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2011 Worldwide Survey of Subsea Processing: Separation, Compression, and Pumping Systems

STATUS OF THE TECHNOLOGY

MARCH 2011

Prepared By: Mac McKee, Kalyana Janardhanan, Cody Moffitt, Spiridon Ionescu, Jim Burton of INTECSEA, and E. Kurt Albaugh, Consulting Engineer

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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 91 2011 Edition

WORLDWIDE LOCATIONS FOR SUBSEA PROCESSING SYSTEMS (As of Feb., 2011)

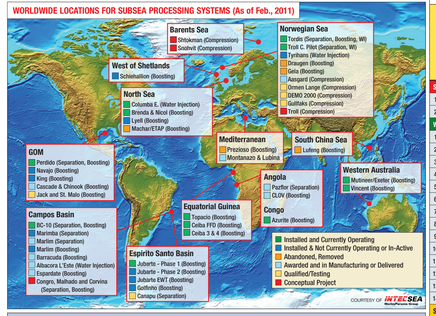

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TABLE 3 – DRIVERS / REASONS FOR:

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.a. – 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
- 4.3 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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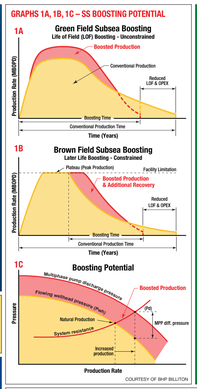
GRAPHS 1A, 1B, 1C – SS BOOSTING POTENTIAL



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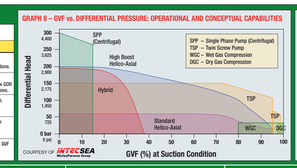
SUBSEA BOOSTING PUMP TYPES

TABLE 6 – PUMP TYPES & APPLICATIONS

	TYPE	NORMAL CONFIG.	APPLICATION
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 ● Handles moderate Gas Volume Fractions (GVF) at suction conditions or low GOR applications where GVF is consistently < 30% at suction conditions.
3	MULTIPHASE ESP	HORIZONTAL OR VERTICAL	● Widely deployed technology used for boosting in wells, caissons, flowline risers, and multiline horizontal boosting applications. ● Applicable for GVF < 30%.
4	HELICO-AXIAL	VERTICAL	● Applicable for higher GVF boosting applications for typical range from 30% to 95% GVF at suction conditions. ● Moderate particulate tolerance.
5	TWIN SCREW	HORIZONTAL OR VERTICAL	● Good for handling high Gas Volume Fractions (GVF) – up to 98% GVF at suction conditions. ● Preferred technology for high viscosity fluids.



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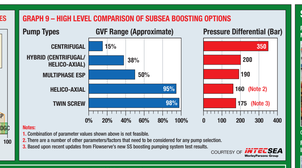

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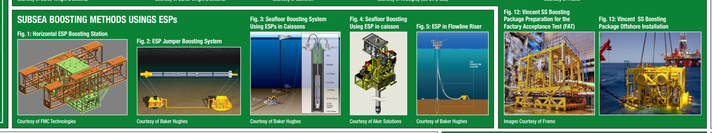
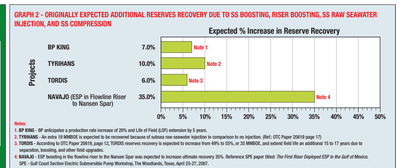


GRAPH 2 – ORIGINALLY EXPECTED ADDITIONAL RESERVES RECOVERY DUE TO SS BOOSTING, RISER BOOSTING, SS RAW SEAWATER INJECTION, AND SS COMPRESSION



GRAPH 3 – WATER DEPTH CAPABILITIES BY DISCIPLINE

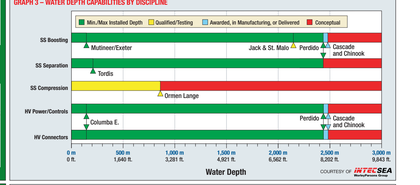


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TABLE 2 – METHODS/CONFIGURATIONS

LEGEND
- C Conceptual Project
- Q Qualified/In Qualification/Testing
- A Awarded and in Manufacturing or Delivered
- I Installed and Currently Operating
- LN Installed & Not Currently Operating or In-Active

	METHOD/CONFIGURATION	TECHNOLOGY STATUS	SAMPLE PROJECTS Where systems have progressed the furthest
	SUBSEA COMPRESSION METHODS/CONFIGURATIONS		
1	Centrifugal	M	Aasgard
2	Contra-Rotating Axial	Q	DEMO 2000, Gullfaks
	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	O	Brenda and Nicol, Mutineer/Exeter
4	MPP at Flowline Inlet	O	Ceiba, Vincent, Azurite
5	MPP at Riser Base	Q	
6	ESP Downhole in SS Well	O	Lihsa
7	ESP Downhole + MPP	O	Mutineer / Exeter
8	ESP Downhole + Caisson ESP	C	
9	ESP Downhole + ESP Horiz. Boost Station	C	
10	Gas Downhole + MPP	O	Brenda & Nicol
11	ESP Vertical Boost Station (Caisson ESP)	O	Jubarte – Phase 1, Perdido, BC-10
12	ESP Horizontal Seafloor Boost Station	M	Cascade/Chinook, Espadarte
13	ESP in Flowline Riser	LN	Navajo
14	ESP in Flowline Jumper	C	
	SUBSEA WATER INJECTION METHODS/CONFIGURATIONS		
1	Produced WI System (with SS Separation)	O	Troll C Pilot, Tordis
2	Raw Sea Water SS Injection System	O	Columba E.
	CAISSON SEPARATION AND ESP BOOSTING METHODS/CONFIGURATIONS		
1	In-line Superconic - Twister Technology	Q	Canapu Field
2	ESP Downhole Oil/Water Separation	Q	
3	ESP Downhole Gas/Liquid Separation	Q	
4	Caisson Separation & ESP Boosting	O	Perdido, BC-10
5	Caisson Non-Separation & ESP Boosting	O	BC-10
6	2-Phase - Gas/Liquid	M	Pazflor
7	2-Phase - Water/Oil with Water Injection	O	Troll C. Pilot
8	2-Phase - Hydrocarbon/Liquids + Sand	O	Tordis
9	3-Phase - Gas/Water/Oil	Q	

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

PROCESSING COUNT		FIELD OR PROJECT (Ordered by Start Date)	CURRENT STATUS	COMMENTS	OWNER/ FIELD OPERATOR	REGION/ BASINS	WATER DEPTH		TIEBACK DISTANCE		SYSTEM TOTAL FLOW RATE (IN LINE CONDITIONS)		DIFFERENTIAL PRESSURE		POWER (2)	GAS VOLUME FRACTION (GVF)	SYSTEM PACKAGER	NO. OF PUMPS	PUMP TYPE or COMPR. TYPE	COMPRESSOR/ PUMP MANUFACTURER	IN-SERVICE/OPERATING INFORMATION			OPERATIONAL HISTORY & FUTURE OPERATIONAL SCHEDULE
					COMPANY		Meters	Feet	Km	Miles	M^3/hr.	MBOPD MBWPD	BAR (3)	PSI (3)	MW	% OF VOL.	COMPANY	PUMPS or COMPR.	TYPE	COMPANY	START (1) (Month-Year)	END or PRESENT	MTHS	1996 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020
SUBSEA GAS COMPRESSION	1	DEMO 2000	Q	Statoil K-Lab Test	Statoil	Offshore Norway									3.60	n/a	Frame Engineering		Counter Axial	Frame Engineering	2001	2004		Test Program
	2	Gullfaks	Q	Wet Gas Compression	Statoil	Offshore Norway	150	492	16.0	10.0	4,800	725	30.0	435	5.00	95%	Frame Engineering	2	Counter Axial	Frame Engineering	2013			Qualification Testing To Complete Q1 2011
	3	Ormen Lange (4)	Q	Wet Gas Compression	Statoil	Offshore Norway	860	2,821	120.0	75.0	520	79	60.0	870	60.00	n/a	Aker Solutions	8	Centrifugal	GE Compr/Aker Pump	2014			
	4	Aasgard - Midgard & Mikkel Fields	C	Wet Gas Compression	Statoil	Offshore Norway	300	984	90.0	31.3	20,000	3,021	60.0	870	20.00	n/a	Aker Solutions	2+1 Spare	Centrifugal	Man Diesel & Turbo	2014			
	5	Troll	C	Wet Gas Compression	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	Snøhvit	C		Statoil	Barents Sea	345	1,132	143.0	89.4					60.00	n/a	TBA		Centrifugal	TBA	2020			
SUBSEA BOOSTING	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 Oil & Gas	1994	1995		
	2	Geia Field	A		AGIP																1994			
	3	Dnugsen Field	A	SMUBS Project, 1 MPP	A/S Norske Shell	Offshore Norway	270	886	6.0	3.7	193	29	53.3	773	0.75	42%	Frame Engineering	1	Helico-Axial	Frame Engineering	Nov-05	15-Nov-06	12.2	
	4	Lufeng 22/1 Field (9) (19)	A	Tieback to FPSO	Statoil	South China Sea	330	1,083	1.0	0.6	875	102	35.0	508	0.40	3%	Frame Eng./FMC Tech.	5+2 Spare	Centrifugal (1Y)	Frame Engineering	Jan-98	15-Jul-09	138.0	
	5	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%	Frame Engineering	2+1 Spare	Helico-Axial	Frame Engineering				Never Installed
	6	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%	Frame Engineering	2+1 Spare	Helico-Axial	Frame Engineering	Aug-00	1-Mar-11	126.2	
	7	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%	Frame Engineering	2+1 Spare	Helico-Axial	Frame Engineering	Oct-02	1-Mar-11	100.3	
	8	Jubarte EWT	LN	Riser lift to Seilman drillship	Petrobras	Espirito Santo Basin	1,400	4,593	1.4	0.9	145	22	140.0	2,000	0.70	22%	FMC Technologies	1	ESP	Schlumberger (REDA)	Dec-02	1-Dec-06	47.9	
	9	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%	Frame Engineering	5	Helico-Axial	Frame Engineering	Dec-03	1-Mar-11	86.3	
	10	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%	Frame Engineering	7 ESPs, 2+1 Spare	Helico-Axial	Frame Engineering (16)	Mar-05	1-Mar-11	71.4	
	11	Lyell	LN	SS Tieback to Nimian 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	Jan-06	Dec-08	11.0	Non Operational
	12	Navajo (17)	LN	ESP in Flowline Riser	Anadarko	GOM	1,110	3,642	7.2	4.5	4.4	4	40.2	583	0.75	57%	Baker Hughes	1	ESP	Baker Hughes	Feb-02	1-Aug-07	5.5	Non Operational
	13	Jubarte Field - Phase 1	O	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	
	14	Brenda & Nicol Fields	O	MultiMainHold with 1 MPP	OILEXCO N.S.	UK North Sea	145	476	8.5	5.3	800	121	19.0	276	1.10	75%	Frame Engineering	1+1 Spare	Helico-Axial	Frame Engineering	Apr-07	1-Mar-11	46.4	
	15	King (7) (13)	LN	SS Tieback to Marlin TLP	BP	GOM, MC Blocks	1,700	5,578	28.0	18.0	497	75	50.0	725	1.30	0-95%	Aker Solutions	2+1 Spare	Twin-Screw	Bornemann TS/Lubar	Nov-07	15-Feb-09	15.0	Non Operational
	16	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%	Frame Engineering	2+2 Spare	Helico-Axial	Frame Engineering	Aug-10	1-Mar-11	7.0	
	17	Marlim	LN	SIBMS-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
	18	Golfinho Field - Phase 1	O	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)
	19	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%	Frame Engineering	2+1 Spare	Helico-Axial	Frame Engineering	Sep-10	15-Mar-11	5.9	
	20	Golfinho Field - Phase 2	LN	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			0.0	Not yet operational at press time
	21	Espadarte	M	Horizontal ESP on Skid	Petrobras	Brazil	1,350	4,429			125	19	100.0	1,450	0.90	10-40%	FMC Technologies	2	ESP	Baker Hughes	2011		0.0	Delayed Start Up
	22	Parque Das Conchas (BC-10) Phase 1 (23)		Caisson/Artificial 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-11	19.5	
	23	Jubarte Field - Phase 2 (25)	LN	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
	24	Cascade & Chinook (6)		Skid BCSS - Horizontal ESP on Skid	Petrobras	US GOM	2,464	8,150	8.0	5.0	135	20	220.0	3,191	1.10	20%	FMC Technologies	2+2 Spare	ESP	Baker Hughes	Q2 2011		0.0	Start delayed until 2011
	25	Barracuda	O	Single MPP System	Petrobras	Campos Basin	1,040	3,412	14.0	8.8	280	42	70.0	1,015	1.00	50%	Frame Engineering	1	Helico-Axial	Frame Engineering	Q2 2011		0.0	Ex-Works Frame Q4 2010
	26	Montanazo & Lubina	N	Single MPP System	Repsol	Mediterranean	740	2,428	8.0	5.0	80	12	45.0	653	0.23	0%	Frame Engineering	1+1 Spare	Centrifugal (1P)	Frame Engineering	Q2 2011		0.0	Ex-Works Frame Q4 2010
	27	Schiehallion	LN	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%	Vetco Gray/Frame Eng.	4	Helico-Axial	Frame Engineering	2013	Delayed Start Up		Pending FPSO rebuild
	28	CLOV (22)		Subsea Boosting	TOTAL	Angola, Blk 17	1,200	3,940	10.0	6.2	660	100	50.0	725	2.30	55%	Frame Engineering	2	MPP	Frame Engineering	2014			
	29	Jack & St. Malo (Phase 1)	Q	Full Wellstream Subsea Boosting	Chevron	US GOM	2,134	7,000	13.0	21	1191	180	241.3	3,500	0.00	10%	TBD	3 (TBC)	Centrifugal (1P)	TBD	2014			
SUBSEA WATER INJECTION	1	Troll C Pilot (15)	Q	SUBSIS (SS Sep. and WI Sys.)	Statoil	Offshore Norway	340	1,116	3.5	2.2	250	38	150.0	2,176	1.60	0%	Vetco/Gray/Frame Eng.	1+1 Spare	Centrifugal (1P)	Frame Engineering	Aug-01	15-Mar-11	114.4	
	2	Columba E.	O	Dual SPP System	CNR	North Sea	145	476	7.0	4.3	32	50	330.0	4,641	2.30	0%	Frame Engineering	2	Centrifugal (1P)	Frame Engineering	May-07	1-Mar-11	45.4	
	3	Tordis (9(f))	O	Single MPP System, WI (12)	Statoil	North Sea	210	689	11.0	6.8	700	106	77.0	1,117	2.30	0%	FMC Technologies	1+1 Spare	Centrifugal (1P)	Frame Engineering	Oct-07	May-08	7.0	See OTC paper 20619, page 16
	4	Albacora L'Este Field	O	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)	Frame Engineering	Q2 2011			Awaiting installation, Frame ex-works
	5	Tyrihans	LN	Raw Water Injection	Statoil	Offshore Norway	270	886	31.0	19.3	583	88	205.0	2,973	5.00	0%	FMC/Aker Solutions	2+1 Spare	Centrifugal (1P)	Aker Solutions	Sep-10	1-Mar-11	5.9	
SUBSEA SEPARATION	1	Troll C Pilot (15) (21)	O	SUBSIS (SS Sep. and WI Sys.)	Statoil	Offshore Norway	340	1,116	3.5	2.2	n/a	n/a	n/a	n/a	n/a	n/a	Vetco/Gray/Frame Eng.	n/a	n/a	n/a	Aug-01	1-Mar-11	113.9	
	2	Marimba Field (24)	LN	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	83.8	Non-operational; Restart undefined
	3	Tordis	O	Separation, Boosting, WI (12)	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	Frame Engineering	Oct-07	1-Mar-11	40.4	See OTC paper 20619, page 16
	4	Parque Das Conchas (BC 10) Phase 1 (23)		Caisson Sep./Artificial 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-11	18.5	
	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-11	11.0	
	6	Pazflor	N	3 x Gas/Liq. Wert. Separation Systems	Total	Angola, Blk 17	800	2,625	4.0	2.5	1,800	272	90.0	1,305	2.30	<10%	FMC Technologies	6+2 Spare	Hybrid H-A	Frame Eng./FMC Tech.	3-4Q, 2011		<10%	Frame ex-works Jan 2010
	7	Marlim	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)	Frame Engineering	Q3 2011			Frame ex-works Q1 2011
	8	Congro, Malhado & Corvina	O	VASPS w/Horizontal ESP	Petrobras	Campos Basin											TBD				2012			
	9	Canapu Field	Q	Twister BV Separation Technology	Petrobras	Espirito Santo Basin	1,760	5,578	21.0	13.1							Tw