Project Number: 900719

Project Start: Jan. 1, **2007** **Project Duration (in years):** **4**

Please indicate what type of project is being proposed (mark only one).

[ ] Feasibility/Scoping [Less than 100 days effort]	[X] Development[1]	[ ] Research	[ ] Infrastructure[1]	[ ] Education
	[ ] Time Series	[X] Institute Initiative		

Project Manager[2]: William Kirkwood

Principal Investigator: Peter Brewer

Lead Scientist:

Lead Engineer:

Project Title: FOCE
Free Ocean CO_2 Enrichment
(continuing project)

[1] Development and infrastructure projects must complete the risk matrix (see item #5 at the end of the proposal form).
[2] Not all projects will require all four titles to be filled in. Please indicate individuals only for those titles that are appropriate for your project.

1) ABSTRACT (new projects only)

In preliminary work we have developed and tested a prototype sea-floor Free Ocean CO_2 Enrichment (FOCE) system, using acid injection with controlled loop pH feedback to maintain a specified ΔpH within a 2m diameter ring. Several aspects of the early work have shown promise as well as strong interest from the science community. The prototype results clearly showed that control was possible, but that a new design was necessary to address issues discovered while performing in situ testing. The primary developments needed are to extend the work to actual CO_2 enrichment, with all the complexity that requires, and to account for the significant lag times for full development of the pH signal. Plans for additional gas manipulation options are desired, for example there is strong interest in controlling oxygen levels. Another area of development still to be addressed is tissue sampling and preservation for recovery of specimens obtained from animals who are exposed to the CO_2 enriched sea water. Depending on the science requirements two distinctly different approaches are being requested. The primary design planned is for a small controlled flume, with a delay loop to allow the full ΔpH signal time to be developed, thereby avoiding the very large pumping requirements associated with high velocity events. We propose using the MARS cable for development purposes, with the power supply and real time access to data created by this facility. Year 1 will see technical development and component testing, with active engagement in the permit planning and public outreach process. Year 2 will see the first short-term assembled system tests, with ROV delivery of CO_2 enriched water to the experimental site. Year 3 will see final testing, and the inclusion of external user groups in developing use scenarios and system training.

2) PROPOSAL

a) <u>New Projects</u>

Statement of the problem, why it is important

N/A

How does it relate/contribute to MBARI's mission and strategic plan?

N/A

Approach to the problem

N/A

Publications (from other projects over the last 5 years)

N/A

b) <u>Continuing Projects</u>

If the proposed project includes multiple individual projects, please list each of these projects as a subheading in the proposal. For each subheading, please address the following:

Current status of project and results to date

The FOCE project has made progress this year albeit not per the original plans. We had expected to plug the first engineering test unit into the MARS Cabled Observatory by May of 2008. That has not been accomplished as yet due to the cable failure on MARS. We did however regroup and come up with a work around, to use the ROV Ventana as a MARS substitute. We changed the build of the FOCE system to fit within the constraints of the Ventana tool-sled system. Working with the Ventana pilots we created a MARS simulation housing that allowed us to imitate to some extent how FOCE should operate when on MARS. The results have been promising.

We have had two deployments with the Ventana system as part of the engineering program. We've demonstrated to our satisfaction that we can control pH as prescribed in the functional specifications. The second tests demonstrated this over 15 and 20 minutes in two separate tests, the time limits were a function of the quantity of CO_2 enriched seawater we could carry with Ventana on top of the FOCE system.

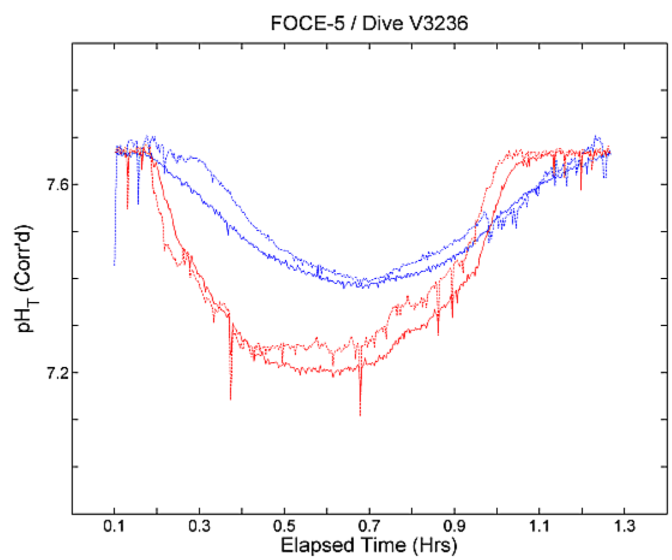

Figure 1. Data snippet from one of the FOCE engineering test dive on *ROV Ventana*, July 23, 2008. The blues traces show the two forward pH sensors, the red traces show the two aft sensors. The difference in pH between the two sets of sensors is due to the slow reaction kinetics of CO_2 in seawater at this temperature.

For the actual FOCE experiment, we will be using a reaction wing that is 2-3 times longer than the short wing used in this deployment. The additional reaction time will nearly eliminate this pH offset and greatly stabilize the short-term variability of the seawater pH within the control volume.

The testing also pointed out some areas we need to improve, mainly the internal velocity sensor. We are currently using a Nortek acoustic device, which we obtained from the Brewer lab at no cost. The device output has proven to be highly variable to the point that data is not suitable for a control systems loop.

For the balance of 2008 we plan on looking at solving the internal velocity instrument issue. We also recently learned that MARS may be repaired in the fall. We are again redirecting resources and planning to take advantage of that development. We are currently planning on building the elevator version of the FOCE originally conceived, which we are hopefully of deploying in late fall or early winter.

Significant changes from previous project proposal

The most significant change was outlined above, the MARS failure and our work around. If we are capable of getting machine shop and technician time this year we believe we can approach getting back on track and make up most of the lost ground in schedule. This is due in great part to the willingness of the Ventana pilots to help us do our engineering testing.

Publications based on the results of this project only

We are currently working on publications for late 2008 and early 2009, particularly focused on the Pacific Ocean regions. The reason for this is simple, the Pacific region governments, researchers, and universities have shown a strong interest in FOCE and are looking to obtain the technology for their research. We plan on supporting that interest as best we can and assisting where ever possible as appropriate for MBARI.

c) New and Continuing Projects: Plans for 2009

Research Activities

The majority of this project is development under the FOCE project number. We will however be searching around the greater Monterey and Carmel bays for near shore sites that are suitable to install a shallow water version of FOCE. This is a key advancement in the systems design since the majority of scientists expressing interest want to use FOCE in near shore shallow eco-systems.

We will also be working under the High CO_2 Initiative with Dr. Barry and plan on doing a first experiment with him in 2009 as a test of the FOCE system. The experiment will likely be days long, possibly weeks as we steadily test and develop the FOCE system capabilities.

As one example of the science directions we note that the rest of the research community has very quickly focused on the negative effects of lower pH on calcification in coral reefs and shell-forming animals, and a large number of papers have now appeared on this topic. MBARI does not have access to reefs in local waters, but does have special access to the deep sea. Thus we have chosen to adopt this as our target and in the closely related Greenhouse Gases project have developed theory with two primary and disturbing results:
1) That since the buffer capacity of waters in the oxygen minimum zone is low we can expect very large changes in deep water pCO_2 (> 1,000 ppm or more).
2) That on the basis of classical Gibbs Free Energy theory we should expect a linear relationship between the energy available from respiration and the log of the pO_2:pCO_2 ratio.

These two results suggest that deep waters near the oxygen minimum should be extraordinarily sensitive to changes in CO_2 status, and that this ratio precisely defines the limit to aerobic life. The depth of the MARS node is sufficiently close to the local O_2 minimum, and the capacity of the FOCE system (based directly upon results from our July 2008 test dives) is large enough that we can quickly test these concepts on marine animals.

Engineering/technology development

We will focus on a series of technology issues that directly support and enhance FOCE for 2009. First will be completing and testing the CO_2 injection and mix system where CO_2 enriched water is created for injection into the FOCE time delay wing sections. We will install this on a second FOCE (already being built in 2008). Parts of the system are already under test in 2008. It is possible we will make more progress this year and testing will be the majority of the effort for 2009. Prudent planning, however, when building a system that has only been attempted once before in the deep ocean (by MBARI post-doctoral investigator Rachel Dunk) implies some level of anticipation of technical challenges. These challenges, which are only encountered in a deep ocean deployment, may lead to system modification or alteration.

Several times over the course of the year, FOCE systems will be rotated between deployment and maintenance. Not only will this allow testing of the recovery and deployment of the systems, but also allows for tuning and upgrades. This would be analogous to a mooring turn around but with much less effort and only using MBARI resources.

Once we are plugged into MARS and the proper network links are in place, we will invite our collaborators and colleagues from Australia, Canada, England, Norway, and France to use the web interface and observe FOCE data in real time as well as participate in some testing. We view this as easy to do using MARS infrastructure but it is a critical point to complete since all have expressed interest in FOCE or are actively pursuing funding for their own FOCE systems.

We will also improve the instrumentation used to verify and calibrate the FOCE system. Currently we use several pH probes and other instruments external to FOCE as a reference to prove we haven't inadvertently introduced signal errors by stray voltages or currents. We've found that the reference systems themselves are not entirely reliable. Our plan is to spend a small amount of time to correct any problems with these reference systems early on so that our future FOCE efforts are always clearly understood and accurate.

Our goal is also to install both FOCE systems by 2010 and perform the comparative experiment using an active CO_2 FOCE and a control as a joint field program with Dr. Jim Barry. To accomplish this we require an extension node. FOCE will require all of the power from one connector port to accomplish the experiment. Therefore we will build the extension cable and node per the MARS specification in the later half of 2009. One concern is the FOCE power budget will be very close to the limit operating two systems. It is possible we will require a variance from the 1 km distance if the voltage drops are too large. If early engineering shows we could accomplish this quickly, we may fast track this activity but we do not have confidence yet since we have not yet completed the CO2 system this year.

We will also spend time on the development of a shore /shallow water specification and an associated concept design suitable for a site around the greater Monterey or Carmel bay areas. If a site is found, partnerships are developed, and permitting is going well, we will proceed with system designs as allowed by manpower constraints.

Field programs (detail ship requirements/deployments)

With the MARS cable being repaired this year we are potentially could install the first MARS connected FOCE sometime in December. Using this as a starting point our field plans are as follows:

March (14th) 2009 – recover FOCE A* from MARS (1 day MOB and 1 dive)
March (16th) 2009 – install FOCE B 1 dive
April (15th) 2009 – FOCE science experiment(s) Barry 2 dives set up
May (4th) 2009 - FOCE Science - 1 dive check up, fill materials (1 day MOB and 1 dive)
May (11th) 2009 – Sci Dive Brewer/Barry
May (18th) 2009 - FOCE Science - 1 dive check up, fill materials (1 day MOB and 1 dive)

May (24th) 2009 – Sci Dive Brewer/Barry
June (4th) 2009 – Sci Dive Brewer/Barry
June (18th) 2009 – Sci Dive Brewer/Barry
July (8th) 2009 – recover FOCE B from MARS (1 day MOB and 1 dive)
July (20th) 2009 – install FOCE A 1 dive (1 day MOB and 1 dive)
Sep (3rd) 2009 – Sci Dive Brewer/Barry
Sep (17th) 2009 – Sci Dive Brewer/Barry
Nov (2nd) 2009 - install the MARS expansion node for FOCE (1 day MOB and 1 dive)

* Like ESP we will develop a naming convention to distinguish between the 2 systems as we rotate and do technical upgrades. Currently they are just A and B.

Specific deliverables

1) Second functional FOCE system
2) Upgrades to the original FOCE system
3) Science experiment using FOCE
4) Publications (technical and science) venue TBD
5) SSDS Software tools for web accessed data
6) CO_2 / O_2 Test Equipment for prelim experiments on Ventana
7) Extension node to support FOCE A & B (control and experiment)
    a. Note: we might be able to accomplish this earlier and if so we will work with the science and operations groups to schedule an earlier FOCE A & B installation.
8) Publication and/or presentation at Oceans and AGU

Milestones

Q1 – Recovery of a cabled FOCE and installation of a second FOCE demonstrated.
Q2 – Collaborators participate in FOCE operation by internet from their respective institutions. Candidates are Bedford Institute, Heron Island Laboratory, University of Plymouth, NOAA station in Seward Alaska, as well as Swedish and French researchers.
Q3 – Barry / Brewer joint FOCE experiment on MARS
Q4 – Benthic MARS extension node for FOCE
Q4 – Installation of benthic node for Q1 2010 installation of FOCE A & B.

Budget justification

The following materials and components are essential elements to the outlined plan for FOCE in 2009. Approximately 50% of the budget is extension cable from MARS to the final FOCE site a per the MARS operations groups request in 2008.

The cost estimates are based on numbers from MARS project management and engineering with an escalator of 20% for materials and %50 for manufactured goods such as the extension cable.

Raw Materials for FOCE modifications to accommodate new science experiments - $2,400
Benthic Expansion Node Housing - $ 15,000
Benthic Node Converter Housing (next to mars node) - $10,000
Benthic Node Electronics - $10,000
Benthic Node Wet Mate Connectors – 3 @ $8,000 - $24,000
Benthic Node Connectors – Min K etc. $24,000 (used 2008 purchase order)
1 Km of extension cable - $15/m @ 1km - $15,000
(cable pricing has low certainty due to small order and copper prices being unstable)
CO_2 Accumulators for liquid CO_2 – 10 @ $11,500 - $115,000
(To handle CO_2 these are carbon fiber wound cylinders with Ti pistons and end caps which gives "unlimited" life theoretically – quote based on previous unit by Jon Erickson and costs exclude labor)
Piping and fittings - $12,500
Pump for FOCE B - $7,000
Mixing chamber for FOCE B - $10,000
Spare Pump - $7,000
Travel to Conference – 2@ $2,000 - $4,000
Expenses – 2 @ 3 days @ $400 - $2,400
Foreign Conference Ocean Acidification – 1 @ $750
Foreign Travel – 1 @ $3,000
Lodging etc. – 1 @ 7 days @ $350 - $2,450
Software package Real Basic and Modules - $3500
Miscellaneous materials - $2,500
Liquid CO_2 - 2 fillings per cylinder for extended experiments at depth - $10,000

Total Estimated Budget: $288,500

Project team

William Kirkwood – Project Manager
Peter Brewer – PI
Jim Barry - Scientist
Ed Peltzer – Research Specialist
Peter Walz – Science Tech
Farley Shane – ME
Bob Herlien – SE (40 hours of Kevin Gomes)
Chad Kecy – EE
Jim Scholfield – ME Tech
Tom Marion – EE Tech

Keith Hester – Post Doc
Support Eng – SE (TBD) - Rich Schramm predominantly we believe

Project lab space

We will use the Brewer lab whenever possible. Builds are done in the high bay as they have been in 2008. Testing is at the test tank on the wet deck next to the AUV lab. Storage is an issue, however, if a system is not actively being worked on or tested we will move the equipment to an acceptable place designated by facilities at that time. Long term storage of any components will be at the warehouse in Castroville.

Data availability outside project team, uniqueness

All data are readily available on the MBARI webpage for anyone with access to SSDS. We are currently creating an open source set of tools also for the user community to integrate the data and publish as needed for their purposes. Per our operational history we will publish as quickly as possible to prevent any data being withheld from the external community.

The data is unique since no one has attempted to control pH in an open ocean system in situ. The impacts on flora and fauna will be the only in situ data of its kind, a first in the world. The science part of this will be published under the associated science components of the High CO_2 Initiative but all technical disclosures will be published from the FOCE development project and team.

Risk matrix (development and infrastructure projects only)

	Technical Risk	Organizational Risk	Tech Transfer Risk	Labor Estimate Risk
High				
Medium	X			
Low		X	X	X

3) MILESTONES (new and continuing projects)

	Milestone 1	Milestone 2	Milestone 3	Milestone 4	Milestone 5	**Total Resources**[3] for each resource category for all milestones listed here
Milestone Date	**Q1**	**Q2**	**Q3**	**Q4**	**Q4**	
Milestone Description	**FOCE A Recover / FOCE B Install**	**Science on MARS and Collaborator interfacing**	**Barry/Brewer Joint Experiments**	**Build of MARS node extension**	**Installation of extension node**	
EE	**220**	**220**	**216**	**185**	**15**	**856**
SE	**270**	**270**	**200**	**150**	**50**	**840**
ME	**200**	**200**	**200**	**200**	**15**	**815**
Support Engineering	**240**	**240**				**480**
EE Tech	**75**	**100**		**75**	**0**	**250**
SE Tech						
ME Tech	**125**	**125**	**35**	**100**	**35**	**420**
Machine Shop	**125**	**109**		**125**		**409**

(See next page for personnel classification information.)

[3] This number should be the same number you entered on the resource requests for this particular resource.

Personnel Classifications

Mechanical Engineers (regular)	**Electrical Engineers** (regular)	**Software Engineers** (regular)	**Support Engineers** (regular)	**Mech Technician** (regular)	**Mechatronics Engineer** (regular)	**Electrical Technician** (regular)	**Software Technician** (regular)	**Observ Support Technician** (regular)
Gene	Mark	Tom	Craig	John F		Carolyn (2/3)	Karen	Mike K
Jon	Ed	Brian	Thom	Jim Sch		Dick L		Paul
Farley	Paul	Rich H	Mike McC	Mike Parker		Tom		Zorba
Brett	Alana	Rob	Rick Schr			Jose		
Doug P	Scott	Brent	Brian Sc			Jim M.		
Bill K (2/3)	Chad	John G	Mark Brown (1/2)					
Jim Birch (2/3)		Kevin						
Andy		Danelle						
Larry Bird		Bob H						
		Mike R						
		Wayne R						
		Duane (2/3)						
		Kent (2/3)						

Mechanical Engineers (term)	**Electrical Engineers** (term)	**Software Engineers** (term)		**Mech Technician (term)** (term)	**Mechatronics Engineer** (term)	**Electrical Technician** (term)	**Software Technician** (term)	**Observ Support Technician** (term)
					Adeline			
					Cheri			

Appendices: Manhour quotes

> Bill,
>
> 800 hrs/100 days for me now looks like it's pretty close to the mark.
> Information from Monday's meeting and other team members reminded me
> of some tasks I had forgotten. My nominal estimate is now 100 days,
> as follows.
>
> Support Deployments 10 days
> 4-5 deployments, 2-3 days each with MOB days
>
> pH Sensor upgrades 5
> Assumes mostly done during '08, but may need further
> mods and/or testing
>
> Velocity sensor 5
> Ditto above. Mostly done in '08, further refinements
>
> CO2 Distribution System 10
>
> Velocity PID Loop
> Design, imlplement, debug, test in test tank 10
>
> pH PID Control Loop (same subtasks as above) 10
>
> GUI Enhancements 10
>
> SAMI
> Includes TT8 firmware changes to make usable, plus 15
> new SIAM driver
>
> Data Presentation - Primarily a Kevin/Mike task, but 5
> this is time for me to assist/consult
>
> Integration/System Test for 'B' System 10
>
> Conferences and Papers 10
> -----
> Total 100 days
>
>
> Please note that this is 100 days for my time. If you're lumping together
> SE time, you need to add Kevin's estimate for him and/or Mike to do
> Data Presentation changes for SSDS.
>
> Also note the comments that some tasks, principally the PID loops, will
> require tank testing. I assume we'll still have a system we can deploy
> in the test tank?
>
> -Bob

Hello all,

After meeting with Ed and Bob, it looked to me like the application that Rich wrote is certainly the best place to start. A good deal of work has been put into that VB application and Ed seemed quite happy with the application. After talking with everyone, it seems the best/ quickest option would be to port the VB code to RealBasic so that it can be downloaded easily and run on any platform (Windows, OS X, Linux). Then Rich can take that port and add more functionality/data and we can connect up the application to interact with SSDS instead of reading data from files. So, to do that we have:

Data Sources (raw data will be in SSDS):
1. 2-3 CTDs
2. ADCP (Workhorse RDI)
3. Another velocity sensor (Nortek now, but might be something later)
4. SAMI

Data processing that needs to happen:
1. Raw CTD data converted to salinity (I would like to make this part of the SSDS functionality for all CTDs)
2. Raw ADCP data converted into useful information (Mike McCann already does this and writes out NetCDF files for the moorings, but I would like to take his processing and submit the data back to SSDS as parallel stream so data access from the GUI will be in a uniform manner).
3. Processing of other velocity sensor (me with Mike McCann's help, similar to ADCP processing).

Functionality to be added to the GUI:
1. Take Ed P's VB scripts from excel and incorporate into the RealBasic application (this will have data input from users as well as

metadata extracted from the data streams for instruments on FOCE).
2. Plotting more of the data mentioned in the above two sections.
3. Other functionality TBD (part of 2009 work is to determine exact functionality)

Assumption: Rich can spend 10 days in 2008 exploring RealBasic to see if it looks like it will work OK.

As a initial shot at man-hours for 2009, I would give Rich 200 hours (5 weeks), Mike McCann 40 hours (1 week) and myself 40 hours (1 week).

Comments? Rich, does that sound reasonable?

Bill, it looks like you have 480 hours of Support Engineering time which, if for this work, covers the time for Mike and Rich (and then some which is great). The 800 hours of SE time does not include any time for me so you might want to add another 40 hours for my time.

Thanks,

Kevin

2009 Electrical Engineering Tasks - Kecy

FOCE A will already be built and deployed.

FOCE B will need to be built.
    It may incorporate changes learned from FOCE A.

pH Sensor Work:_____10_____

Build FOCE B Electronics:__40__
- Main Electronics Housing
  - DC-DC Converter Board
  - Distribution Board
  - PC/104 Stack
  - Ethernet Interfaces
- 3 Junction Boxes
- Motor Housings
  - EZ Servo
- Cables
  - 12 Housing-to-JBox
  - 01 MARS to Housing
  - Whips to Science/CO2 System

CO2 Distribution System:____10____

Test FOCE B Electronics:__5___
Integrate FOCE B Electronics:___5_____
Test Tank Verification:___5___

Upgrades to FOCE A:___10____
Testing FOCE A:____5____
Test Tank Verification:____5_____

Total ship days: 12

Total FOCE B Days: 55
Total FOCE A Days: 20
pH Sensor Work: 10
CO2 Distribution: 10
Total Ship Days: 12
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107 days

equals >> 856 hours EE