

**West Coast Regional Carbon Sequestration Partnership  
(WESTCARB)**

**Assessment of Natural Gas Combined Cycle Plants for Carbon  
Dioxide Capture and Storage in Gas-Dominated Electricity Market –  
Request for Proposals  
RFP# 500-10-502**

**PRELIMINARY ASSESSMENT PAPER**

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## SUMMARY OF KNOWN CO<sub>2</sub> CAPTURE TECHNOLOGIES

TECHNOLOGY DEVELOPER	CAPTURE PROCESS	METHOD and/or MEDIUM	LEVEL OF DEVELOPMENT	REMARKS
3H Company	Chemical Absorption	Phase Transition Absorbent – Proprietary solvent	Laboratory-scale testing	Uses a two-part proprietary absorbent that consists of an activated agent dissolved in a solvent with separation of two liquid phases after absorption.
ADA-ES, Inc.	Chemical Adsorption	Solid Sorbents	In development	Uses reversible adsorption of CO <sub>2</sub> on amine surface-bonded materials such as silica gel.
Air Products	Membrane	Ion Transfer Membranes (ITM) – Non-porous “Perovskite” Ceramic Materials	Pilot-scale testing with larger modules under production	Membranes being developed to reduce parasitic load from cryogenic air separation units used in oxy-combustion process.
Aker Clean	Chemical Absorption	Just Catch – Proprietary Amine	Pilot-scale (slip-stream) testing	Testing two different solvent mixtures.
Alstom	Chemical Absorption	Chilled Ammonia	Pilot-scale (slip-stream) testing	Uses ammonia-CO <sub>2</sub> -water system to capture CO <sub>2</sub> from flue gas.
Alstom	Chemical Looping	Limestone-Based Chemical Looping	In development	Separates oxygen from air without using cryogenics or membrane separation. Converts fuel to energy with capture of CO <sub>2</sub> produced inherent in the process.
Cansolv	Chemical Absorption	DC 103 – Proprietary Amine	Pilot-scale (slip-stream) testing	Can integrate CO <sub>2</sub> and SO <sub>2</sub> capture in a single absorber.

<b>TECHNOLOGY DEVELOPER</b>	<b>CAPTURE PROCESS</b>	<b>METHOD and/or MEDIUM</b>	<b>LEVEL OF DEVELOPMENT</b>	<b>REMARKS</b>
Carbozyme, Inc.	Membrane	Enzymatic Carbonic Anhydrase	Laboratory-scale testing	Uses two sets of micro-porous hollow fiber membranes separated by a liquid enzyme to promote absorption and conversion of CO <sub>2</sub> on the feed side and then reverses the process on the permeate side to enrich CO <sub>2</sub> in the captured stream.
Clean Energy Systems (CES)	Cryogenic Oxy-Fuel	Conventional Cryogenic Oxygen	Pilot-scale testing planned	Cryogenic air separation to produce oxygen. Advanced concepts are being developed to reduce parasitic load.
CO2/CRC-Australia	Membrane	Hollow Fiber Membrane (HFM)	In development	Uses a membrane to separate feed gas from a liquid solvent. CO <sub>2</sub> is selectively absorbed into the solvent through the pores in the membrane. Testing a range of membrane materials with a range of solvents.
Codexis	Chemical Absorption	Carbonic Anhydrase Enzyme Catalyzed	Laboratory-scale testing	Uses methyldiethanolamine (MDEA) solution instead of the more common monoethanolamine (MEA) to increase solvent CO <sub>2</sub> capacity and thermal stability, reduce regeneration heat, and reduce solvent corrosivity.
Eltron Research	Membrane	H <sub>2</sub> Transport Membrane (HTM)	In development	Uses composite metal alloy or ceramic/metallic mixture to separate hydrogen from syngas. CO <sub>2</sub> on feed side remains at high pressure and at a concentration suitable for capture.
Fluor-Daniel	Chemical Absorption	Econamine FG Plus <sup>SM</sup> - Inhibited Amine	In demonstration and/or commercially available	Fluor's Econamine FG Plus <sup>SM</sup> is an advanced version of Econamine FG <sup>SM</sup> , a patented commercially available process.

<b>TECHNOLOGY DEVELOPER</b>	<b>CAPTURE PROCESS</b>	<b>METHOD and/or MEDIUM</b>	<b>LEVEL OF DEVELOPMENT</b>	<b>REMARKS</b>
Georgia Tech, et al	Chemical/ Physical Absorption	Ionic Liquid	In development with preliminary results	Uses organic salts with low melting points and negligible vapor pressure to increase CO <sub>2</sub> loading and reduce heating costs for regeneration.
HTC Pureenergy	Chemical Absorption	Proprietary Amine	Pilot-scale (slip-stream) testing	Solvent tailored to customer needs to reduce costs of capture.
Kerr-McGee/ABB Lummus	Chemical Absorption		Developed/applied in small scale in last 30 years.	
Linde AG & Lurgi AG	Physical Absorption	Rectisol Process - Methanol-Based Solvent	Commercially available	
Membrane Technology & Research (MTR)	Membrane	Hollow Fiber Membrane	In development	Requires high CO <sub>2</sub> partial pressure difference to drive gas diffusion across membrane. Lower post-combustion pressures necessitate membranes with higher permeabilities.
Mitsubishi Heavy Industries (MHI) & Kansai Electric	Chemical Absorption	KM-CDR – Proprietary solvent	In demonstration phase and/or commercially available	Typifies basic chemical absorption process commonly used. Flue gas is cooled and reacted with an amine-based CO <sub>2</sub> absorbing solution. The CO <sub>2</sub> -rich solution is then heated to release the CO <sub>2</sub> for capture and the treated solution reused. Proprietary solvent solution used.
Powerspan	Chemical Absorption	ECO2 Aqueous Ammonia	Pilot-scale (20 tons CO <sub>2</sub> /day) testing	Scrubber process uses an ammonia-based solution to capture CO <sub>2</sub> from flue gas.
Praxair	Cryogenic Oxy-Fuel	Conventional Cryogenic Oxygen	In development	Uses low temperature cryogenic distillation to capture CO <sub>2</sub> from oxy-combustion flue gas.

<b>TECHNOLOGY DEVELOPER</b>	<b>CAPTURE PROCESS</b>	<b>METHOD and/or MEDIUM</b>	<b>LEVEL OF DEVELOPMENT</b>	<b>REMARKS</b>
Praxair	Membrane	Oxygen Transport Membrane	In development	Membranes being developed to reduce parasitic load from cryogenic air separation units used in oxy-combustion process.
RTI International	Membrane	Polymeric Membrane	In development	Requires high CO <sub>2</sub> partial pressure difference to drive gas diffusion across membrane. Lower post-combustion pressures necessitate membranes with higher permeabilities.
RTI	Physical Adsorption	Warm Gas Cleanup	Pilot-scale (0.5 MWe) testing	Separates CO <sub>2</sub> from syngas at higher temperatures thereby reducing costs associated with cooling the gas.
Siemens	Chemical Absorption	POSTCAP – Proprietary Amine	Pilot-scale (slip-stream) testing	Uses amino-acid salt formulations.
SRI International	Chemical Adsorption	Solid Sorbents	In development	Uses reversible adsorption of CO <sub>2</sub> on amine surface-bonded materials such as silica gel.
TDA Research, Inc.	Chemical Adsorption	Solid Sorbents	In development	Uses reversible adsorption of CO <sub>2</sub> on amine surface-bonded materials such as silica gel.
University of Akron	Chemical Adsorption	Amine-Grafted Zeolite	In development	
UOP	Chemical/Physical Adsorption	Metal Organic Framework	In development with preliminary results	Pillared and inter-layered microporous compounds with open channels sized for gas molecules.
UOP	Physical Absorption	Selexol Process - Glycol-Based Solvent	Commercially available	
Vattenfall/Air Products	Cryogenic Oxy-Fuel	Conventional Cryogenic Oxygen	Pilot plant in operation	Air Products ion transfer membranes are also being developed to help reduce parasitic load.

**WESTCARB NGCC-CCS Study**  
**Large California NGCC Plants - Summary for Plants Planned or Under Construction**

**Configuration Key:**

CS = Common Shaft (ST and GT drive a single generator);  
 IEC= Inlet Evaporative Cooling; IAC = Inlet Air Chiller; SI = Steam Injection; DF = Duct Firing;  
 1P-1T = single-pressure, once-through HRSG;  
 Wet CT = Wet Mechanical Draft Cooling Tower; Wet/PA = Wet, Plume-Abated CT;  
 ACC = Air Cooled Condenser; WS-ACC = Wet Surface Air Cooled Condenser;  
 ACHE = Air-cooled heat exchanger for condenser cooling;  
 WSAC = Wet Surface Air Cooler for Lube Oil, etc;  
 ZLD = Zero Liquid Discharge Wastewater System

**Notes:**

- (1) From pointer location on aerial photos at www.msrmaps.com
- (2) "Est'd Capacity Factor" from licensing documents
- (3) Per AFC and Compliance documents, not confirmed with owner.
- (4) "CPUC approves plans to convert Tracy power plant to flexible combined cycle facility." PennEnergy.com: August 2, 2010.

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**From CEC List of Approved Projects as of 7/30/2010**  
**Plants Approved and/or Under Construction (Arranged By Target Online Date)**

	Project Name - Developer	Docket Number	Location County	Capacity (MW)	Date Approved by CEC	Const. Start Date	Target (Original) Online Date	Status	Const. Completed (%)	Technology	Configuration	No. of F & H GT's	No. of F & H Power Blocks	Combustion Turbine Model	Water/Wastewater <sup>(3)</sup>	NOTES	Plant Latitude <sup>(1)</sup>	Plant Longitude <sup>(1)</sup>	Est'd Capacity Factor <sup>(2)</sup>	
3	Colusa II Generation Station - PG&E	2006-AFC-9	Colusa	660	4/23/2008	7/28/2008	10/2010 (6/2010)	Under Construction	91	Combined Cycle	2x1, IEC, DF, ACC, WSAC for lube oil, aux boiler 44 MMBtu/hr, gas-fired water bath fuel-gas heater	2	1	GE 7FA	<400 acre-feet per year (AFY) from Tehama-Colusa Canal for process and utility water; sanitary septic system		39.368	-122.270		
5	Lodi Energy Center - NCPA	2008-AFC-10	San Joaquin	296	4/21/2010	7/2010	5/2012 (4/2012)	Under Construction	1	Combined Cycle	1x1 Flex Plant 30, IEC, Wet CT, aux boiler 36.5 MMBtu/hr	1	1	Siemens STG6-5000F	~1651 AFY recycled water from WPCF treated onsite. 1281 avg to 1810 max gpm. 189 gpm max process WW to Underground Injection Well.	Originally 255 MW with GE 7FA Rapid Response with DF	38.0880	-121.3876	70-80%	
6	Avenal Energy - Avenal Power Center, LLC	2008-AFC-1	Kings	600	12/16/2009	4/2010	6/2012 (12/2011)	Pre-Construction	0	Combined Cycle	2x1, IAC, DF, ACC, aux boiler 34.7 MMBtu/hr	2	1	GE 7FA	Raw water from City of Avenal/San Luis Canal for Steam cycle makeup; potable for FW & domestic. ZLD. Sanitary septic system.		36.0943	-120.0611		
7	El Segundo Repower - NRG (per pending Amendment)	2000-AFC-14 (See also El Segundo Amend. 00-AFC-14C in Active list)	Los Angeles	560	2/2/2005	11/13/2009	12/2012 (2007)	Under Construction	1	Siemens Rapid Response Combined Cycle (R2C2)	2x1X1 CS, IEC, SI, 1P(-1T?), ACC+ACHes, ZLD,	2	2	Siemens SGT6-5000F	647.3 AFY Reclaim-single-pass-RO + Irrigation Quality; 0.84 AFY Potable; ZLD + Offsite demineralizer regen	Originally 630 MW. Now 1x1 w/ 60 MW single pressure, non-reheat STs; exhaust is condensed in the air cooled back pressure heat exchanger (BPHX); ACHes for auxiliaries	33.9106	-118.4250	up to 60% as amended	
8	Victorville Hybrid Gas-Solar - City of Victorville	2007-AFC-1	San Bernardino	563	7/16/2008	?	2013 (8/2010)	Pre-Construction	0	Combined Cycle + Solar Thermal	2x1, IEC, DF+Solar, Wet CT	2	1	GE 7FA	Reclaimed water from Victor Valley Wastewater Reclamation Authority; ZLD process wastewater; city water & sanitary sewer for domestic use	250 acre solar thermal = ~50 MW duct firing	34.6437	-117.3710		
11	Tracy Combined Cycle - GWF Energy LLC	2008-AFC-7	San Joaquin	169+145 =314	3/24/2010	?	Summer 2012 <sup>(3)</sup> (?)	Approved	0	Combined Cycle (Upgrade from Simple Cycle)	2x1, IEC, DF, ACC, WSAC for lube oil, aux boiler 85 MMBtu/hr			GE 7EA	54.4 AFY; 87 gpm avg: 37 gpm of raw water from BBID/Delta-Mendota Canal and 50 gpm of plant process recycled water. Process wastewater stored/trucked; sanitary septic system	GE 7EA simple cycle units to be upgraded to flexible combined cycle. Key power purchase agreement approved by CPUC in July 2010. Construction start targeted for Q4 2010.	37.7144	-121.4888		
<b>Total Approved In Development or Under Construction</b>				<b>2,679 MW</b>											<b>9 F &amp; H GTs</b>	<b>6 F &amp; H Power Blocks</b>				

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From CEC List of Approved Projects as of 7/30/2010 Projects Approved and On Hold										Technology	Configuration	No. of F & H GT's	No. of F & H Power Blocks	Combustion Turbine Model	Water/Wastewater (3)	NOTES	Plant Latitude <sup>(1)</sup>	Plant Longitude <sup>(1)</sup>	Est'd Capacity Factor <sup>(2)</sup>
1	Russell City - Calpine & GE	2001-AFC-07	Alameda	600	10/03/2007	On Hold	On Hold (12/2004)	On Hold	-	Combined Cycle	2x1, DF, Wet CT	2	1	Siemens W501FD	Onsite treatment of secondary effluent for Recycled Water, ZLD; city water for domestic/firewater		37.6380	-122.1364	
3	Morro Bay - L.S. Power	2000-AFC-12	San Luis Obispo	1,200	8/2/2004 Note: Commission decision not finalized pending NPDS permit	On Hold	On Hold	On Hold	-	Combined Cycle	2 -- 2x1, DF, Once- through CW	4	2	GE 7FA	Seawater, subject to flow limits & habitat remediation	Site judged not suitable for ACC; will use once-through seawater and habitat mitigation. Wells for industrial/domestic supply; WW treat on site to outfall or disch to sanitary sewer.	35.3756	-120.8589	
4	Tesla - FPL	2001-AFC-21	Alameda	1,120	6/16/2004	On Hold	On Hold (License Expired?)		-	Combined Cycle	2x2x1, IEC, DF, Wet/PA	4	2	GE 7FA	~5100 AFY from CA Aqueduct per Agreement with Rosedale/Rio Bravo District; ZLD + sanitary septic system		37.7410	-121.5720	
6	Pastoria Simple Cycle Addition - Calpine	2005-AFC-1	Kern	160	12/18/2006	On Hold	On Hold (6/2007)		-	Simple Cycle	1xSC, IEC (fogging)			GE 7FA	Existing PL from CA Aqueduct; source: Wheeler Ridge Maricopa Water Storage District, Kern Water Bank contacts; existing ZLD	Addition to 2x1 + 1x1 config	34.955	-118.846	
8	East Altamont - Calpine	2001-AFC-04	Alameda	1,100	8/20/2003	8/19/2011 (Deadline extended)	On Hold (7/2005)	On Hold	-	Combined Cycle	3x1, IEC, SI, DF, Wet CT, ZLD, aux boiler	3	1	GE 7FB	~4618 AFY surface water from the Byron Bethany Irrigation District (BBID).	1 MW NG fired emergency gen; diesel fire pump	37.8056	-121.5755	
11	Blythe II - Caithness	2002-AFC-01, 2009-10- 26_Amendment.pd f	Riverside	569-520	12/14/2005	On Hold	On Hold		-	Siemens Flex Plant 30 Rapid Start Combined Cycle	2x1, IAC, DF, Wet CT, Aux Boiler 60 MMBtu/hr	2	1	Siemens SGT6- 5000F	3,300 AFY degraded groundwater from 2x3000 gpm well, ZLD with standby evap pond; sanitary septic system; voluntary conservation offset.	CO2e = 1,870,000 – 1,930,000 metric tons/year; 538 MW max output	33.6139	-114.6864	
<b>Total Approved -- On Hold</b>				<b>4,700 MW</b>									<b>15 F &amp; H GTs</b>	<b>7 F &amp; H Power Blocks</b>					

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From CEC List of Projects in Review as of 7/30/2010 (Arranged in Alphabetical Order)														Technology	Configuration	No. of F & H GT's	No. of F & H Power Blocks	Combustion Turbine Model	Water/Wastewater (3)	NOTES	Plant Latitude <sup>(1)</sup>	Plant Longitude <sup>(1)</sup>	Est'd Capacity Factor <sup>(2)</sup>
Project Name - Developer	Docket Number	Location County	Capacity (MW)	AFC Filing Date	Const. Start Date	Target (Original) Online Date	Status	Const. Completed (%)															
6	Carlsbad - NRG	2007-AFC-6	San Diego	558 gross 540 net	9/14/2007	Q1-2 2010 in Nov'09 FSA	Summer 2012 in Nov'09 FSA (7/2010)		-	flex Plant 10 Combined Cycle	2x1, IEC, SI, ACC	2	1	Siemens SGT6- PAC5000F	Reclaimed or desal for industrial water uses; potable from Carlsbad Municipal Water District		33.1431	-117.3324					
8	CPV Vaca- Station - CPV Vacaville LLC	2008-AFC-11	Solano	660	11/18/2008		?		-	Combined Cycle	2x1, IEC, SI, DF, Wet CT, Aux Boiler	2	1	GE 7FA or Siemens SGT6- PAC5000F	Reclaimed (Secondary) WW, treat on site, up to 6.3 mgd; Tertiary backwash to WWTF; ZLD for balance (+sanitary sewer)		38.3390	-121.8970					
9	El Segundo Power Redevelopment Projects, Dry Cooling Amendment - NRG	2000-AFC-14C	Los Angeles	See 00-AFC-14	6/22/2007		? (6/10)		-	SEE ABOVE under licensed projects				SEE ABOVE under licensed projects		33.9106	-118.4250						
11	Hybrid Gas-Solar City of Palmdale (555 MW gas + <b>62 MW solar</b> )	2008-AFC-9	Los Angeles	617	8/4/2008		2013		-	Combined Cycle + Solar Thermal	2x1, IEC, DF+Solar, Wet CT, ZLD	2	1	GE 7FA	Tertiary WW for cooling from City of Palmdale w Backup from Lancaster via regional backbone, ZLD (+Sanitary Sewer)	250 Acre Solar Field	34.6465	-118.1042					
14	Marsh Landing Generating Station - Marsh Landing LLC	2008-AFC-3	Contra Costa	999 760	5/30/2008		?		-	Now Simple Cycle (originally CC + SC)	Four Simple Cycle peakers with IEC plus two NG fired preheaters (dew point heaters)	(four "F" in SC)		Siemens SGT6- 5000F	On-site degraded groundwater	Originally filed as two Flex Plant 10 CC units (550 MW) at 40-50% capac factor plus two simple cycle peakers at <10% est capac factor; The FP10 units can operate at partial load, with the CTGs operating down to minimum load (60 percent) while keeping the STG on-line or off-line.	38.0186	-121.7662	Up to 20%				
15	Oakley Generating Station (formerly Contra Costa)	2009-AFC-4	Contra Costa	624	6/30/2009		?		-	Combined Cycle	2x1, IEC, ACC, ACHE+WSAC for aux- cooling loop, Aux boiler 34 kpph	2	1	GE 7FA with metallurgical upgrade for 213 MW nominal	Potable water (95 gpm average, 369 gpm peak, 240 AFY average annual) for process/domestic; discharge to Ironhouse Sanitary District sewer		38.0112	-121.7481	60-80%				
-	San Gabriel - Reliant	2007-AFC-2	San Bernardino	[656]	4/13/2007		-	Suspended During Review	-														
25	Willow Pass Generating Station - Mirant	2008-AFC-6	Contra Costa	550	6/30/2008		7/2012		-	Flex Plant 10 Combined Cycle	2--1x1, IEC, DF, ACC, Fuel Gas Preheater	2	1	Siemens SGT6- 5000F	~781 AFY total consumption; Delta Diablo Sanitation District recycled water/wastewater return. City of Pittsburg potable water. Reclaimed (Secondary) WW, treat on site, up to 6.3 mgd; Tertiary backwash to WWTF; ZLD for balance (+sanitary sewer)		38.0415	-121.8935	40-50%				
<b>Total in Review by CEC</b>				<b>3,201 MW</b>							<b>10 F &amp; H GTs</b>	<b>5 F &amp; H Power Blocks</b>											

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