2010 Worldwide Survey of Subsea Processing: Separation, Compression, and Pumping Systems

STATUS OF THE TECHNOLOGY

MARCH 2010

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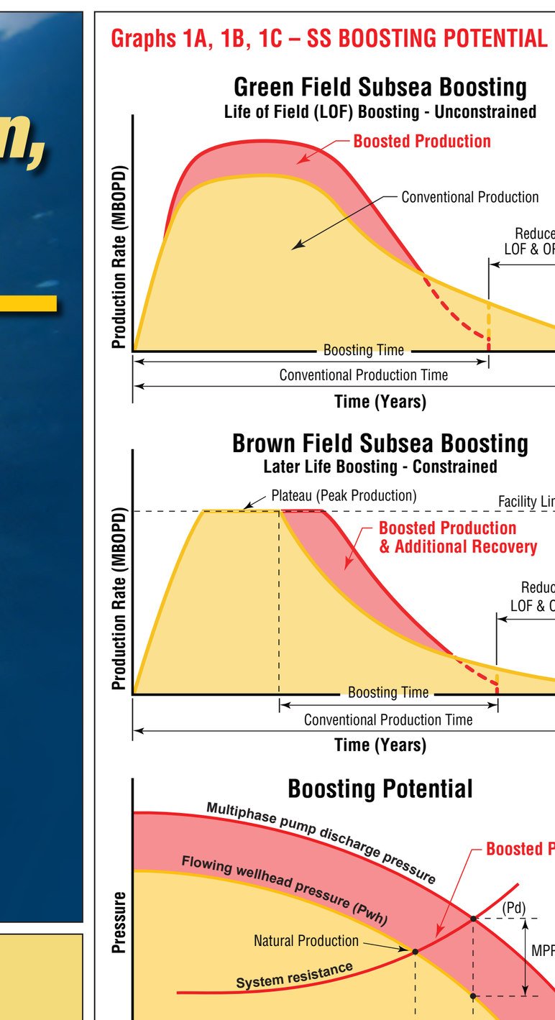
Information Accuracy: We have attempted to use correct and current, as of press time, information for the subsea processing systems and equipment described herein. No installed, sanctioned, nor pending application was intentionally excluded. We have summarized the capability and operating experience 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 **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.

POSTER 83

Graphs 1A, 1B, 1C – SS BOOSTING POTENTIAL



SUBSEA PUMP TYPES

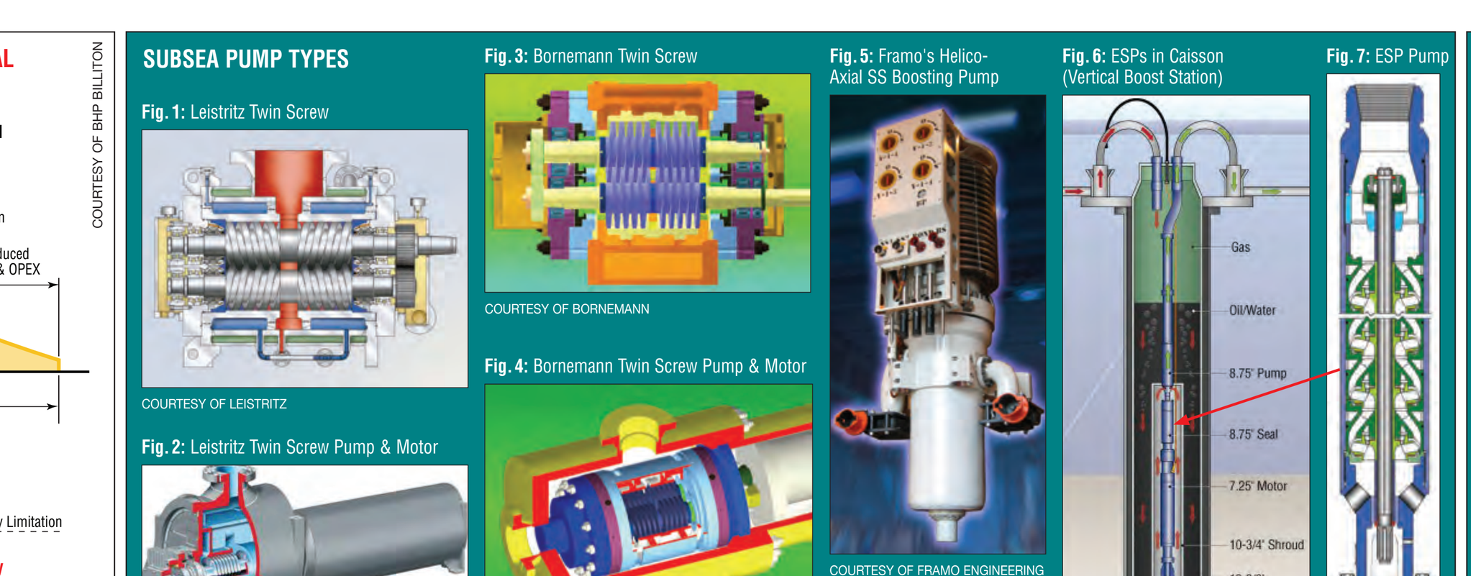


Fig. 1: Leistritz Twin Screw — COURTESY OF LEISTRITZ
Fig. 2: Leistritz Twin Screw Pump & Motor — COURTESY OF LEISTRITZ
Fig. 3: Bornemann Twin Screw — COURTESY OF BORNEMANN
Fig. 4: Bornemann Twin Screw Pump & Motor — COURTESY OF BORNEMANN
Fig. 5: Framo's Helico-Axial SS Boosting Pump — COURTESY OF FRAMO ENGINEERING
Fig. 6: ESPs in Caisson (Vertical Boost Station)
Fig. 7: ESP Pump — COURTESY OF BAKER HUGHES CENTRILIFT

SUBSEA GAS COMPRESSION SYSTEMS & PRODUCTS BY COMPANY

Fig. 1: Aker Solutions – Proposed Ormen Lange SS Gas Compression Package — COURTESY OF AKER SOLUTIONS
Fig. 2: Aker Solutions – GasBooster™ SS Wet Gas Compression System — COURTESY OF AKER SOLUTIONS
Fig. 3: FMC Technologies SS Gas Compression Station — COURTESY OF FMC TECHNOLOGIES
Fig. 4: Kvaerner Booster Station (KBS) for SS Gas Compression — COURTESY OF GE OIL & GAS
Fig. 5: FRAMO Wet Gas Compressor (Conceptual) — COURTESY OF FRAMO ENGINEERING
Fig. 6: Extended Loop Testing of Full Scale FRAMO 4MW Multi-Phase Compressor — COURTESY OF FRAMO ENGINEERING

SUBSEA MULTIPHASE PUMPING SYSTEMS

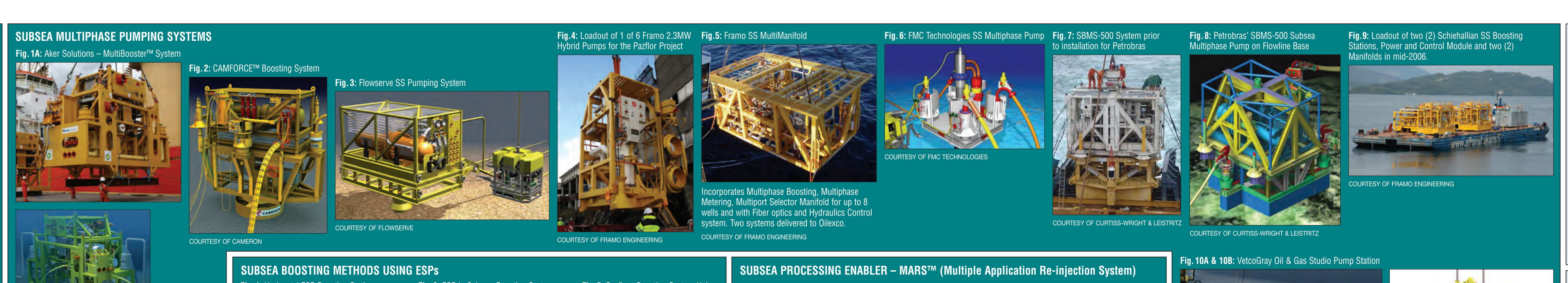


Fig. 1A: Aker Solutions – MultiBooster™ System; Fig. 1B — COURTESY OF AKER SOLUTIONS
Fig. 2: CAMFORCE™ Boosting System — COURTESY OF CAMERON
Fig. 3: Flowserve SS Pumping System — COURTESY OF FLOWSERVE
Fig. 4: Loadout of 1 of 6 Framo 2.3MW Hybrid Pumps for the Pazflor Project — COURTESY OF FRAMO ENGINEERING
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 Oilexco. — COURTESY OF FRAMO ENGINEERING
Fig. 6: FMC Technologies SS Multiphase Pump — COURTESY OF FMC TECHNOLOGIES
Fig. 7: SBMS-500 System prior to installation for Petrobras — COURTESY OF CURTISS-WRIGHT & LEISTRITZ
Fig. 8: Petrobras' SBMS-500 Subsea Multiphase Pump on Flowline Base — COURTESY OF CURTISS-WRIGHT & LEISTRITZ
Fig. 9: Loadout of two (2) Schiehallian SS Boosting Stations, Power and Control Module and two (2) Manifolds in mid-2006. — COURTESY OF FRAMO ENGINEERING
Fig. 10A & 10B: VetcoGray Oil & Gas Studio Pump Station — COURTESY OF VETCOGRAY, A GE OIL & GAS BUISINESS

SUBSEA BOOSTING METHODS USING ESPs

Fig. 1: Horizontal ESP Boosting Station — COURTESY OF FMC TECHNOLOGIES
Fig. 2: ESP in Caisson Boosting System — COURTESY OF BAKER HUGHES
Fig. 3: ESP Jumper Boosting System — COURTESY OF BAKER HUGHES CENTRILIFT
Fig. 4: ESP in Flowline Riser — COURTESY OF BAKER HUGHES
Fig. 5: Seafloor Boosting System Using ESPs in Caissons — COURTESY OF AKER SOLUTIONS

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

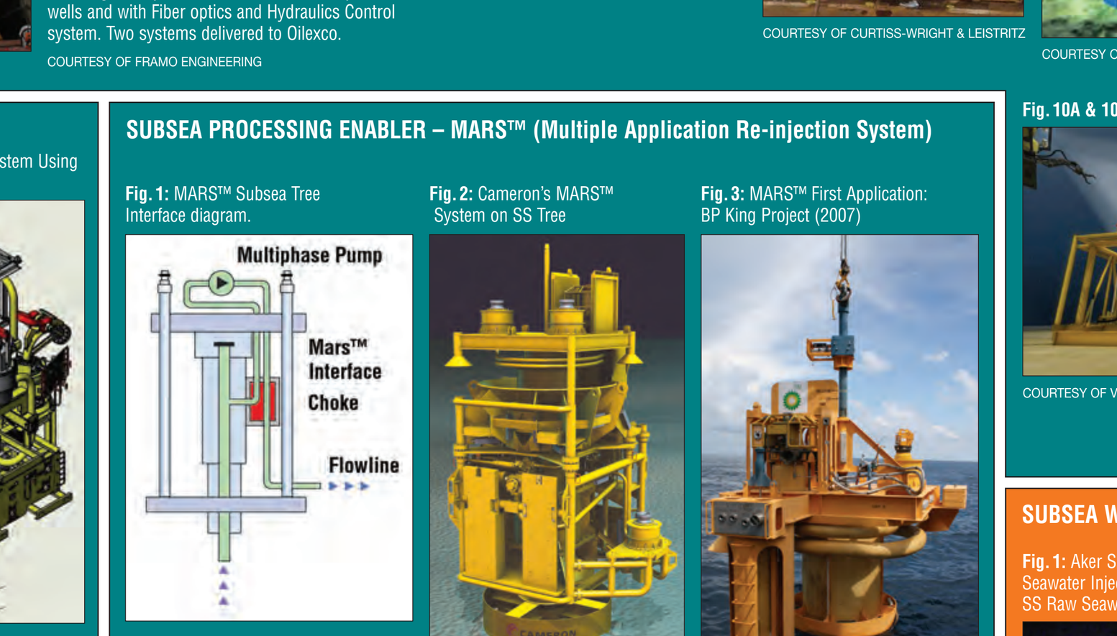


Fig. 1: MARS™ Subsea Tree Interface diagram.
Fig. 2: Cameron's MARS™ System on SS Tree
Fig. 3: MARS™ First Application: BP King Project (2007)
COURTESY OF CAMERON MARS™ was developed by DES Operations Ltd., now a Cameron Company

SUBSEA WATER INJECTION SYSTEMS

Fig. 1: Aker Solutions LiquidBooster™ Subsea Raw Seawater Injection System (Photo: StatoilHydro Tyrihans SS Raw Seawater Injection (SRSWI) System) — COURTESY OF AKER SOLUTIONS
Fig. 2: Installation of the Tyrihans SS Raw Seawater Injection (SRSWI) System — COURTESY OF AKER SOLUTIONS
Fig. 3: One of four (4) Albacora Raw Seawater WI Pump Systems undergoing system integration testing in Framo test dock in late 2009. — COURTESY OF FRAMO ENGINEERING
Fig. 4: Well Processing SWIT System as a template. — COURTESY OF WELL PROCESSING
Fig. 5: Well Processing's new Sea Water Injection and Treatment System (SWIT) now in development in Norway. — COURTESY OF WELL PROCESSING

GLOBAL DISTRIBUTION OF SUBSEA PROCESSING TECHNOLOGY

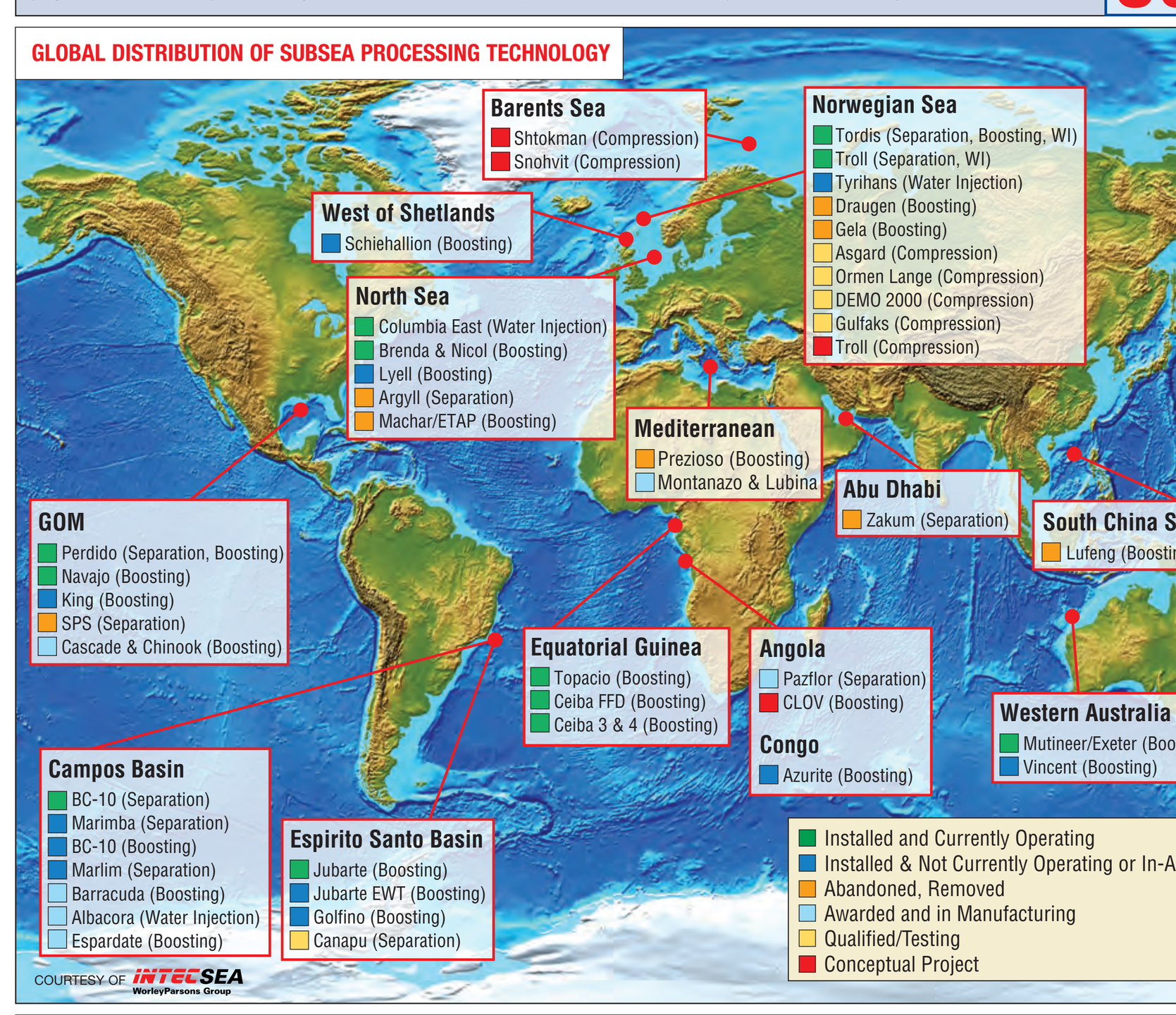


TABLE 2 – METHODS/CONFIGURATIONS

	METHOD/CONFIGURATION	TECHNOLOGY STATUS: CONCEPTUAL	QUALIFIED	INSTALLED OR OPERATING	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			O	Ceiba C3 & C4
2	MPP at SS Manifold			O	Ceiba
3	MPPs Incorporated within SS Manifold			I	Brenda, Exeter + Mutineer
4	MPP at Flowline Inlet			I	Ceiba, Shiehallion, Vincent, Azurite
5	MPP at Riser Base		Q		
6	ESP Downhole in SS Well			O	Otter, Gannet, Lihua
7	ESP Downhole + MPP			O	Mutineer/Exeter
8	ESP Downhole + Caisson ESP			O	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			O	Navajo
13	ESP in Flowline Jumper (Note 1)	C			
	SUBSEA WATER INJECTION METHODS/CONFIGURATIONS				
1	Produced WI System (with SS Separation)			O	Troll C Pilot
2	Raw Sea Water SS Injection System			I	Colomba 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			I	Marimba (VASPS)
5	2-Phase - Gas/Liquid		Q		Pazflor
6	2-Phase - Water/Oil with Water Reinjection			I	Troll C Pilot
7	3-Phase - Gas, then Oil/Water			I	Tordis

NOTE 1. Brownfield application using existing infrastructure. COURTESY OF INTECSEA & BHP BILLITON

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

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 TOTAL FLOW RATE (@LINE CONDITIONS) M3/Hr.	MBOPD MBWPD	DIFFERENTIAL PRESSURE BAR (3)	PSI (3)	POWER (2) MW	GAS VOLUME FRACTION (GVF) (5) % OF VOL.	SYSTEM PACKAGER (COMPANY)	NO. OF PUMPS (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	StatoilHydro	Offshore Norway									3.60	n/a	Framo Engineering		Counter Axial	Framo Engineering	2001			
	2	Ormen Lange (4)	Q	Wet Gas Compression	StatoilHydro	Offshore Norway	860	2,821	120	75.0	520	78.5	60.0	870	60.00	n/a	Aker Solutions	8	Centrifugal	GE Compr/Aker Pump	2011			
	3	Aasgard - Midgard & Mikkel Fields	Q	Wet Gas Compression	StatoilHydro	Offshore Norway	300	984	53.0	33.1	TBD	TBD	TBD	TBD	16.00	n/a	FMC Tech./Aker Sol.		Centrifugal	Man Turbo/Siemens	2012			
	4	Gullfaks	Q	Wet Gas Compression	StatoilHydro	Offshore Norway	150	492	16.0	10.0	4,800	725.1	30.0	435	5.00	95%	Framo Engineering	1	Counter Axial	Framo Engineering	2012			
	5	Troll	C		StatoilHydro	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	2020			
	7	Snohvit	C		StatoilHydro	Barents Sea	345	1,132	143.0	89.4					60.00	n/a	TBA		Centrifugal	TBA	2020			
FULL WELLSTREAM SUBSEA BOOSTING (SEABED & RISER ONLY, EXCLUDES DOWNHOLE ESPs)	1	Prezioso (20)	A	MPP at Base of Platform	AGIP	Italy	50	164	0.0	0.0	65	9.8	40.0	580	0.15	30-90%	Nuovo Pignone (8)	1	Twin-Screw	GE Oil & Gas	1994			
	2	Gela Field	A		AGIP																1994			
	3	Draugen Field	A	SMUBS Project, 1MPP	A/S Norske Shell	Offshore Norway	270	886	6.0	3.7	193	29.2	53.3	773	0.75	42%	Framo Engineering	1	Helico-Axial	Framo Engineering	Nov-95	Nov-96	12.2	
	4	Lufeng 22/1 Field (9)(19)	A	Tieback to FPSO	StatoilHydro	South China Sea	330	1,083	1.0	0.6	1,600	241.7	35.0	508	0.40	3%	Framo Eng./FMC Tech.	5+2 Spare	Centrifugal (1P)	Framo Engineering	Jan-98	Jul-09	138.0	Field Abandonment
	5	Machar Field (ETAP Project)	A	Hydraulic Turbine Drive	BP Amoco	North Sea	85	277	35.2	21.9	1,100	166.2	22.0	319	0.65	64%	Framo Engineering	2+1 Spare	Helico-Axial	Framo Engineering	1999	Never Installed		
	6	Topacio Field	O	1 x Dual MPP System	ExxonMobil	Equatorial Guinea	500	1,641	9.0	5.6	940	142.0	35.0	508	0.86	75%	Framo Engineering	2+1 Spare	Helico-Axial	Framo Engineering	Aug-00	Feb-10	113.8	
	7	Ceiba C3 and C4	O	Phase 1 SS MPP Project	Amerada Hess	Equatorial Guinea	750	2,461	7.5	4.7	600	90.6	45.0	653	0.84	75%	Framo Engineering	2+1 Spare	Helico-Axial	Framo Engineering	Oct-02	Feb-10	87.9	
	8	Jubarte EWT	I,N	Riser lift to Seillean drillship	Petrobras	Espirito Santo Basin	1,400	4,593	1.4	0.9	145.0	21.9	140.0	2,000	0.70	22%	FMC Technologies	1	ESP	Schlumberger (REDA)	Dec-02	Dec-06	47.9	
	9	Ceiba Field (FFD)	O	Full Field Development (FFD)	Amerada Hess	Equatorial Guinea	700	2,297	7.5	4.7	2,500	337.6	45.0	580	1.10	75%	Framo Engineering	5	Helico-Axial	Framo Engineering	Dec-03	Feb-10	73.9	
	10	Mutineer/Exeter	O	2 x Single MPP Systems	Santos	NW Shelf, Australia	145	476	7.0	4.3	1,200	181.3	30.0	435	1.10	0-40%	Framo Engineering	7 ESPs, 2+1 Spare	Helico-Axial	Framo Engineering (16)	Mar-05	Feb-10	59.0	
	11	Lyell	I,N	SS Tieback to Ninian South	CNR	UK North Sea	146	479	15.0	9.3	1,100	166.2	18.0	261	1.60	40-70%	Aker Solutions	1	Twin-Screw	Bornemann	Jan-06	Dec-06	11.0	Non Operational
	12	Navajo Field (17)	O	ESP in Flowline Riser	Anadarko	GOM	1,110	3,642	7.2	4.5	24	3.6	40.2	583	0.75	57%	Baker Hughes	1	ESP	Baker Hughes	Feb-07	Feb-10	35.9	Operating
	13	Jubarte Field	O	Seabed ESP-MOBO, Uses BCSS (14)	Petrobras	Espirito Santo Basin	1,350	4,429	4.0	2.5	120	18.1	138.0	2,002	0.90	10-40%	FMC Technologies	1	ESP	Schlumberger (REDA)	Mar-07	Jul-09	27.5	Stopped in Mid 2009
	14	Brenda & Nicol Fields	O	MultiManifold with 1 MPP	OILEXCO N.S.	UK North Sea	145	476	8.5	5.3	800	120.8	19.0	276	1.10	75%	Framo Engineering	1+1 Spare	Helico-Axial	Framo Engineering	Apr-07	Feb-10	34.0	
	15	King (7) (27)	I,N	SS Tieback to Marlin TLP	BP	GOM, MC Blocks	1,700	5,578	29.0	18.0	497	75.0	50.0	725	1.30	0-95%	Aker Solutions	2+1 Spare	Twin-Screw	Bornemann TS/Loher	Nov-07	Feb-09	15.0	Non Operational
	16	Vincent	I,N	Dual MPP System	Woodside	NW Shelf, Australia	470	1,542	3.0	1.9	2,700	407.9	28.0	406	1.80	25-80%	Framo Engineering	2+2 Spare	Helico-Axial	Framo Engineering	May-08	Feb-10	21.0	Commissioned, Start Pending
	17	Marlim	I,N	SBMS-500 SS Field Test	Petrobras	Campos Basin	1,900	6,234	3.1	1.9	500	75.0	60.0	870	1.20	0-100%	Curtiss-Wright/Aker	1	Twin-Screw	Leistritz	Apr-10		0.0	Non Operational
	18	Argonauta (BC-10)	I,N	Caisson/Artificial Lift Manifold	Shell	Brazil	1,900	6,234	9.0	5.6	64	9.7	165.0	2,393	1.10	30%	FMC Technologies	2	ESPs	Baker Hughes	2009		0.0	Pending Start
	19	Golfinho Field	I,N	Seabed ESP-MOBO, Uses BCSS (14)	Petrobras	Espirito Santo Basin	1,350	4,429			146	22.1	138.0	2,002	1.10	10-40%	FMC Technologies	4	ESPs	Baker Hughes	Aug-09		0.0	Non Operational due to poor well performance (excessive water)
	20	Azurite Field	I,N	Dual MPP System	Murphy Oil	Congo, W. Africa	1,338	4,390	3.0	1.9	920	139.0	42.0	609	1.00	28%	Framo Engineering	2+1 Spare	Helico-Axial	Framo Engineering	3Q, 2009		0.0	Commissioned, Start Pending
	21	Golfinho Field	I,N	Four BCSS Caissons (14)	Petrobras	Espirito Santo Basin	1,350	4,429			146	22.1	138.0	2,002	1.10	10-40%	Aker Solutions	2	ESPs	Baker Hughes	Jan-10		0.0	Non Operational at press time
	22	Espadarte	M	Horizontal ESP on Skid	Petrobras	Brazil	1,350	4,429			125	18.9	100.0	1,450	0.90	10-40%	FMC Technologies	2	ESPs	Baker Hughes	2010		0.0	
	23	Parque Das Conchas (BC 10) Phase 1 (23)	I,N	Caisson/Artifical Non-Separated	Shell	Campos Basin	2,150	7,054	40.0	25.0	185	27.9	152.0	2,205	1.10	5%	FMC Technologies	2	ESPs	Baker Hughes	Mar-10			Start immenent at press time
	24	Jubarte Field - Phase 2 (25)	M	Tieback to FPSO P-57, Uses BCSS	Petrobras	Espirito Santo Basin	1,400	4,593	8.0	5.0	1,325	200.2	200.0	3,000	1.20	30-40%	Aker Solutions	15	ESPs	Schlumberger (REDA)	Nov-10		0.0	
	25	Cascade & Chinook (26)	M	Skid BCSS - Horizontal ESP on Skid	Petrobras	GOM	2,484	8,150	8.0	5.0	135	20.4	220.0	3,191	1.10	20%	FMC Technologies	2+2	ESPs	Baker Hughes	2011		0.0	Start delayed until 2011
	26	Barracuda	M	Single MPP System	Petrobras	Campos Basin	1,040	3,412	14.0	8.8	280.0	42.3	70.0	1,015	1.50	50%	Framo Engineering	1	Helico-Axial	Framo Engineering	2011			
	27	Montanazo & Lubina	M	Single MPP System	Repsol	Mediterranean	740	2,428	8.0	5.0	80.0	12.1	45.0	653	0.23	0%	Framo Engineering	1	Centrifugal (1P)	Framo Engineering	2011			
	28	Schiehallion	I,N	2 x Dual MPP Systems	BP	UK, West of Shetland	400	1,312	3.0	1.9	2 x 1,350	2 x 204	26.0	377	1.80	74%	VetcoGray/Framo	4	Helico-Axial	Framo Engineering	Mid 2012	Delayed Start Up		Pending FPSO Rebuild
	29	CLOV	C	Subsea Boosting	TOTAL	Angola, Blk 17	1,200	3,940	10.0	6.2	330.0	49.8	50.0	725	2.30	55%	TBD	2	MPP	TBD	2016			
SUBSEA WATER INJECTION	1	Troll C Pilot (15)	O	SUBSIS (SS Sep.& WI Sys.)	NorskHydro AS	Norway	340	1,116	4.0	2.5	250	37.8	151.0	2,190	1.60	0%	VetcoGray/Framo	1+1 Spare	Centrifugal	Framo Engineering	Sep-99	Feb-10	124.8	(Note 21)
	2	Columba E.	O	Dual SPP System	CNR	North Sea	145	476	7.0	4.3	331	50.0	320.0	4,641	2.30	0%	Framo Engineering	2	Centrifugal	Framo Engineering	May-07	Feb-10	33.0	
	3	Tordis	O	(12), Separation, Boosting, WI	Statoil	North Sea	200	656	11.0	6.8	700	105.7	77.0	1,117	2.30	0%	FMC Technologies	1+1 Spare	Centrifugal	Framo Engineering	Nov-07	Feb-10	27.0	
	4	Albacora Leste Field	M	Raw Water Injection	Petrobras	Brazil	400	1,312	4 to 9	2.5-6.0	1,125	169.9	85.0	1,233	1.2	0%	FMC Technologies	3+1 Spare	Centrifugal	Framo Engineering	2010		0.0	Awaiting Installation, Framo Ex-Works Sept 09
	5	Tyrihans	I,N	SS Raw Sea WI System	Statoil	Norway	300	984	31.0	19.3	710	107.3	195.0	2,828	2.70	0%	FMC Tech./Aker Sol.	2+1 Spare	Centrifugal	Aker Solutions	Jan-10		0.0	Pending Start-Up
SUBSEA SEPARATION	1	SPS Project	A		Exxon	GOM	610	2,001			80	12.1									1968			
	2	Zakum	A		BP	Abu Dhabi	22	72	0.0	0.0											1970			
	3	Argyll	A		BOET (6)	North Sea	75	246													1989			
	4	Troll C Pilot (15)	O	SUBSIS (SS Sep.and WI Sys.)	NorskHydro AS	Offshore Norway	340	1,116	4.0	2.5	250	37.8	151.0	2,190	1.60	0%	VetcoGray / Framo Eng.	1+1 Spare	Centrifugal	Framo Engineering	Sep-99	Feb-10	124.8	(Note 21)
	5	Marimba Field (24)	I,N	VASPS Field Test	Petrobras	Campos Basin	395	1,296	1.7	1.1	60	9.1	52.0	754	0.3		Cameron	1	ESP	Schlumberger (REDA)	Jul-01	Jul-08	83.8	Non Operational; Restart Undefined
	6	Tordis	O	(12), Separation, Boosting, WI	Statoil	Offshore Norway	200	656	11.0	6.8	1,500	226.6	27.0	392	2.30	10-68%	FMC Technologies	1 +1 Spare	Helico-Axial	Framo Engineering	Nov-07	Feb-10	27.0	
	7	Perdido	O	Gas Separation and Boosting	Shell	GOM	2,438	7,999	0.0	0.0	132-264	20-40	158.8	2,303	1.00	15%	FMC Technologies	5	ESPs	Baker Hughes	Feb-10		0.25	Started Up in Feb. 2010
	8	Parque Das Conchas (BC 10) Phase 1 (23)	O	Caisson / Artifical Lift Manifold	Shell	Campos Basin	2,150	7,054	40.0	25.0	185	27.9	152.0	2,205	1.10	15%	FMC Technologies	4	ESPs	Baker Hughes	Mar-10			
	9	Pazflor (5)	M	3 Gas/Liq. Vert. Separation Sys.	TOTAL	Angola, Blk 17	800	2,625	4.0	2.5	1,800	271.9	90.0	1,305	2.30	<16%	FMC Technologies	6+2 Spare	Hybrid H-A	Framo Eng./FMC Tech.	3-4Q, 2011			Framo Ex-Works Jan. 2010
	10	Marlim	M	In-Line Separation	Petrobras	Campos Basin	878	2,881	3.8	2.4	135	20.0	245.0	3,553	1.9	0	FMC Technologies	1	Centrifugal (1P)	Framo Engineering	Q3 2011			Framo Ex-Works Q1 2011
	11	Canapu Field	Q	Twister Separation Technology	Petrobras	Espirito Santo Basin	1,700	5,578	21.0	13.1							TwisterBV	none						

Operational history timeline years: 1995–2020; PRESENT; ← HISTORICAL | FUTURE →

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

NOTES:
1. See information accuracy statement below title block.
2. Power for gas compression is for the entire compression station. Pump power listed is for individual pump motors.
3. Differential Pressure values are for individual pumps.
4. Ormen Lange is a gas field, pumping low volumes of condensate. The hardware currently being built is 1 out of the 4 compression trains that ultimately will be deployed subsea when pilot unit is tested.
5. **GVF** = Gas Volume Fraction at inlet of pump.
6. British Offshore Engineering Technology.
7. **King** utilizes an umbilical which combines HV cables with the service umbilical.
8. **Nuovo Pignone** is now part of GE Oil & Gas.
9. Low wellhead pressure of 100 psig at seabed dictated that artificial lift was required.
10. **VASPS** - Vertical Annular Separation and Pumping System.
11. Year indicates first 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. **Shelley & Ptarmigan** projects were deleted from the 2010 poster due to the boosting projects for these fields were either cancelled or postponed. OILEXCO filed bankruptcy and assets were taken over by Premier Oil company.
14. **BCSS** - Centrifugal Subsea Submersible Pumps. Pumps are placed in protective holes in the seabed, 200m from the producing wells. MOBO - Modulo de Bombas (Pumping Module)
15. **Troll SUBSIS** - The world's longest operating subsea separation system and first subsea water injection pump system.
16. Manufacturers are: Framo Engineering and Centrilift. There are 2 ESPs per well feeding Framo MPP on seafloor.
17. **Navajo field** is a SS tieback to Anadarko's Nansen spar.
18. **Baker Hughes Centrilift** is now **Baker Hughes**.
19. **LUFENG** - World Operational Record: 7 Years of operation without intervention. 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. However, SS boosting began in late 2005 after natural flow period ended.
22. **CLOV** - Total reports that the CLOV development will utilize seabed multiphase pumps to boost Orquidea and Violeta Miocene from FO+2years
23. **Parque Das Conchas (BC 10) Phase 1** - Composed of 5 fields: Ostra, Abalone, Argonauta B-West, Argonauta O-North and Nautilus
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)** - Is to be implemented in 2011. Eleven (11) new wells will be connected to the FPSO P-57. All wells will have gas-lift as a backup.
26. **Cascade & Chinook** - Utilizes ESPs on a skid. It is an alternative to the MOBO system, which needs a cased hole. It is a new intiative to cover the low GVF and high DeltaP multiphase flow.
27. "According to BP: Two King pump units are installed in the field but remain shut-in due to operational issues, or capacity constraints at the Marlin TLP related to additional production from the Dorado field and King South well. One King pump is currently being repaired and upgraded."

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TABLE 3 – DRIVERS / REASONS FOR:

1.0 SUBSEA COMPRESSION
- 1.1 Increase subsea tieback distance
- 1.2 Improve flow assurance issues
- 1.3 Eliminate offshore platform(s)
- 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 Arctic regions)

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
  - 2.1.4 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 Reduce OPEX by reducing recovery time (shorten life of field)
  - 2.2.3 Offset high friction pressure losses in flowline due to fluid viscosity
  - 2.2.4 Offset elevation head pressure loss
- **2.3 FACILITIES ADVANTAGES**
  - 2.3.1 Longer subsea tiebacks
  - 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 Remove liquids from gas stream

4.0 SUBSEA SEPARATION (continued)
- 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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TABLE 4 – INDUSTRY ACRONYMS & ABBREVIATIONS

Acronym	Meaning
AL	Artifical Lift
BCSS	"Subsea Separation Systems" pictures figure 12a and 12b
BPD	Barrels per Day
BOPD	Barrels of Oil per Day
CAPEX	Capital Expenditures
COSSP	Configurable Subsea Separation & Pumping
CSSP	Centrifugal Subsea Submersible Pump
CTCU	Cable Traction Control Unit
DMBS	Deepwater Multiphase Boosting System
ESP	Electrical Submersible Pump
FFD	Full Field Development
FO	First Oil
FPS	Floating Production System
FPSO	Floating, Production, Storage, & Offloading Vessel
GOWSP	Gas-Oil-Water Separation Platform
GVF	Gas Volume Fraction
GLR	Gas Liquid Ratio
Hp	Horsepower
HV	High Voltage
ICS	Integrated Compressor System
IOR	Improved (Increased) Oil Recovery
JIP	Joint Industry Project
KBS	Kvaerner Booster Station
kW	Kilowatt
LDDM	Long Distance Delivery Management
LDDS	Long Distance Delivery System
LOF	Life of Field
MARS™	Multiple Application Re-Injection System
MBLPD	Thousand Barrels of Liquid per Day
MBOPD	Thousand Barrels of Oil Per Day
MBWPD	Thousand Barrels of Water Per Day
MMBO	Million Barrels of Oil
MMBOE	Million Barrels of Oil Equivalent
MPP	Multiphase Pump
MW	Mega Watts
NF	Natural Flow
OPEX	Operating 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
SFB	Seafloor Boosting
SIORS	Subsea Increased Oil Recovery System
SMUBS	Shell Multiphase Underwater Boost Station
SPEED	Subsea Power Electrical Equipment Distribution
SS	Subsea
SSBI	Subsea Separation Boosting Injection
SUBSIS	Subsea Separation and Injection System
SWIT	Subsea Water Injection and Treatment System
TLP	Tension Leg Platform
VASPS	Vertical Annular Separation and Pumping System
VFD	Variable Frequency Drive
VSD	Variable Speed Drive
WD	Water Depth
WGC	Wet Gas Compressor
WI	Water Injection
WIP	Water Injection Pump

ADDITIONAL RESOURCE
For those who want to understand "Subsea Processing Terminology" view Poseidon Group AS's document from the following web path: http://posccaesar.vestforsk.no/intra/Portals/0/reports/processing.pdf

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

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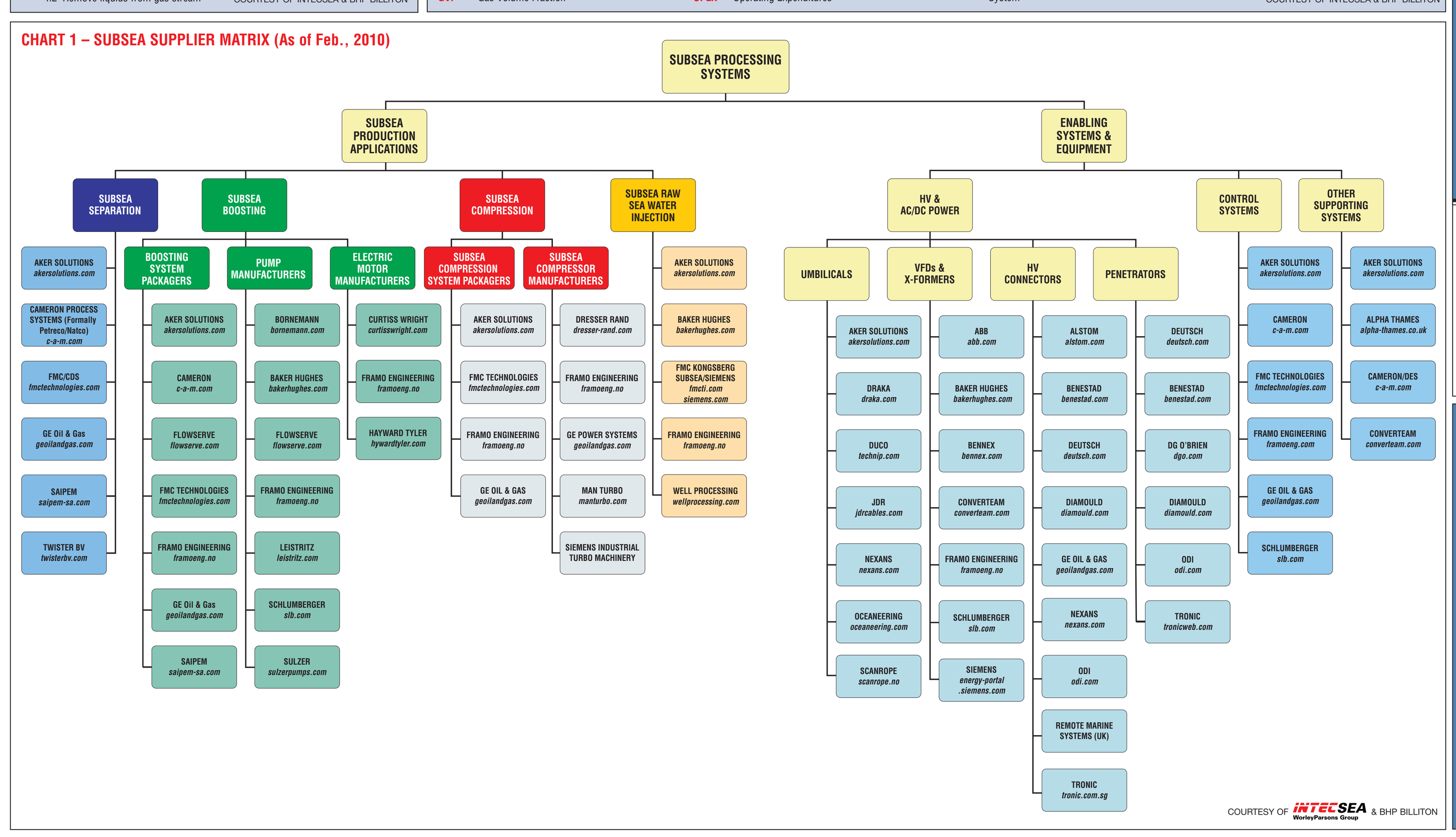
CHART 1 – SUBSEA SUPPLIER MATRIX (As of Feb., 2010)



SUBSEA SEPARATION SYSTEMS

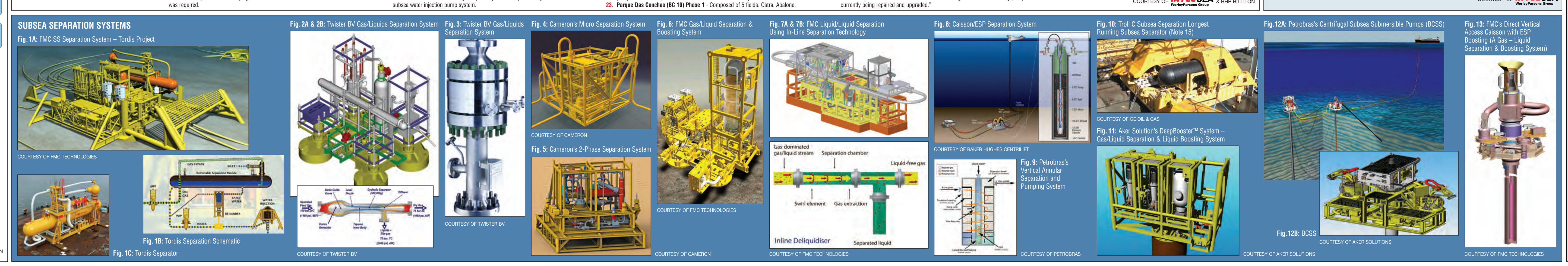
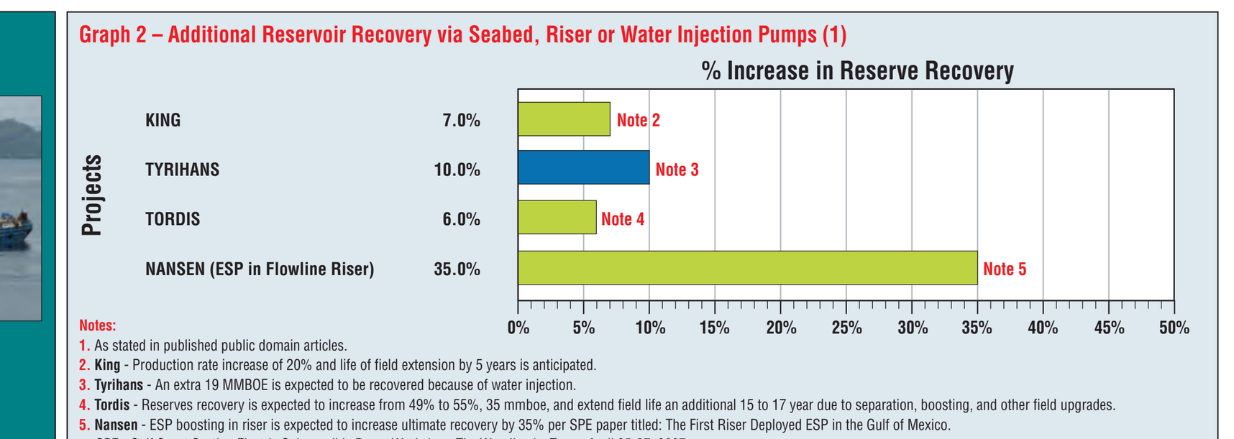


Fig. 1A: FMC SS Separation System – Tordis Project — COURTESY OF FMC TECHNOLOGIES
Fig. 1B: Tordis Separation Schematic
Fig. 1C: Tordis Separator
Fig. 2A & 2B: Twister BV Gas/Liquids Separation System — COURTESY OF TWISTER BV
Fig. 3: Twister BV Gas/Liquids Separation System — COURTESY OF TWISTER BV
Fig. 4: Cameron's Micro Separation System — COURTESY OF CAMERON
Fig. 5: Cameron's 2-Phase Separation System — COURTESY OF CAMERON
Fig. 6: FMC Gas/Liquid Separation & Boosting System — COURTESY OF FMC TECHNOLOGIES
Fig. 7A & 7B: FMC Liquid/Liquid Separation Using In-Line Separation Technology — COURTESY OF FMC TECHNOLOGIES
Fig. 8: Caisson/ESP Separation System — COURTESY OF BAKER HUGHES CENTRILIFT
Fig. 9: Petrobras's Vertical Annular Separation and Pumping System — COURTESY OF PETROBRAS
Fig. 10: Troll C Subsea Separation Longest Running Subsea Separator (Note 15) — COURTESY OF GE OIL & GAS
Fig. 11: Aker Solution's DeepBooster™ System – Gas/Liquid Separation & Liquid Boosting System — COURTESY OF AKER SOLUTIONS
Fig. 12A: Petrobras's Centrifugal Subsea Submersible Pumps (BCSS); Fig. 12B: BCSS — COURTESY OF AKER SOLUTIONS
Fig. 13: FMC's Direct Vertical Access Caisson with ESP Boosting (A Gas – Liquid Separation & Boosting System) — COURTESY OF FMC TECHNOLOGIES

Graph 2 – Additional Reservoir Recovery via Seabed, Riser or Water Injection Pumps (1)



Notes:
1. As stated in published public domain articles.
2. **King** - Production rate increase of 20% and life of field extension by 5 years is anticipated.
3. **Tyrihans** - An extra 19 MMBOE is expected to be recovered because of water injection.
4. **Tordis** - Reserves recovery is expected to increase from 49% to 55%, 35 mmboe, and extend field life an additional 15 to 17 year due to separation, boosting, and other field upgrades.
5. **Nansen** - ESP boosting in riser is expected to increase ultimate recovery by 35% per SPE paper titled: The First Riser Deployed ESP in the Gulf of Mexico. SPE - Gulf Coast Section Electric Submersible Pump Workshop, The Woodlands, Texas, April 25-27, 2007.

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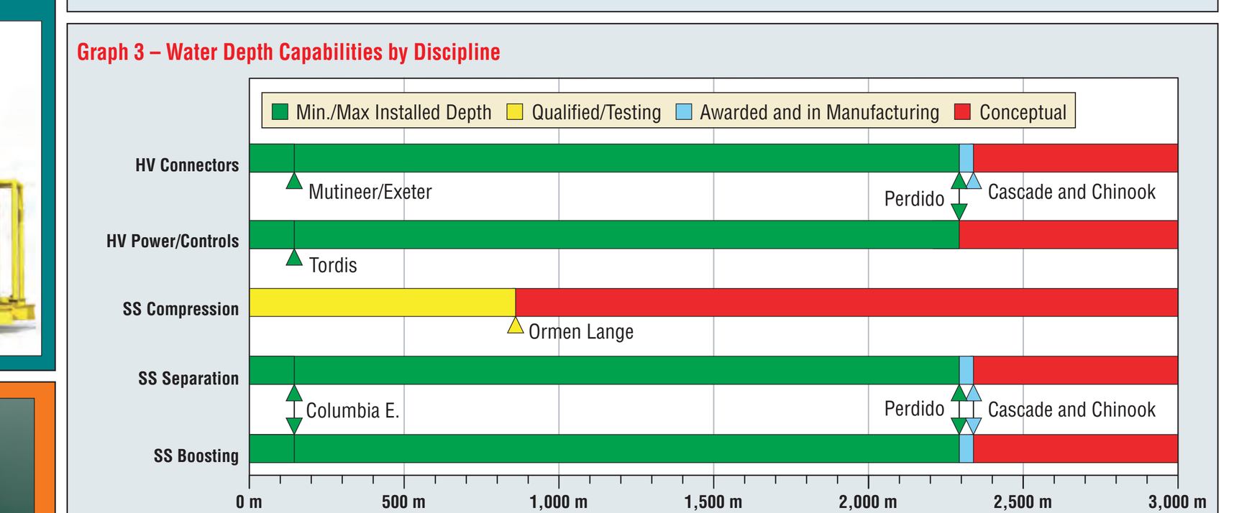
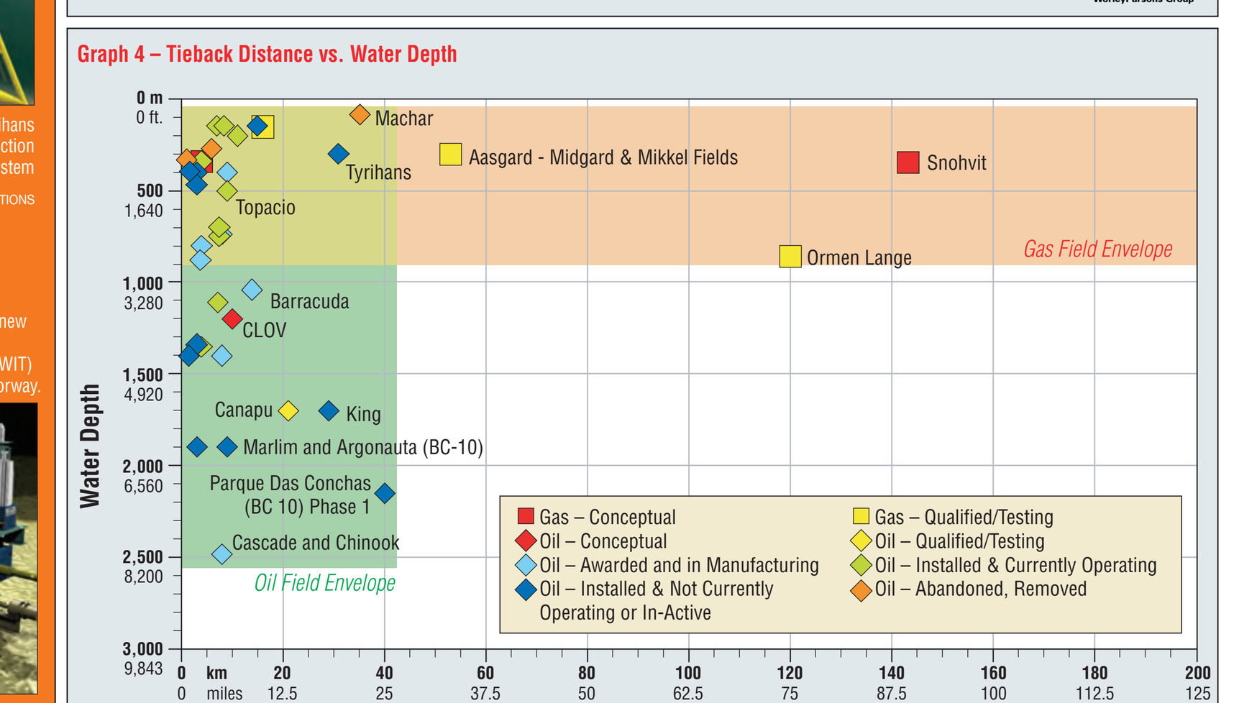
Graph 3 – Water Depth Capabilities by Discipline

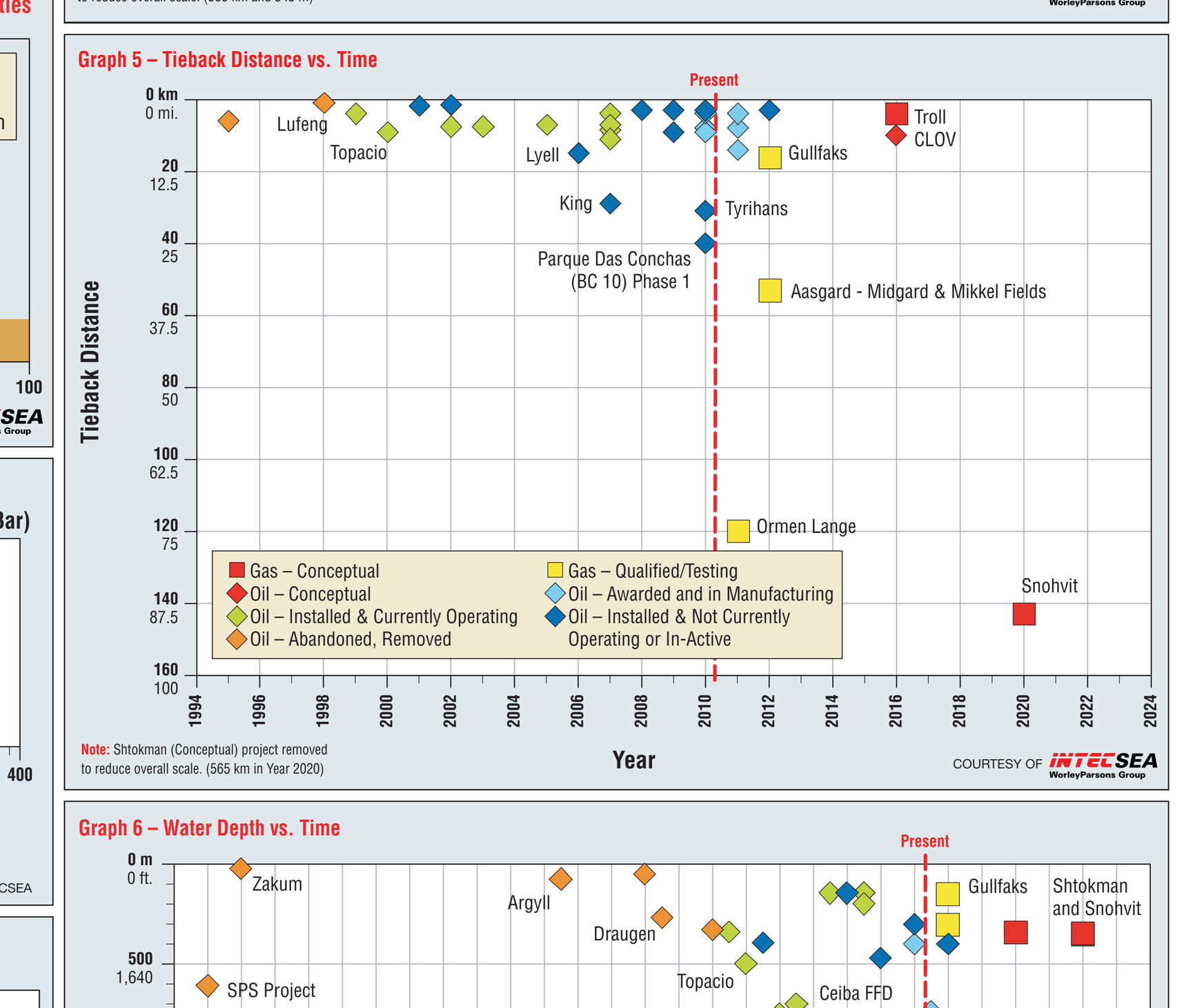


Graph 4 – Tieback Distance vs. Water Depth



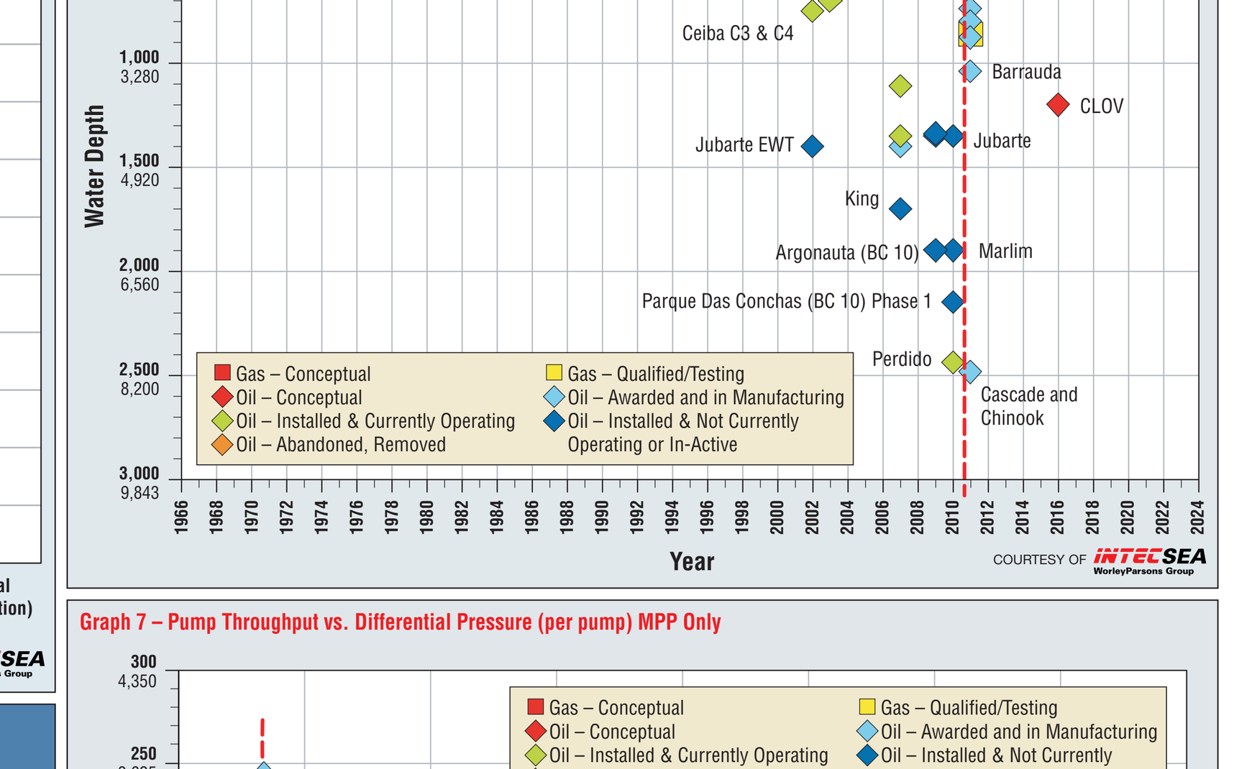
Note: Shtokman (Conceptual) project removed to reduce overall scale. (565 km and 345 m)

Graph 5 – Tieback Distance vs. Time

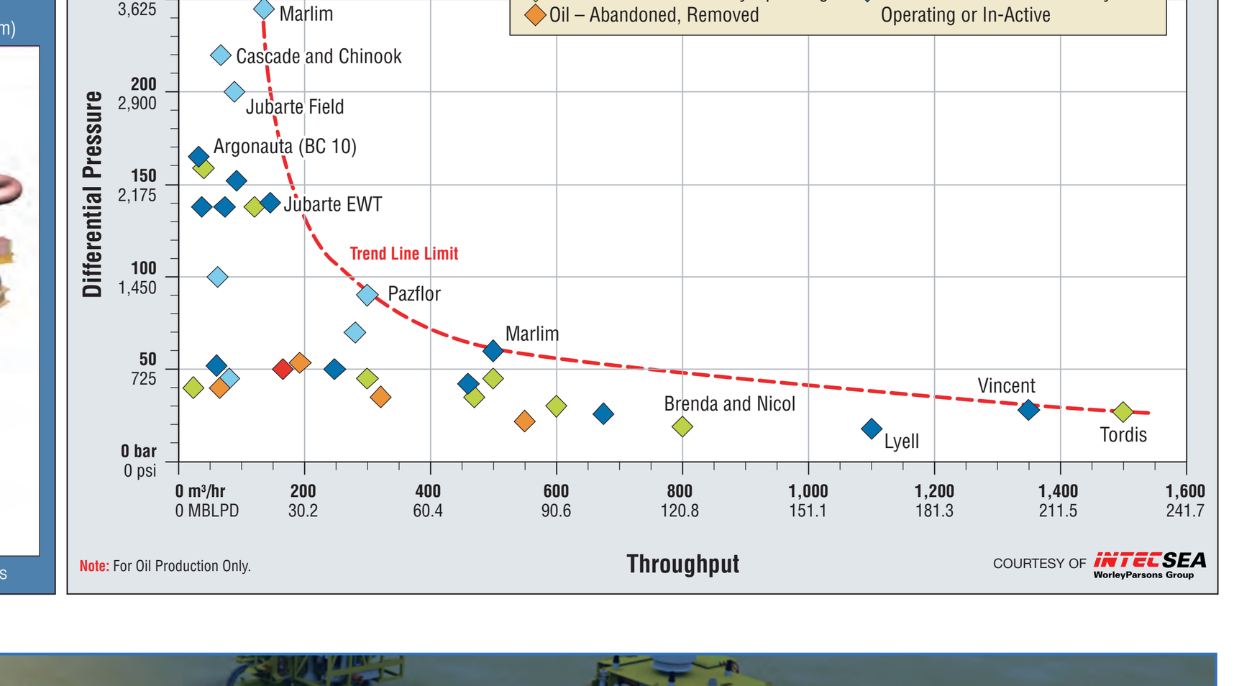


Note: Shtokman (Conceptual) project removed to reduce overall scale. (565 km in Year 2020)

Graph 6 – Water Depth vs. Time

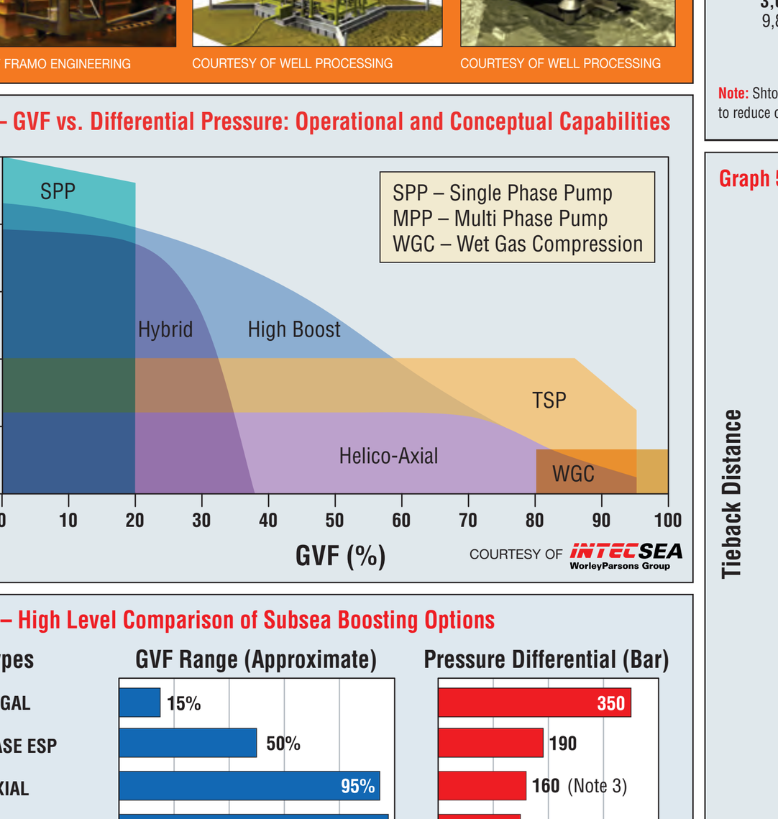


Graph 7 – Pump Throughput vs. Differential Pressure (per pump) MPP Only



Note: For Oil Production Only.

Graph 8 – GVF vs. Differential Pressure: Operational and Conceptual Capabilities



Graph 9 – High Level Comparison of Subsea Boosting Options

Pump Types	GVF Range (Approximate)	Pressure Differential (Bar)
CENTRIFUGAL	15%	350
MULTIPHASE ESP	50%	190
HELICO AXIAL	95%	160 (Note 3)
TWIN SCREW	98%	150 (Note 3)
HYBRID (CENTRIFUGAL/ HELICO AXIAL)	38%	200

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

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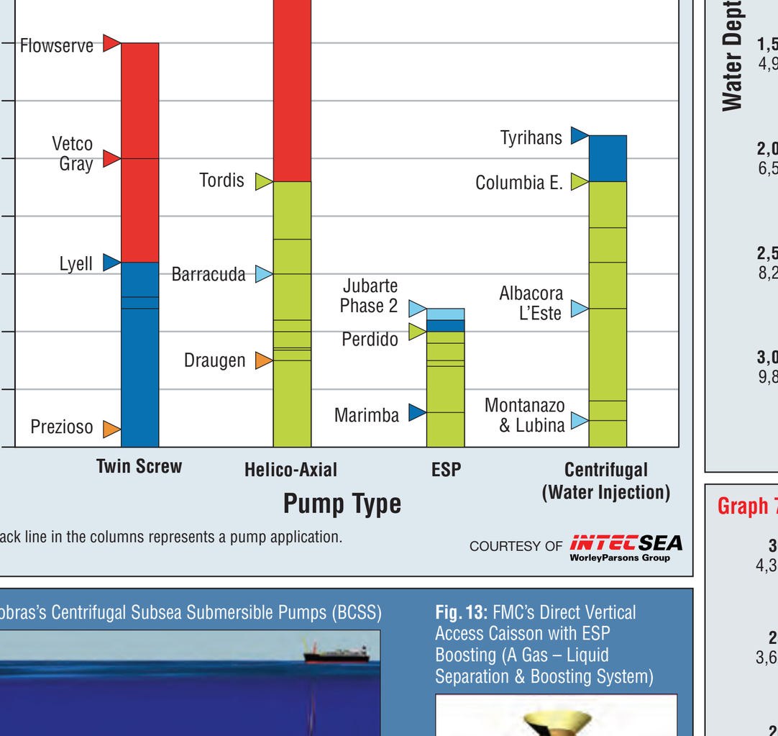
Graph 10 – Power Requirements - Individual Pumps • Separation and Boosting Only



Note: Each black line in the columns represents a pump application.