEPTUAL CAPABILITIES



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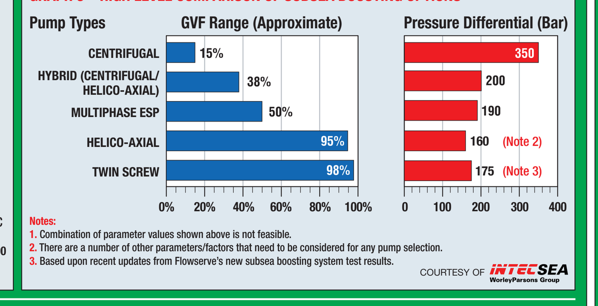
GRAPH 3 – HIGH LEVEL COMPARISON OF SUBSEA BOOSTING OPTIONS



Notes:
1. Combination of parameter values shown above is not feasible.
2. There are a number of other parameters/factors that need to be considered for any pump selection.
3. Based upon recent updates from Flowserve's new subsea boosting system test results.

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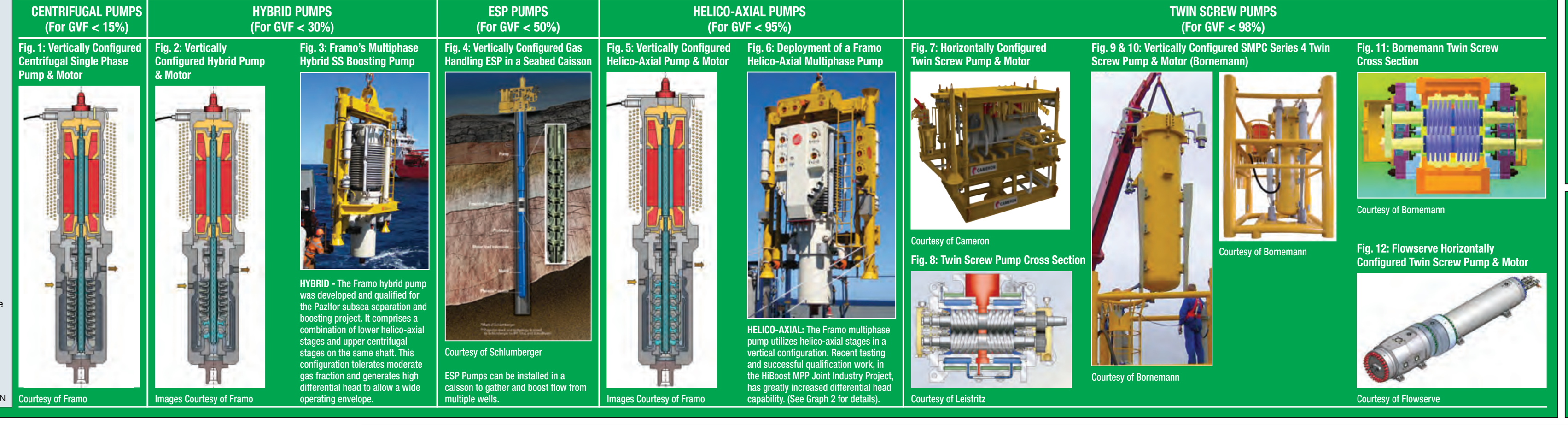


CENTRIFUGAL PUMPS (For GVF < 15%) — Fig. 1: Vertically Configured Centrifugal Single Phase Pump & Motor. Courtesy of Framo

HYBRID PUMPS (For GVF < 30%) — Fig. 2: Vertically Configured Hybrid Pump & Motor. Fig. 3: Framo's Multiphase Hybrid SS Boosting Pump. Images Courtesy of Framo

HYBRID - The Framo hybrid pump was developed and qualified for the Pazflor subsea separation and boosting project. It comprises a combination of lower helico-axial stages and upper centrifugal stages on the same shaft. This configuration tolerates moderate gas fraction and generates high differential head to allow a wide operating envelope.

ESP PUMPS (For GVF < 50%) — Fig. 4: Vertically Configured Gas Handling ESP in a Seabed Caisson. Courtesy of Schlumberger

ESP Pumps can be installed in a caisson to gather and boost flow from multiple wells.

HELICO-AXIAL PUMPS (For GVF < 95%) — Fig. 5: Vertically Configured Helico-Axial Pump & Motor. Fig. 6: Deployment of a Framo Helico-Axial Multiphase Pump. Images Courtesy of Framo

HELICO-AXIAL: The Framo multiphase pump utilizes helico-axial stages in a vertical configuration. Recent testing and successful qualification work, in the HiBoost MPP Joint Industry Project, has greatly increased differential head capability. (See Graph 2 for details).

TWIN SCREW PUMPS (For GVF < 98%) — Fig. 7: Horizontally Configured Twin Screw Pump & Motor. Courtesy of Cameron. Fig. 8: Twin Screw Pump Cross Section. Courtesy of Leistritz. Fig. 9 & 10: Vertically Configured SMPC Series 4 Twin Screw Pump & Motor (Bornemann). Courtesy of Bornemann. Fig. 11: Bornemann Twin Screw Cross Section. Courtesy of Bornemann. Fig. 12: Flowserve Horizontally Configured Twin Screw Pump & Motor. Courtesy of Flowserve

SUBSEA MULTIPHASE BOOSTING SYSTEMS BY COMPANY (Delivered & Conceptual)

Fig. 1: Aker Solutions MultiBooster™ System (BP King). Courtesy of Aker Solutions
Fig. 2: Aker Solutions MultiBooster™ System. Courtesy of Aker Solutions
Fig. 3: FMC/Flowserve SS Multiphase Pumping System with 2 retrievable pump modules. Courtesy of FMC Technologies
Fig. 4: Framo - Loadout of 1 of 6, 2.3 MW Hybrid Pumps for Pazflor Project. Courtesy of Framo
Fig. 5: Framo SS Multimanifold with Boosting and Metering. One of two systems delivered to OILEXCO (now Premier Oil). Courtesy of Framo
Fig. 6: FMC Technologies SS Multiphase Pumping Module with Sulzer Pump. Courtesy of Sulzer
Fig. 7: SBMS-500 Motor/Pump Module Installation for Petrobras' Marlim Field. Courtesy of Curtis-Wright & Leistritz
Fig. 8: SBMS-500 Motor/Pump Module on Seafloor Hooked-Up. Courtesy of Curtis-Wright & Leistritz
Fig. 9: Cameron's CAMFORCE™ Subsea Boosting System. Courtesy of Cameron
Fig. 10: GE Oil & Gas Boosting Station. Courtesy of Vetcogray (GE Oil & Gas)
Fig. 11: Framo – Loadout of two (2) Schiehallion SS Boosting Stations, Power and Control Module, and two (2) Manifolds (mid-2006). Courtesy of Framo

SUBSEA BOOSTING METHODS USINGS ESPs

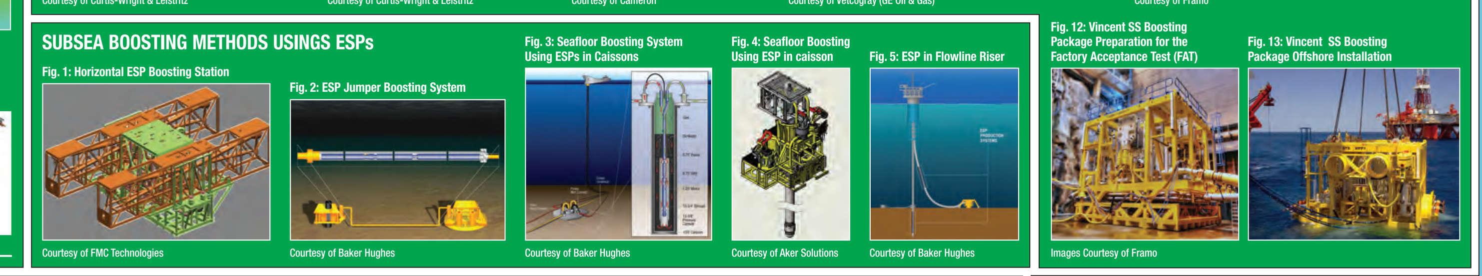


Fig. 1: Horizontal ESP Boosting Station. Courtesy of FMC Technologies
Fig. 2: ESP Jumper Boosting System. Courtesy of Baker Hughes
Fig. 3: Seafloor Boosting System Using ESPs in Caissons. Courtesy of Baker Hughes
Fig. 4: Seafloor Boosting Using ESP in caisson. Courtesy of Aker Solutions
Fig. 5: ESP in Flowline Riser. Courtesy of Baker Hughes
Fig. 12: Vincent SS Boosting Package Preparation for the Factory Acceptance Test (FAT)
Fig. 13: Vincent SS Boosting Package Offshore Installation
Images Courtesy of Framo

SUBSEA SEAWATER INJECTION AND TREATMENT

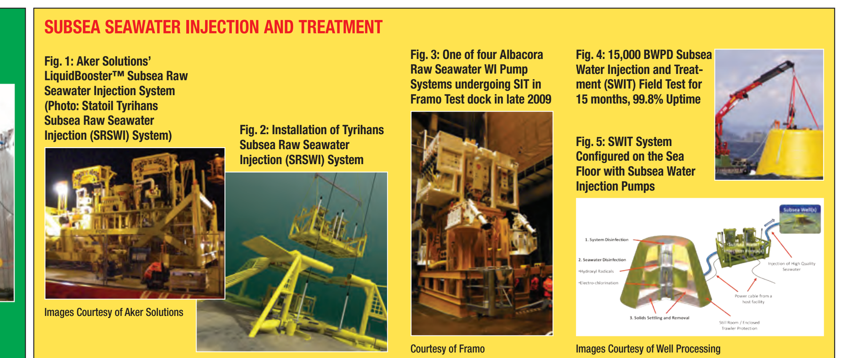


Fig. 1: Aker Solutions' LiquidBooster™ Subsea Raw Seawater Injection System (Photo: Statoil Tyrihans Subsea Raw Seawater Injection (SRSWI) System)
Fig. 2: Installation of Tyrihans Subsea Raw Seawater Injection (SRSWI) System
Images Courtesy of Aker Solutions
Fig. 3: One of four Albacora Raw Seawater WI Pump Systems undergoing SIT in Framo Test dock in late 2009. Courtesy of Framo
Fig. 4: 15,000 BWPD Subsea Water Injection and Treatment (SWIT) Field Test for 15 months, 99.8% Uptime
Fig. 5: SWIT System Configured on the Sea Floor with Subsea Water Injection Pumps
Images Courtesy of Well Processing

TABLE 3 – SUBSEA PROCESSING SYSTEM CONFIGURATIONS

FIG. NO.	SERVICE	PUMP TYPE & CONFIGURATION	LOCATION: SEABED CAISSON	LOCATION: AT THE MUD LINE	SEPARATION: SEPARATED	SEPARATION: NON-SEPARATED	INTERVENTION: DIRECT VERTICAL (RIG) ACCESS	INTERVENTION: INTERVENTION VESSEL	PROJECT REFERENCE
1	Wellstream Oil Production	Vertical ESP	●			●		●	BC-10/Jubarte
2	Wellstream Oil Production	Vertical ESP	●		●			●	BC-10
3	Wellstream Oil Production	Vertical ESP	●			●	●		NA
4	Wellstream Oil Production	Vertical ESP	●		●		●		Perdido
5	Wellstream Oil Production	Horizontal ESP (Slant)		●		●		●	Espadarte/Cascade-Chinook
6	Wellstream Oil Production	Horizontal ESP (Slant)		●	●			●	Congro-Corvina
7	Wellstream Oil Production	Mud Line Boosting		●		●		●	Ceiba/Lufeng/Lyell/King
8	Wellstream Oil Production	Mud Line Boosting		●	●			●	Pazflor
9	Raw Water Injection	Centrifugal Pump		●	Filtration			●	Columba-E/Tyrihans/Albacora
10	Local Re-injection of Produced Water	Centrifugal Pump		●	●			●	Troll/Tordis/Marlim
11	Wellstream Gas Production	Wet Gas Compressor		●		●		●	Gullfaks
12	Wellstream Gas Production	Dry Gas Compressor		●	●			●	Aasgard

Figures 1–12 are Courtesy of Chevron Energy Technology Company. Legend: Filter, Pump, Separator

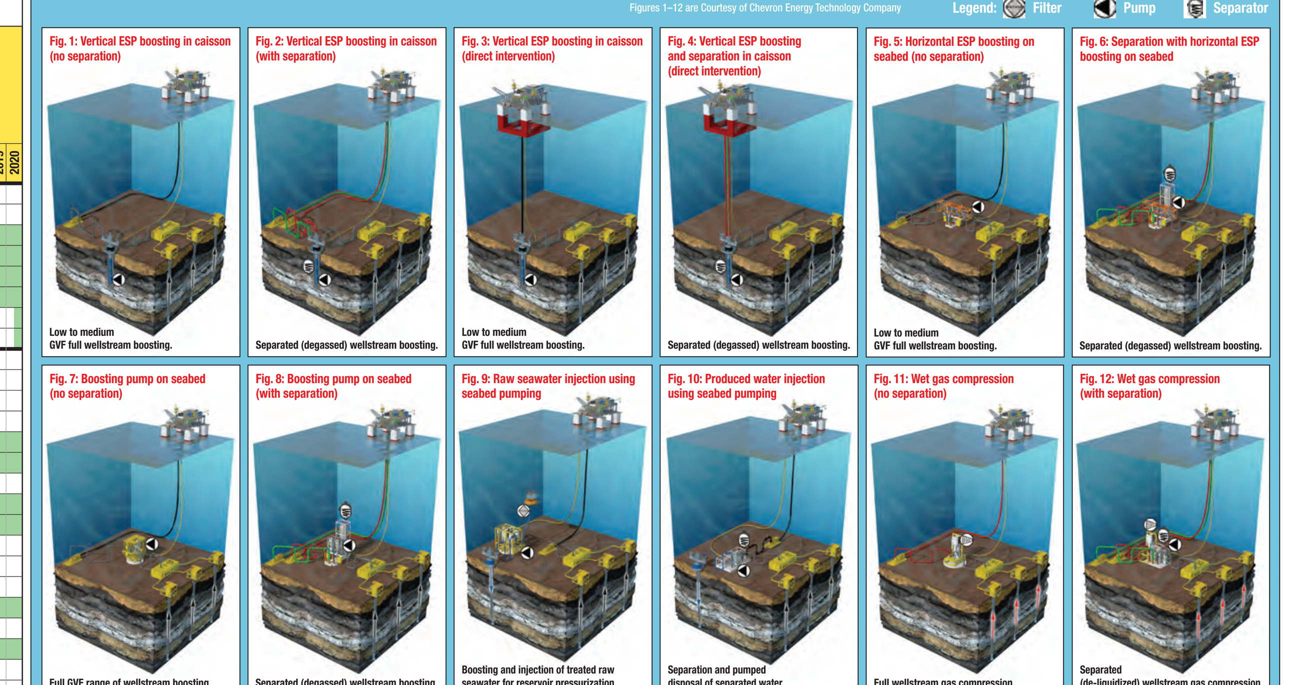
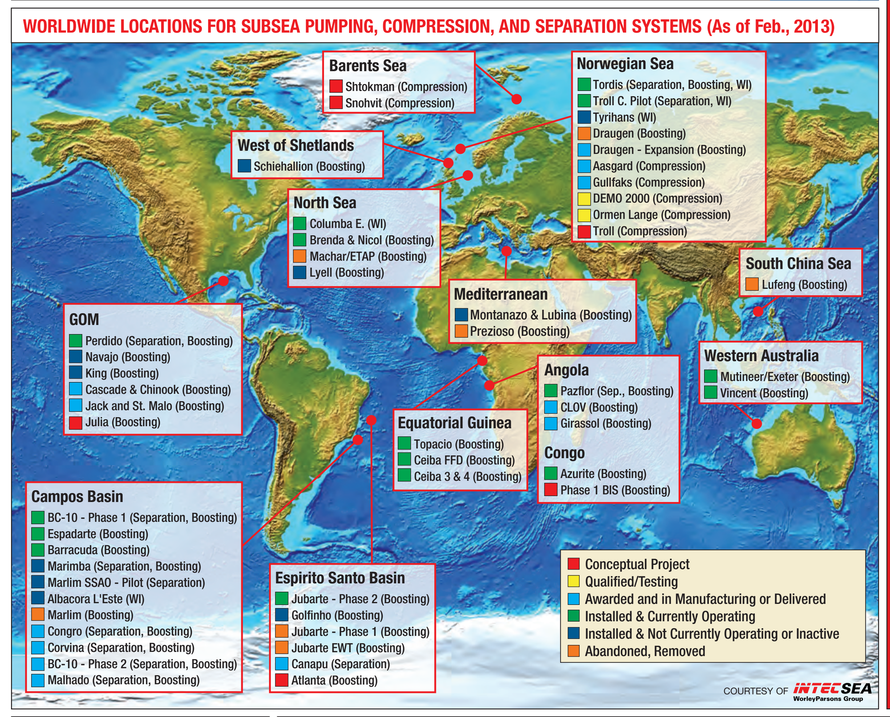


Fig. 1: Vertical ESP boosting in caisson (no separation) — Low to medium GVF full wellstream boosting.
Fig. 2: Vertical ESP boosting in caisson (with separation) — Separated (degassed) wellstream boosting.
Fig. 3: Vertical ESP boosting in caisson (direct intervention) — Low to medium GVF full wellstream boosting.
Fig. 4: Vertical ESP boosting and separation in caisson (direct intervention) — Separated (degassed) wellstream boosting.
Fig. 5: Horizontal ESP boosting on seabed (no separation) — Low to medium GVF full wellstream boosting.
Fig. 6: Separation with horizontal ESP boosting on seabed — Separated (degassed) wellstream boosting.
Fig. 7: Boosting pump on seabed (no separation) — Full GVF range of wellstream boosting.
Fig. 8: Boosting pump on seabed (with separation) — Separated (degassed) wellstream boosting.
Fig. 9: Raw seawater injection using seabed pumping — Boosting and injection of treated raw seawater for reservoir pressurization.
Fig. 10: Produced water injection using seabed pumping — Separation and pumped disposal of separated water.
Fig. 11: Wet gas compression (no separation) — Full wellstream gas compression.
Fig. 12: Wet gas compression (with separation) — Separated (de-liquidized) wellstream gas compression.

WORLDWIDE LOCATIONS FOR SUBSEA PUMPING, COMPRESSION, AND SEPARATION SYSTEMS (As of Feb., 2013)



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SS GAS COMPRESSION SYSTEMS & PRODUCTS BY COMPANY

Fig. 1: Aker Solutions Site Integration Testing (SIT) of Ormen Lange Compression Pilot. Courtesy of Aker Solutions
Fig. 2: Wet Gas Compressor Station for Gullfaks. Courtesy of Framo
Fig. 3: FMC Technologies SS Gas Compression Station. Courtesy of FMC Technologies
Fig. 4: MAN Turbo & Diesel's Aasgard Subsea Compressor. Courtesy of MAN Turbo & Diesel
Fig. 5: Aasgard Subsea Compression Station. Courtesy of Aker Solutions
Fig. 6: Framo Counter-rotating 5 MW Wet Gas Compressor built for Gullfaks qualification tests. Courtesy of Framo
Fig. 7: Kvaerner Booster Station (KBS) for SS Gas Compression. Courtesy of GE Oil & Gas

TABLE 1 – 2013 WORLDWIDE SURVEY OF SUBSEA GAS COMPRESSION, BOOSTING, WATER INJECTION, AND SEPARATION (1)(2) – As of Feb. 2013

PROCESSING DISCIPLINE	COUNT	FIELD OR PROJECT (Ordered by Start Date)	CURRENT STATUS	COMMENTS	OWNER/FIELD OPERATOR (COMPANY)	REGION/BASINS	WATER DEPTH (Meters)	WATER DEPTH (Feet)	TIEBACK DISTANCE (Km)	TIEBACK DISTANCE (Miles)	SYSTEM FLOW RATE (@LINE CONDITIONS) ($M^3/Hr.$)	SYSTEM FLOW RATE (MBOPD MBWPD)	DIFFERENTIAL PRESSURE (BAR (4))	DIFFERENTIAL PRESSURE (PSI (4))	UNIT MOTOR POWER (3) (MW)	GVF (GAS VOLUME FRACTION) (5) (% OF VOL.)	SYSTEM PACKAGER (COMPANY)	NO. OF PUMPS UNITS (PUMPS or COMPR.)	PUMP TYPE or COMPR. TYPE	COMPRESSOR/PUMP MANUFACTURER (COMPANY)	START (11) (Month-Year)	END or PRESENT	MTHS	OPERATIONAL HISTORY & FUTURE OPERATIONAL SCHEDULE
SUBSEA GAS COMPRESSION	1	DEMO 2000	Q	Statoil K-Lab Test	Statoil	Offshore Norway									3.60	n/a	Framo Engineering		Counter Axial	Framo Engineering	2001			Test Program Completed 2004
	2	Ormen Lange Gas Compression Pilot	Q	Subsea Gas Compression	Statoil	Offshore Norway	860	2,821	120.0	75.0	25,000	3776	60.0	870	12.50	n/a	Aker Solutions	1	Centrifugal	GE Compr/Aker Pump	2011			
	3	Aasgard - Midgard & Mikkel Fields	M	Subsea Gas Compression	Statoil	Offshore Norway	300	984	50.0	31.3	40,000	6,042	60.0	870	11.50	n/a	Aker Solutions	2+1 Spare +1	Centrifugal	MAN/Aker pumps	2014			
	4	Gullfaks South Brent (28)	M	Wet Gas Compression	Statoil	Offshore Norway	150	492	15.5	9.7	9,600	1450	30.0	435	5.00	95%	Framo Engineering	2+1 Spare	Counter Axial	Framo Engineering	2015			Qualification Testing to Complete Q2 2011
	5	Troll	C		Statoil	Offshore Norway	340	1,116	4.0	2.5						n/a	TBA		Undecided	TBA	2016			
	6	Shtokman	C		Gazprom	Barents Sea	350	1,148	565.0	353.1					240.00	n/a	TBA		Centrifugal	TBA	2016			
	7	Ormen Lange Gas Compression	Q	Subsea Gas Compression	Shell	Offshore Norway	860	2,821	120.0	75.0	50,000	7553	60.0	870	12.50	n/a	TBA	2	Centrifugal	TBA	2020			
	8	Snohvit	C		Statoil	Barents Sea	345	1,132	143.0	89.4					60.00	n/a	TBA		Centrifugal	TBA	2020			
FULL WELLSTREAM SUBSEA BOOSTING (NOTE 1. SEABED & RISER ONLY, NOTE 2. EXCLUDES DOWNHOLE ESPs)	1	Prezioso (20)	A	MPP at Base of Platform	AGIP	Italy	50	164	0.0	0.0	65	10	40.0	580	0.15	30-90%	Nuovo Pignone (8)	1	Twin-Screw	GE	1994	1995		
	2	Draugen Field	A	SMUBS Project, 1MPP	A/S Norske Shell	Offshore Norway	270	886	6.0	3.7	193	29	53.3	773	0.75	42%	Framo Engineering	1	Helico-Axial	Framo Engineering	Nov-95	15-Nov-96	12.2	
	3	Lufeng 22/1 Field (9) (19)	A	Tieback to FPSO	Statoil	South China Sea	330	1,083	1.0	0.6	675	102	35.0	508	0.40	3%	Framo Eng./FMC Tech.	5+2 Spare	Centrifugal (1P)	Framo Engineering	Jan-98	15-Jul-09	138.0	See OTC Paper 20619, page 7
	4	Machar Field (ETAP Project)	A	Hydraulic Turbine Drive	BP Amoco	UK North Sea	85	277	35.2	21.9	1,100	166	22.0	319	0.65	64%	Framo Engineering	2+1 Spare	Helico-Axial	Framo Engineering	1999	Never Installed		
	5	Topacio Field	O	1 x Dual MPP System	ExxonMobil	Equatorial Guinea	500	1,641	9.0	5.6	940	142	35.0	508	0.86	75%	Framo Engineering	2+1 Spare	Helico-Axial	Framo Engineering	Aug-00	1-Mar-13	150.2	
	6	Ceiba C3 and C4	O	Phase 1 SS MPP Project	Hess	Equatorial Guinea	750	2,461	7.5	4.7	600	91	45.0	653	0.84	75%	Framo Engineering	2+1 Spare	Helico-Axial	Framo Engineering	Oct-02	1-Mar-13	124.3	
	7	Jubarte EWT	A	Riser lift to Seillean drillship	Petrobras	Espirito Santo Basin	1,400	4,593	1.4	0.9	145.0	22	140.0	2,000	0.70	22%	FMC Technologies	1	ESP	Schlumberger (REDA)	Dec-02	1-Dec-06	47.9	
	8	Ceiba Field (FFD)	O	Full Field Development (FFD)	Hess	Equatorial Guinea	700	2,297	7.5	4.7	2,500	378	45.0	580	1.20	75%	Framo Engineering	5	Helico-Axial	Framo Engineering	Dec-03	1-Mar-13	110.3	
	9	Mutineer / Exeter	O	2 x Single MPP Systems	Santos	NW Shelf, Australia	145	476	7.0	4.3	1,200	181	30.0	435	1.10	0-40%	Framo Engineering	7 SS ESP, 2 MPP	Helico-Axial	Framo Engineering (16)	Mar-05	1-Mar-13	95.3	
	10	Lyell (Original Install)	A	SS Tieback to Ninian South	CNR	UK North Sea	146	479	15.0	9.3	1,100	166	18.0	261	1.60	40-70%	Aker Solutions	1	Twin Screw	Bornemann SMPC 9	Jan-06	Dec-06	11.0	Non Operational
	11	Navajo (17)	I, N	ESP in Flowline Riser	Anadarko	GOM	1,110	3,642	7.2	4.5	24	4	40.2	583	0.75	57%	Baker Hughes	1	ESP	Baker Hughes	Feb-07	1-Aug-07	5.5	Non Operational
	12	Jubarte Field - Phase 1	A	Seabed ESP-MOBO, Uses BCSS (14)	Petrobras	Espirito Santo Basin	1,350	4,429	4.0	2.5	120	18	138.0	2,002	0.90	10-40%	FMC Technologies	1	ESP	Schlumberger (REDA)	Mar-07	Aug-07	5.0	
	13	Brenda & Nicol Fields	O	MultiManifold with 1 MPP	Premier Oil	UK North Sea	145	476	8.5	5.3	800	121	19.0	276	1.10	75%	Framo Engineering	1+1 Spare	Helico-Axial	Framo Engineering	Apr-07	1-Mar-13	58.4	
	14	King (7) (13)	A	SS Tieback to Marlin TLP	Plains E & P	GOM, MC Blocks	1,700	5,578	29.0	18.0	497	75	50.0	725	1.30	0-95%	Aker Solutions	2+1 Spare	Twin-Screw	Bornemann/Loher	Nov-07	15-Feb-09	15.0	Non Operational
	15	Vincent	O	Dual MPP System	Woodside	NW Shelf, Australia	470	1,542	3.0	1.9	2,700	408	28.0	406	1.80	25-80%	Framo Engineering	2+2 Spare	Helico-Axial	Framo Engineering	Aug-10	1-Mar-13	19.0	
	16	Marlim	A	SBMS-500 SS Field Test	Petrobras	Campos Basin	1,900	6,234	3.1	1.9	500	75	60.0	870	1.20	0-100%	Curtiss-Wright/Cameron	1	Twin-Screw	Leistritz	Q1 2011		0.0	Non Operational
	17	Golfinho Field	I, N	Seabed ESP-MOBO, Uses BCSS (14)	Petrobras	Espirito Santo Basin	1,350	4,429			146	22	138.0	2,002	1.10	10-40%	FMC Technologies	4	ESP	Baker Hughes	Aug-09		0.0	Non-operational due to poor well performance (excessive water)
	18	Azurite Field	O	Dual MPP System	Murphy Oil	Congo, W. Africa	1,338	4,390	3.0	1.9	920	139	42.0	609	1.00	28%	Framo Engineering	2+1 Spare	Helico-Axial	Framo Engineering	Sep-10	1-Mar-13	29.4	
	19	Golfinho Field	I, N	Four BCSS Caissons (14)	Petrobras	Espirito Santo Basin	1,350	4,429			146	22	138.0	2,002	1.10	10-40%	Aker Solutions	2	ESP	Baker Hughes	Mar-07	Aug-07	5.0	Not yet operational at press time
	20	Espadarte	O	Horizontal ESP on Skid	Petrobras	Brazil	1,350	4,429	11.5	7.1	125	19	100.0	1,450	0.90	10-40%	FMC Technologies	2	ESP	Baker Hughes	Dec-11	Dec-12	12.0	
	21	Parque Das Conchas (BC 10) Phase 1 (23)	O	Caisson / Artifical Non-Separated	Shell	Campos Basin	2,150	7,054	9.0	5.6	185	28	152	2,205	1.10	30%	FMC Technologies	2	ESP	Baker Hughes	Jul-09	1-Mar-13	43.4	
	22	Jubarte Field - Phase 2 (25)	O	Tieback to FPSO P-57, Uses BCSS (14)	Petrobras	Espirito Santo Basin	1,400	4,593	8.0	5.0	1,325	200	200	3,000	1.20	30-40%	Aker Solutions	15	ESP	Schlumberger (REDA)	Q2 2011		0.0	Installation to be complete by 2011 year end
	23	Cascade & Chinook (6)	O	Skid BCSS - Horizontal ESP on Skid	Petrobras	US GOM	2,484	8,150	8.0	5.0	135	20	220.0	3,191	1.10	20%	FMC Technologies	2+2 Spare	ESP	Baker Hughes	Q4 2013		0.0	Pump installation expected Q4 2013
	24	Barracuda	O	Single MPP System	Petrobras	Campos Basin	1,040	3,412	14.0	8.8	280.0	42	70.0	1,015	1.50	50%	Framo Engineering	1	Helico-Axial	Framo Engineering	Q2 2012	Aug-12	7.0	
	25	Montanazo & Lubina	I, N	Single MPP System	Repsol	Mediterranean	740	2,428	8.0	5.0	80.0	12	45.0	653	0.23	0%	Framo Engineering	2	Centrifugal (1P)	Framo Engineering	2012			Pump Installed Nov., 2012. Deferred start up
	26	Schiehallion	I, N	2 x Dual MPP Systems	BP	UK, West of Shetland	400	1,312	3.0	1.9	2,700	408	26.0	377	1.80	74%	GE/Framo Engineering	4	Helico-Axial	Framo Engineering	2013	Delayed Start Up		Pending FPSO rebuild
	27	CLOV (22)	M	Subsea Boosting	TOTAL	Angola, Blk 17	1,350	4,429	10.0	6.2	660.0	100	45.0	652	2.30	55%	Framo Engineering	2	Helico-Axial	Framo Engineering	Q3 2014			
	28	Jack & St. Malo TQP	M	Full Wellstream subsea Boosting	Chevron	US GOM	2,134	7,000	13.0	21	1191	180	241.3	3,500	3.00	10%	Framo Engineering	3+2 Spare	Centrifugal (1P)	Framo Engineering	Q3 2014			
	29	Lyell Retrofit	I, N	MPP Retrofit System - Tieback to Ninian	CNR	UK North Sea	145	476	7.0	4.3	700	106	21.0	305	1.10	97%	Framo Engineering	1	Helico-Axial	Framo Engineering				Installed, pending start
	30	Girassol (27)	M	Field Expansion Project	Total	Angola, Blk 17	1,350	4,429	18.0	11.2	600	91	130.0	1,885	2.50	53%	Framo Engineering	4	Helico-Axial	Framo Engineering	Q1 2015			
	31	Parque Das Conchas (BC 10) Phase 2 (23)	M	2 additional ESP systems	Shell	Campos Basin	2,150	7,054	9.0	5.6	185	28	152	2,205	1.10	30%	FMC Technologies	2	ESP	Baker Hughes				
	32	Draugen Field	M	Field Expansion Project	Shell	Norway N Sea	250	800	4.0	2.5	1600	242	45.0	653	2.30		Framo Engineering	2	Helico-Axial	Framo Engineering	Q3 2014			
	33	Julia	C	Tieback to Jack & St Malo Host	ExxonMobil	US GOM	2,287	7,500	27.2	17.0							TBD	2	Centrifugal (1P)	TBD	Mid-2016			
	34	Phase 1 bis	C	Brownfield Tieback to Alima FPU	Total	Congo, W. Africa	650	2,133	6.7	4.0							TBD	2	Helico-Axial	TBD	Q4 2015			
	35	Atlanta Field	C	Caisson Application	QGEP (26)	Santos Basin, Blk BS-4	1,500	4,922									TBD		ESP		2015			
SUBSEA WATER INJECTION	1	Troll C Pilot (15)	O	SUBSIS (SS Sep. and WI Sys.)	NorskHydro AS	Norway	340	1,116	3.5	2.2	250	38	150.0	2,176	1.60	0%	GE/Framo Engineering	1+1 Spare	Centrifugal (1P)	Framo Engineering	Aug-01	1-Mar-13	137.9	
	2	Columba E.	O	Dual SPP System	CNR	North Sea	145	476	7.0	4.3	331	50	320.0	4,641	2.30	0%	Framo Engineering	2	Centrifugal (1P)	Framo Engineering	May-07	1-Mar-13	69.4	
	3	Tordis (WI)	O	(12), Separation, Boosting, WI	Statoil	North Sea	210	689	11.0	6.8	700	106	77.0	1,117	2.30	0%	FMC Technologies	1+1 Spare	SPP&MPP	Framo Engineering	Oct-07	May-08	7.0	See OTC paper 20619, page 16
	4	Albacora L'Este Field	I, N	Raw Water Injection	Petrobras	Brazil	400	1,312	4 to 9	2.5-6.0	1,125	170	85.0	1,233	1.2	0%	FMC Technologies	3+1 Spare	Centrifugal (1P)	Framo Engineering	Q2 2013		0.0	1 installation to date, startup Q1 2013
	5	Tyrihans	I, N	SS Raw Sea WI System	Statoil	Norway	270	886	31.0	19.3	583	88	205.0	2,973	2.50	0%	FMC/Aker Solutions	2+1 Spare	Centrifugal (1P)	Aker Solutions	Q2 2013		0.0	Periodically Started - Pending WI Wells
SUBSEA SEPARATION	1	Troll C Pilot (15) (21)	O	Horizontal SUBSIS (SS Sep. & WI Sys.)	Statoil	Offshore Norway	340	1,116	3.5	2.2	n/a	n/a	n/a	n/a	n/a	n/a	GE/Framo Engineering	n/a	n/a	n/a	Aug-01	1-Mar-13	125.9	
	2	Marimba Field (24)	I, N	VASPS Field Test	Petrobras	Campos Basin	395	1,296	1.7	1.1	60	9	52.0	754	0.3		Cameron	1	ESP	Schlumberger (REDA)	Jul-01	1-Jul-08	96.0	Non Operational; Restart undefined
	3	Tordis	O	(12), Separation, Boosting, WI	Statoil	Offshore Norway	210	689	11.0	6.8	1,250	189	27.0	392	2.30	10-68%	FMC Technologies	1+1 Spare	Helico-Axial	Framo Engineering	Oct-07	1-Mar-13	52.4	See OTC paper 20619, page 16
	4	Parque Das Conchas (BC 10) Phase 1 (23)	O	Sep. Caisson/Artifical Lift Manifold	Shell	Campos Basin	2,150	7,054	25.0	15.6	185	28	152.0	2,205	1.10	15%	FMC Technologies	4(+2 Future?)	ESP	Baker Hughes Centrilift	Aug-09	1-Mar-13	30.5	
	5	Perdido	O	Caisson Separation and Boosting	Shell	GOM	2,438	7,999	0.0	0.0	132-264	20-40	158.8	2,303	1.20	15%	FMC Technologies	5	ESP	Baker Hughes Centrilift	Mar-10	1-Mar-13	23.0	
	6	Pazflor	O	3 Gas/Liquid Vertical Separation Systems	Total	Angola, Blk 17	800	2,625	4.0	2.5	1,800	272	90.0	1,305	2.30	<16%	FMC Technologies	6+2 Spare	Hybrid H-A	Framo Eng./FMC Tech.	Aug-11	1-Mar-13	6.2	
	7	Marlim SSAO - Pilot	I, N	In-Line Separation	Petrobras	Campos Basin	878	2,881	3.8	2.4	135	20	245	3,553	1.9	0	FMC Technologies	1	Centrifugal (1P)	Framo Eng./FMC Tech.	Q3 2012			Installed 4Q 2011. Expected start was 3Q 2012
	8	Congro (29)	M	VASPS with Horizontal ESP	Petrobras	Campos Basin	197	646	11.0	7.0	135	20	21	305	0.4	<10%	FMC Technologies	2	ESP	Baker Hughes Centrilift				On hold. Petrobras is re-evaluating commercial feasibility
	9	Malhado	M	VASPS with Horizontal ESP	Petrobras	Campos Basin											FMC Technologies		ESP					
	10	Parque Das Conchas (BC 10) Phase 2 (23)	M	2 additional ESP systems	Shell	Campos Basin	2,150	7,054	25.0	15.6	185	28	152.0	2,205	1.10	15%	FMC Technologies	2	ESP	Baker Hughes Centrilift				
	11	Canapu	M	In-Line Separation by Twister BV	Petrobras	Espirito Santo Basin	1,700	5,579																
	12	Corvina (29)	M	VASPS w/Horizontal ESP	Petrobras	Campos Basin	280	919	8.0	5.0	135	20	21	305	0.4	<10%	FMC Technologies	1	ESP	Baker Hughes Centrilift				On hold. Petrobras is re-evaluating commercial feasibility

Operational history & future operational schedule timeline: 1995–2020; HISTORICAL ← PRESENT (2013) → FUTURE

CURRENT STATUS CATEGORIES
- C — Conceptual Project
- Q — Qualified/Testing
- M — Awarded and in Manufacturing or Delivered
- O — Installed & Currently Operating
- I, N — Installed & Not Currently Operating or In-Active
- A — Abandoned, Removed

TIMELINE CATEGORIES
- Operating
- Installed & Not Operating or In-Active
- Future – Anticipated Operational Period

NOTES:
1. See information accuracy statement below title block and note that the qualification status categorizations shown in this table, and throughout the poster, are based on unverified claims from equipment suppliers and field operators. These qualification status designations are not necessarily derived using technology readiness level (TRL) assessments per API RP 17Q or DNV-RP-A203.
2. **Pumping & Boosting:** The terms "Pumping" and "Boosting" are used interchangeably throughout this poster and in the industry.
3. **Unit Motor Power:** Is the unit motor power for either a pump or compressor motor.
4. **Differential Pressure:** Differential Pressure values are for individual pumps.
5. **GVF** = Gas Volume Fraction at inlet of pump.
6. **Cascade & Chinook** - Utilizes a horizontal ESPs on a skid above mudline. It is an alternative ESP boosting configuration to caisson in the seabed. This technology is designed to cover the low GVF and high DeltaP multiphase flow.
7. **King Field:** HV cables are incorporated within the service umbilical.
8. **Nuovo Pignone** is now part of GE.
9. **Lufeng 22/1:** Low wellhead pressure of 100 psig at seabed dictated that artificial lift was required. System has now been decommissioned due to field abandonment.
10. **VASPS** - Vertical Annular Separation and Pumping System
11. **START:** Month & Year indicates first month and year of operation for the SS processing system.
12. **Tordis Field:** 1+1 Spare Multiphase Boosting Pumps, and 1+1 Spare Water Injection Pumps; Tieback to Gullfaks C platform. Statoil hopes to increase oil recovery from 49% to 55%, an additional 36 MMBO, due to the world's first commercial subsea separation, boosting, injection and solids disposal system.
13. **King Field:** Is a subsea tieback to the Marlin TLP. In 2012, BP sold the field to Plains Exploration and Production. Pumps remain shut-in due to operational issues. Future use of pumps is unknown at this date.
14. **BCSS** - Centrifugal Subsea Submersible Pumps. Pumps are placed in protective holes in the seabed, 200m from producing wells. MOBO - Modulo de Bombas (Pumping Module)
15. **Troll C Pilot:** SUBSIS - The world's longest operating subsea separation system and first subsea water injection pump system.
16. **Mutineer/Exter Projects:** Manufacturers are: Framo Engineering and Centrilift. There are 2 ESPs per well feeding 1 x Framo MPP per asset on seafloor.
17. **Navajo Field:** Is a Subsea tieback to Anadarko's Nansen spar.
18. **BH Centrilift** = Baker Hughes Centrilift
19. **LUFENG** - Closed down due to field economics, after 11 years of operation.
20. **PREZIOSO** - World's first deployment of an electrically driven twin screw MPP operating on a live well. Testing occurred in 1994 and 1995 for a total of 7,850 hours of operation at base of platform on seafloor.
21. **Troll C Pilot** - Separation began on Aug. 25, 2001. See OTC paper 20619, page 10 for further details on operating experience. Note that injection pump data is only shown in the subsea water injection section of the table.
22. **CLOV** - Total reports that the CLOV development will utilize seabed multiphase pumps to boost Cravo, Lirio, Orquidea and Violeta Miocene from First Oil + 2 years
23. **Parque Das Conchas (BC 10) Phase 1** - Composed of 3 reservoirs: Ostra, Abalone and Argonauta B-West. Argonauta O-North to be added in Phase 2.
24. Marimba VASPS - 2000 - First installation in Marimba (JIP Petrobras / Eni-Agip/ ExxonMobil, 2001 - Startup and Operation (July to Dec.) until ESP failure, 2002 End of JIP, By-pass production, 2003 - Workover Plan (IWP), 2004 - Workover and Re-start on May 8, 2004. From 2005 until 2008 VASPS operated well until well failure.
25. **Jubarte Field (Phase 2)** - Was installed in 2011. Wells were connected to the FPSO P-57. All wells will have gas-lift as a backup.
26. **QGEP** - Queiroz Galvao Exploracao e Producao
27. **Girassol Field Pumping System** - for the Girassol Resources Initiatives (GirRI)
28. **Gullfaks South Brent** - Accoding to Statoil the SS wet gas compression will increase recovery from the reservoir by 22 million barrels of of oil equivalent.
29. Project on hold. Petrobras re-evaluating commercial feasibility.

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POSTER COLOR CODE KEY

The poster is divided into discrete sections and each section is marked by a background color. The color denotes the type of technology presented in the section. This color code is carried throughout the poster. Below are the color code designations for each of the six themes.

- Full Wellstream Subsea Boosting
- Subsea Separation
- Subsea Gas Compression
- Water Injection with Subsea Pumps
- Power Transmission/Distribution and Controls
- Miscellaneous Information/Combination of Technologies

TABLE 8 – DRIVERS / REASONS FOR SS COMPRESSION, SS BOOSTING, SS WI, AND SS SEPARATION

1.0 SS COMPRESSION
- 1.1 Increase subsea tieback distance range for a field
- 1.2 Improve flow assurance issues
- 1.3 Eliminate the need for a fixed or floating offshore platform
- 1.4 Enabler – without the technology the field could not be economically and/or technically developed (i.e. gas subsea tieback under the ice in artic regions)

2.0 SS 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
  - 2.1.4 Enable oil recovery where otherwise not possible
  - 2.1.5 Increase drainage area per well
- 2.2 Production advantages
  - 2.2.1 Increase production rate by reducing the flowing wellhead pressure
  - 2.2.2 Dampen slug flows to host topsides and possibly reduce process upsets
  - 2.2.3 Reduce OPEX by reducing recovery time (shorten life of field)
  - 2.2.4 Offset high friction pressure losses in flowline due to fluid viscosity
  - 2.2.5 Offset elevation head pressure loss
- 2.3 Facilities advantages
  - 2.3.1 Extend subsea tieback distance range for a field
  - 2.3.2 Reduce capex on topsides equipment and pipelines

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 Hydrate control by removing liquids from gas stream
- 4.3 Increase hydrocarbon production volume
- 4.4 Decrease total boost system power requirements
- 4.5 Accelerate and/or increase recovery
- 4.6 Improve flow management and flow assurance
- 4.7 Reduce CAPEX on topsides processing equipment and pipelines
- 4.8 Reduce chemical treatment costs
- 4.9 Improve economics of field with low GOR, high viscosity and low permeability

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CHART 1 – SUBSEA SUPPLIER MATRIX (As of Feb., 2013)

SUBSEA PROCESSING

- **SUBSEA PUMPING**
  - PUMP SYSTEM PACKAGERS: AKER SOLUTIONS (akersolutions.com); CAMERON (4) (c-a-m.com); FMC TECHNOLOGIES (7) (fmctechnologies.com); FRAMO ENGINEERING (4) (slb.com); GE (ge-energy.com)
  - PUMP MANUFACTURERS: BAKER HUGHES (bakerhughes.com); BORNEMANN (9) (bornemann.com); FLOWSERVE (flowserve.com); FRAMO ENGINEERING (4) (slb.com); LEISTRITZ (leistritzcorp.com); SCHLUMBERGER (slb.com); SULZER (7) (sulzer.com)
  - ELECTRIC MOTOR MANUFACTURERS: CURTISS WRIGHT (curtisswright.com); DIRECT DRIVE SYSTEMS (1) (fmcti.com); FRAMO ENGINEERING (4) (slb.no); FLOWSERVE (flowserve.com); HAYWARD TYLER (haywardtyler.com); LOHER (2) (automation.siemens.com)
- **SUBSEA RAW SEA WATER INJECTION (3)**: AKER SOLUTIONS (akersolutions.com); BAKER HUGHES (bakerhughes.com); FMC TECHNOLOGIES/ SULZER (7) (fmcti.com, sulzer.com); FRAMO ENGINEERING (4) (slb.com); SAIPEM (saipem-sa.com); SEABOX (sea-box.no)
- **SUBSEA SEPARATION SYSTEMS**: ASCOM (ascomseparation.com); AKER SOLUTIONS (akersolutions.com); CAMERON PROCESS SYSTEMS Formally Petreco/Natco (c-a-m.com); FMC/CDS (fmctechnologies.com); GE (ge-energy.com); SAIPEM (saipem-sa.com); TWISTER BV (twisterbv.com)
- **SUBSEA COMPRESSION**
  - COMPRESSION SYSTEM PACKAGERS: AKER SOLUTIONS (akersolutions.com); FMC TECHNOLOGIES (fmctechnologies.com); FRAMO ENGINEERING (4) (slb.com); GE (ge-energy.com)
  - COMPRESSORS: DRESSER RAND (dresser-rand.com); FRAMO ENGINEERING (4) (slb.com); GE POWER SYSTEMS (ge-energy.com); MAN TURBO (mandieselturbo.com); SIEMENS INDUSTRIAL TURBO MACHINERY (turbomachinerysolutions.com)
- **HV & AC/DC POWER**
  - POWER CABLES: ALCATEL (alcatel-lucent.com); BRUGG (bruggcables.com); HITACHI (hitachi.com); NEXANS (nexans.com); NSW (nsw.com); PRYSMIAN (prysmiangroup.com)
  - UMBILICALS: ABB (abb.com); BICC BERCA (biccberca.com); FURUKAWA (Furukawa.co.jp); MITSUBISHI (mitsubishielectric.com); NKT (nktcables.com); OKONITE (okonite.com); SUMITOMO (sumitomo.com)
  - ASDs/VSDs & X-FORMERS: AKER SOLUTIONS (akersolutions.com); DRAKA (draka.com); DUCO (technip.com); JDR (jdrcables.com); NEXANS (nexans.com); OCEANEERING (oceaneering.com); PARKER (parker.com)
  - HV CONNECTORS: ABB (abb.com); BAKER HUGHES (bakerhughes.com); CONVERTEAM (8) (ge-energy.com); FRAMO ENGINEERING (4) (slb.com); SCHNEIDER ELECTRIC (schneider-electric.com); SIEMENS (energy.siemens.com)
  - PENETRATORS: ALSTOM (alstom.com); BENNEX (5) (energy.siemens.com); DEUTSCH (deutsch.com); DIAMOULD (diamould.com); GE (ge-energy.com); SEACON (seaconworldwide.com); TELEDYNE ODI (odi.com); TRONIC (5) (energy.siemens.com); BENESTAD (benestad.com); DEUTSCH (6) (te.com); DIAMOULD (diamould.com); TELEDYNE D.G.O'BRIEN (dgo.com); TELEDYNE ODI (odi.com); TRONIC (5) (energy.siemens.com)
- **CONTROL SYSTEMS**: AKER SOLUTIONS (akersolutions.com); BAKER HUGHES (bakerhughes.com); CAMERON (c-a-m.com); FMC TECHNOLOGIES (fmctechnologies.com); FRAMO ENGINEERING (4) (slb.com); GE (ge-energy.com); SCHLUMBERGER (slb.com); SCHNEIDER ELECTRIC (schneider-electric.com)
- **OTHER SUPPORTING SYSTEMS**: AKER SOLUTIONS (akersolutions.com); ALPHA THAMES (alpha-thames.co.uk); CAMERON/DES (c-a-m.com); CONVERTEAM (8) (ge-energy.com); SCHNEIDER ELECTRIC (schneider-electric.com); VETCO GRAY SCANDINAVIA (ge-energy.com); SULZER (7) (sulzer.com); BORNEMANN (9) (bornemann.com); BAKER HUGHES (bakerhughes.com)
- **TESTING FACILITIES**: AKER SOLUTIONS (akersolutions.com); FRAMO ENGINEERING (4) (slb.com); PROLAB (prolabnl.com); SHELL GASMER (Houston, TX); STATOIL: P-LAB & K-LAB (Norway); PETROBRAS ATALAIA LAB (Brazil); FMC TECHNOLOGIES (fmctechnologies.com); FLOWSERVE (flowserve.com); LEISTRITZ (leistritzcorp.com); SCHLUMBERGER (slb.com)

NOTES:
1. Direct Drive Systems is a subsidiary of FMC Technologies.
2. Loher is a Siemens company.
3. Subsea raw seawater injection refers to only those projects utilizing a subsea pump to inject seawater and does not include typical water injection using a pump on a topside facility.
4. Framo is currently a Schlumberger company. Cameron and Schlumberger announced in 2012 the creation of OneSubsea™, a joint venture to develop and manufacture products, systems, and services for the subsea oil and gas market.
5. Tronic and Bennex are both Siemens companies.
6. Deutsch is part of the TE connectivity group.
7. FMC Technologies and Sulzer have formed a joint venture.
8. CONVERTEAM is a GE company.
9. Bornemann is an ITT Company.

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SUBSEA POWER TRANSMISSION

Fig. 1: SUBSEA POWER SYSTEM STEP-OUT CONFIGURATIONS

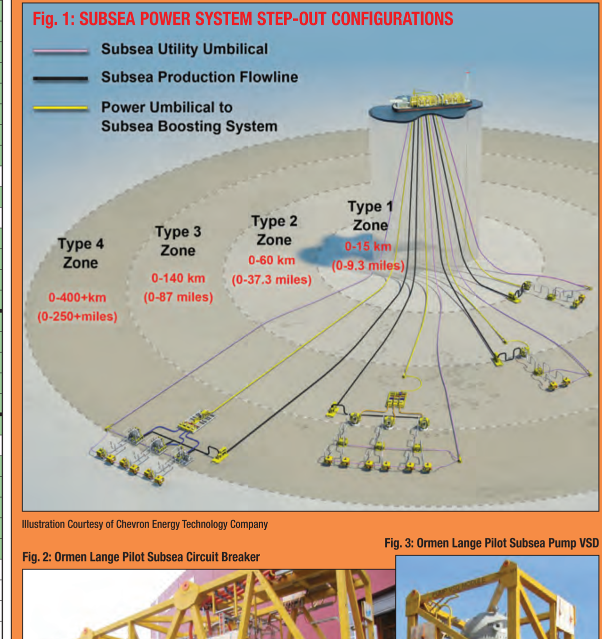

Illustration Courtesy of Chevron Energy Technology Company

TABLE 4: POWER SYSTEM STEP-OUT CONFIGURATIONS

CATEGORY	INDICATIVE VOLTAGE & POWER RATING	INDICATIVE STEP-OUT (4) Radius (1)	ADJUSTABLE SPEED DRIVE (ASD): Topside	ASD: Subsea	POWER TRANSFORMERS: Topside (Step Up)	POWER TRANSFORMERS: Subsea (Step Down)	NOMINAL TRANSMISSION FREQ.: 50 or 60 Hz AC	NOMINAL TRANSMISSION FREQ.: 16.7-25 Hz AC	DEPLOYED EXAMPLES: Step Out	DEPLOYED EXAMPLES: Ref. Project
Type 1	Capacity: 1-4 MW; Transmission: ~6kV; Distribution: ~6kV	0-15 km (0-9.3 miles)	●				●		14 km (8.7 miles)	Barracuda
Type 2	Capacity: 1-4 MW; Transmission: Up to 36kV; Distr./Motor Input: ~6kV	0-60 km (0-37.3 miles)	●		● (2)	● (2)	●		31 km (19.3 miles)	Tyrihans
Type 3	Capacity: Up to 70 MW; Transmission: 36kV-145kV; Distr. Switchgear: Up to 36kV; Distr./Motor Input: ~6kV	0-140 km (0-87 miles)		●	● (3)	● (3)	●		TBD	TBD
Type 4	Capacity: Up to ~100 MW; LF Transmission: Up to 145kV; LF Dist. Switchgear: Up to 36kV; Distr./Motor Input: ~6kV	0-400+km (0-250+miles)		●	● (3)	● (3)		●	TBD	TBD

1. Indicative radius subject to system power rating. See Fig. 1: Subsea Power System Step-Out Configurations.
2. Step-up/step-down transformers likely required after ASD to optimize umbilical power transmission.
3. Step-up/step-down transformers likely required before ASD to optimize umbilical power transmission.
4. Step-out is the distance from host facility.

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Fig. 2: Ormen Lange Pilot Subsea Circuit Breaker
Fig. 3: Ormen Lange Pilot Subsea Pump VSD
Figs. 2 & 3: Courtesy of Aker Solutions
Fig. 4: Pressure Compensated ASD
Fig. 5: Spectron 10 Wet-Mate Connectors
Figs. 4 & 5: Courtesy of Siemens

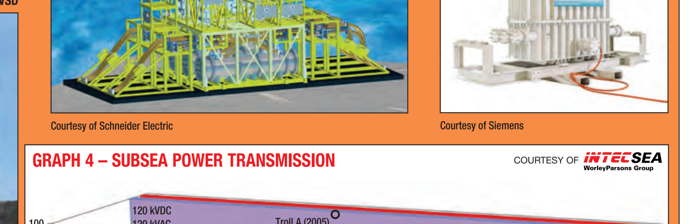
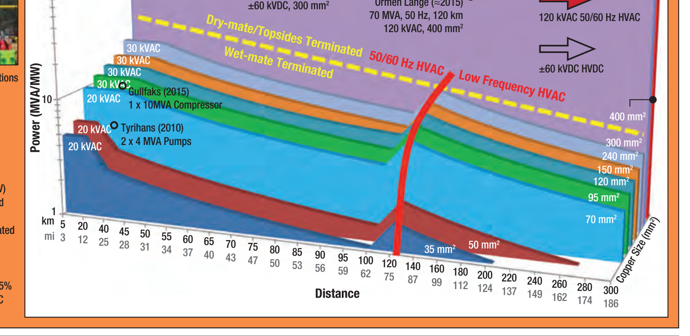


Fig. 6: Subsea HV Multi Circuit Breaker 60 MVA. Courtesy of Schneider Electric
Fig. 7: Subsea Transformer. Courtesy of Siemens

GRAPH 4 – SUBSEA POWER TRANSMISSION



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GRAPH 4 NOTES & ASSUMPTIONS
1. Cable insulation ratings in accordance with IEC 60502 Part 2
2. Cables for rated voltages from 6 kV (U_m = 7.2 kV) up to 30 kV (U_m = 36 kV)
3. Per IEC 60502, 55 mm² conductor rated at 20 kV nominal L-L voltage
4. Per IEC 60502, conductors >55 mm² rated at 30kV nominal L-L voltage
5. Theoretical I^2R threshold per phase = 10 W/m (AC) or 15 W/m (DC)
6. Theoretical voltage drop threshold = 15%
7. Conductor sizes in accordance with IEC 60228

TABLE 7 – INDUSTRY ACRONYMS & ABBREVIATIONS

AC	Alternating Current
AL	Artificial Lift
ALM	Artificial Lift Manifold
ASD	Adjustable Speed Drive
BPD	Barrels per Day
BOPD	Barrels of Oil per Day
CAPEX	Capital Expenditures
COSSP	Configurable Subsea Separation and Pumping
CSSP	Centrifugal Subsea Submersible Pump
DC	Direct Current
DMBS	Deepwater Multiphase Boosting System
ESP	Electrical Submersible Pump
GLCC	Gas/Liquid Centrifugal Cyclonic
GVF	Gas Volume Fraction
GLR	Gas-to-Liquid Ratio
GOR	Gas-to-Oil Ratio
Hp	Horsepower
HV	High Voltage
IOR	Improved (Increased) Oil Recovery
kW	Kilowatt
LF	Low Frequency
LOF	Life of Field
MBOPD	Thousand Barrels of Oil per Day
MPP	Multiphase Pump
MW	Mega Watts
OPEX	Operational Expenditures
PSI	Pounds per Square Inch
ROV	Remote Operated Vehicle
RPM	Revolutions Per Minute
SIORS	Subsea Increased Oil Recovery System
SMUBS	Shell Multiphase Underwater Boost Station
SS	Subsea
SSBI	Subsea Separation, Boosting, and Injection
SUBSIS	Subsea Separation and Injection System
VASPS	Vertical Annular Separation and Pumping System
VSD	Variable Speed Drive
WD	Water Depth

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TABLE 6 – OTHER INFORMATION RESOURCES

(Recommended Papers and Additional Resources)

Go to *www.onepetro.org* to order the SPE & OTC papers listed below.

	Paper	Year	Company	Title
SUBSEA BOOSTING PROJECTS				
1	OTC 23178	2012	FMC	Pazflor: Test/Qual. of Novel Tech.
2	SPE 160292	2012	WOODSIDE	Subsea Boosting Offshore Australia
3	SPE 152188	2012	BAKER HUGHES/SHELL	BC-10 - Replacement of ESPs
4	OTC 20537	2010	SHELL	Parque das Conchas - BC-10
5	OTC 20882	2010	SHELL	Perdido Development
6	SPE 134393	2010	SHELL/BAKER HUGHES	Dev. for Perdido & BC-10 Assets
7	OTC 20146	2009	BP	BP King SS Boosting
8	OTC 17899	2006	FRAMO/OILEXCO	SS Boosting at Brenda Field
NEW MULTIPHASE BOOSTING SYSTEM				
1	SPE 134341	2010	SHELL/FLOWSERVE	Dev. of High Boost System
SUBSEA SEPARATION				
1	OTC 23223	2012	FMC/EXMOB/WOODSIDE	Compact SS Sep. for Deep Water
2	OTC 23478	2012	ENI	SS Gas/Liquid Separation
3	OTC 23417	2012	PETROBRAS/FMC	Marlim 3-Phase Separation
4	OTC 20748	2010	STATOIL	Separation in the Gullfaks Field
5	DOT Amst.	2010	SAIPEM	Testing of Multi-Pipe Separator
6	DOT Monaco	2009	SAIPEM	Gas / Liquid Separator for DW
7	OTC 20080	2009	TOTAL / FMC	Comparison of SS Sep. Systems
8	SPE 123159	2009	FMC	Over View of Projects
9	OTC 18914	2007	PETROBRAS	SS Oil/Water Sep.- Campos Basin
SUBSEA RAW SEAWATER AND PRODUCED WATER INJECTION				
1	OTC 22667	2011	SAIPEM/VEOLIA	Subsea Produced Water Re-Injection
2	OTC 20078	2009	AKER SOLUTIONS	Tyrihans Raw Seawater Injection
3	SPE 109090	2007	CNR/FRAMO	Columba E. Raw Seawater Inj.
4	SPE 18749	2007	FMC	Tordis IOR Project
SUBSEA COMPRESSION				
1	IPTC 14231	2011	FRAMO	Advances in SS Wet Gas Comp.
2	OTC 21346	2011	STATOIL/FRAMO	Testing of SS Wet Gas Comp.
3	OCT 24211	2011	AKER SOLUTIONS	SS Compression: A Game Changer
4	DOT AMST.	2010	SHELL	Qualifying the Technology
5	OTC 20030	2009	AKER SOLUTIONS	Subsea Compression Station
6	OTC 20028	2009	STATOILHYDRO	SS Compression Pilot System
POWER TRANSMISSION/DISTRIBUTION				
1	OTC 23846	2012	INTECSEA	HVDC Enables SS Processing
2	OTC 22430	2011	BPP CABLES	Deep Water High Capacity Cables
3	OTC 20483	2010	TOTAL	Electrical Transmission
4	OTC 20532	2010	STATOIL	HV Power Umbilical Design
5	OTC 20621	2010	STATOIL	Subsea Power Systems
6	OTC 20042	2009	VETCOGRAY/ABB	Long Step-Out Power Supply
COMPANY EXPERIENCE & APPROACH TO SUBSEA PROCESSING				
1	OTC 20619	2010	STATOIL	Subsea Processing at Statoil
2	DOT AMST.	2010	STATOIL	Statoil's Experience & Plans
3	OTC 20186	2009	PETROBRAS	Subsea Processing & Boosting
4	OTC 18198	2006	PETROBRAS	Application in Campos Basin
STUDIES & OVERVIEWS				
1	OTC 22860	2012	CRANFIELD UNIV.	SS Processing: A Holistic Approach
2	OTC 20687	2010	SHELL	Deepstar SS Processing Study
3	OTC 19262	2008	ASME / ACERGY	Impact on Field Architecture
4	OTC 18261	2006	SHELL	Technical Challenges & Opport.
5	SPE 84045	2003	TEXAS A & M	SS Production Systems Overview

COURTESY OF INTECSEA

SUBSEA SEPARATION SYSTEM TYPES: 1. GRAVITY SEPARATION SYSTEMS (Figures 1–6) | 2. CAISSON SEPARATION SYSTEMS (Figures 7–10) | 3. COMPACT/DYNAMIC SEPARATION SYSTEMS (Figures 11–15)

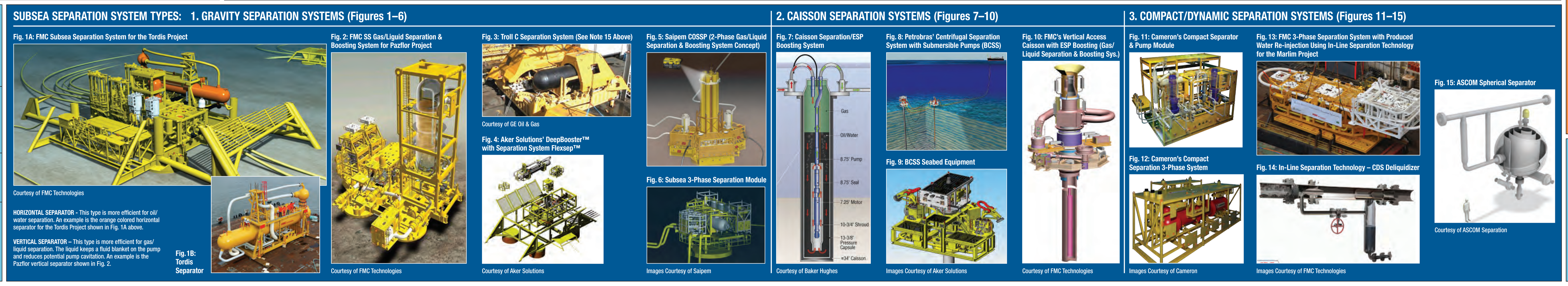

Fig. 1A: FMC Subsea Separation System for the Tordis Project. Courtesy of FMC Technologies
Fig. 1B: Tordis Separator

HORIZONTAL SEPARATOR - This type is more efficient for oil/ water separation. An example is the orange colored horizontal separator for the Tordis Project shown in Fig. 1A above.

VERTICAL SEPARATOR – This type is more efficient for gas/ liquid separation. The liquid keeps a fluid blanket on the pump and reduces potential pump cavitation. An example is the Pazflor vertical separator shown in Fig. 2.

Fig. 2: FMC SS Gas/Liquid Separation & Boosting System for Pazflor Project. Courtesy of FMC Technologies
Fig. 3: Troll C Separation System (See Note 15 Above). Courtesy of GE Oil & Gas
Fig. 4: Aker Solutions' DeepBooster™ with Separation System Flexsep™. Courtesy of Aker Solutions
Fig. 5: Saipem COSSP (2-Phase Gas/Liquid Separation & Boosting System Concept)
Fig. 6: Subsea 3-Phase Separation Module
Images Courtesy of Saipem
Fig. 7: Caisson Separation/ESP Boosting System. Courtesy of Baker Hughes
Fig. 8: Petrobras' Centrifugal Separation System with Submersible Pumps (BCSS)
Fig. 9: BCSS Seabed Equipment
Images Courtesy of Aker Solutions
Fig. 10: FMC's Vertical Access Caisson with ESP Boosting (Gas/ Liquid Separation & Boosting Sys.). Courtesy of FMC Technologies
Fig. 11: Cameron's Compact Separator & Pump Module
Fig. 12: Cameron's Compact Separation 3-Phase System
Images Courtesy of Cameron
Fig. 13: FMC 3-Phase Separation System with Produced Water Re-injection Using In-Line Separation Technology for the Marlim Project
Fig. 14: In-Line Separation Technology – CDS Deliquidizer
Images Courtesy of FMC Technologies
Fig. 15: ASCOM Spherical Separator. Courtesy of ASCOM Separation

TABLE 5 – KEY TECHNOLOGY FOCUS AREAS

Item No.	TECHNOLOGY FOCUS AREAS (Active/Currently Funded by Operators)	Water Depth (m)	Water Depth (ft)	Pressure Rating (bar)	Pressure Rating (psi)	Flow Rate (m^3/hr)	Flow Rate (ft^3/hr)	Flow Rate (MW)	Flow Rate (hp)	KEY TECHNOLOGY GAPS
1	Long Distance SS Power Distribution	3,048	10,000	NA	NA	NA	NA	3 x (6)*	4,021 x (6)*	Subsea Switchgear/ASDs/Wet Mate Connectors
2	High Head Multiphase Booster Pump	3,048	10,000	1,034	15,000	517	18,258	4	5,362	Motor, Balance Piston & Housings
3	Liquid Tolerant Subsea Compressor	1,524	5,000	689	10,000	20,000	706,293	12	16,086	Motor, Rotor-Dynamics
4	High Power/dP Water Injection Pump	3,048	10,000	1,034	15,000	517	18,258	6	8,043	Pump, Housings, Motor & Penetrators
5	Raw Water Sulphate Reduction	3,048	10,000	1,034	15,000	517	18,258	NA	NA	Marinizing Sulfate Reduction Technologies

(Columns 3–10: INDICATIVE PARMAMETER FOR BASIS OF DESIGN)

*Indicative to support up to 6 consumers at 3 MW each; system to be configurable to suit more smaller or fewer larger consumers as needed

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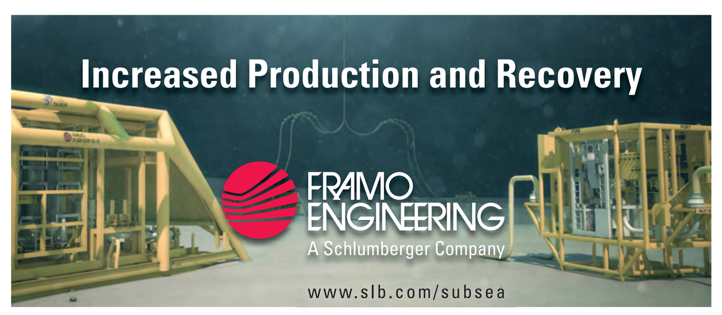

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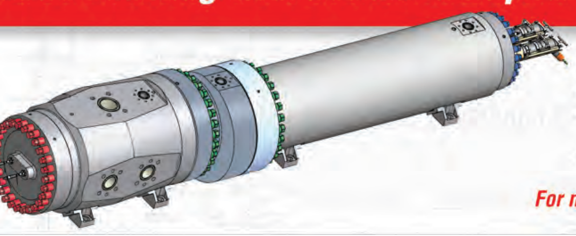
Design Ratings
- Depths to 3050 m (10 000 ft)
- Suction pressures to 5000 psi (345 bar)
- Discharge pressures to 10 000 psi (690 bar)
- Nominal 3.5 MW (4693 hp) motor rating
- Voltage 6.6 kV
- Frequencies from 10 to 66 Hz (+10% over-speed)



Operating Parameters
- Pressure boost exceeding 2200 psi (150 bar)
- Displacement flow rates to 90 000 bpd (447 m^3/h) @ 1800 rpm
- Nominal speed of 1800 rpm (+10% over-speed)

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