FESC ENERGY SUMMIT

Clean Drinking Water using Advanced Solar Energy Technologies

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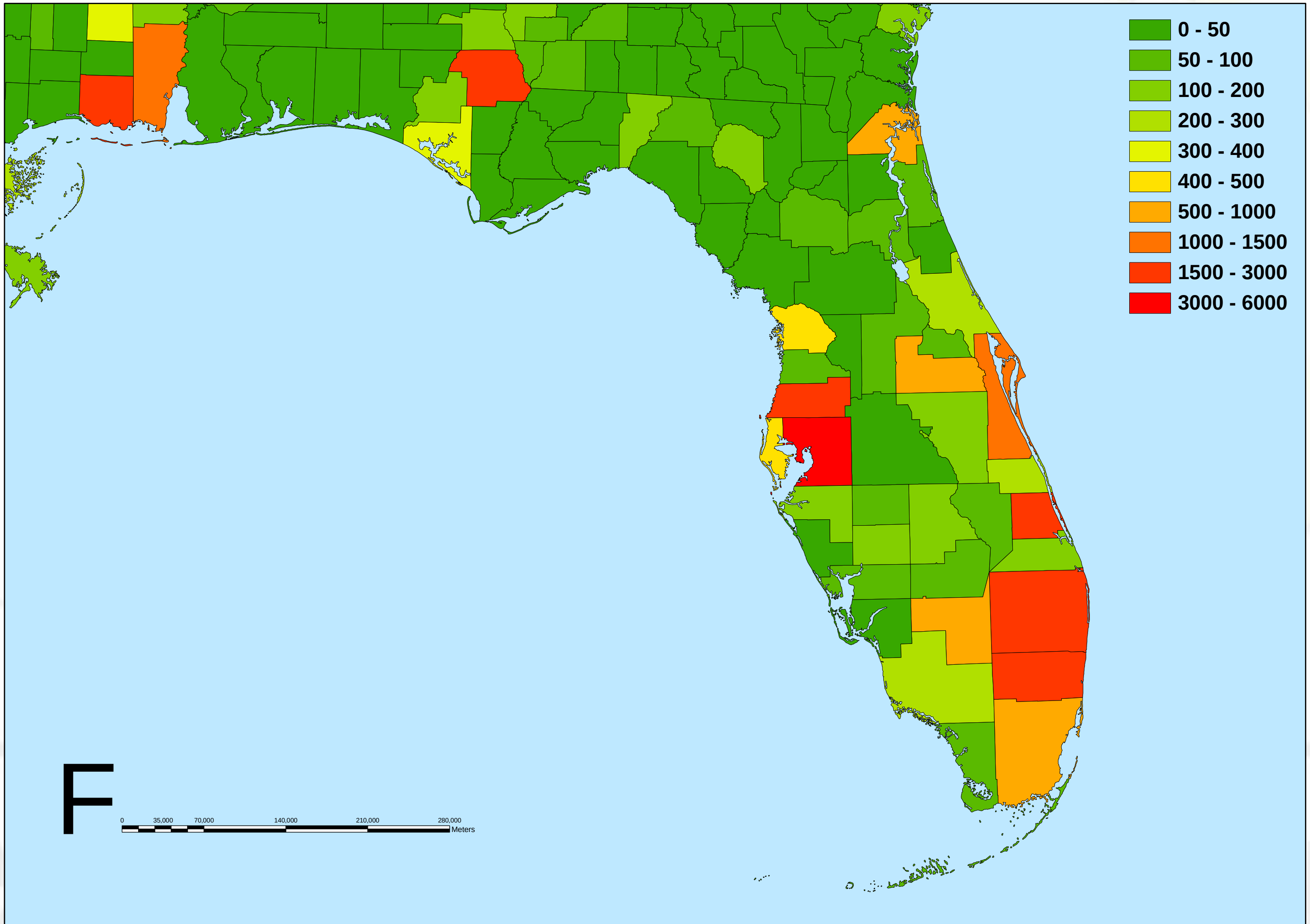
Water Demand

Year 2000 Estimated Water Consumption
(Million Gallons / Day)



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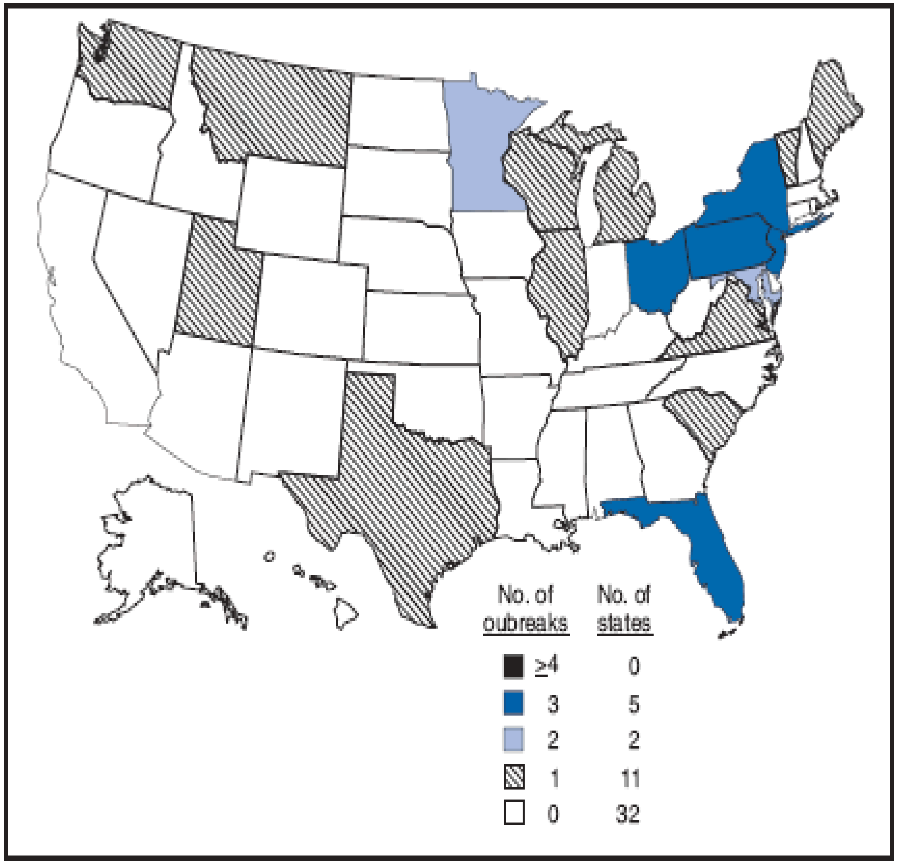
Waterborne Disease Outbreaks

- Drinking water requires disinfection to remove pathogens (bacteria, viruses and protozoa)
- It is estimated that 1.2 billion episodes of waterborne infections occur worldwide every year
- The US has a reputation for high drinking water standards, but severe outbreaks have occurred (*e.g. Milwaukee 1993 Cyptosporidium outbreak*)
- The number of food and waterborne disease outbreaks in Florida averages about 300/yr



Number of waterborne disease outbreaks associated with drinking water in the US 2003-2004

Water Disinfection

- Chlorine is the most common disinfection method, but forms potentially carcinogenic byproducts (e.g. trihalomethanes)
- Regulations limit the amount of disinfection byproducts in drinking water
- Alternative disinfection methods are available, but many are energy intensive and require expensive chemicals and equipment

Traditional chlorination contact tank for water disinfection

Clean Drinking Water using Advanced Solar Energy Technologies

A. Sustainable Solar Flash Desalination

B. Photocatalytic Water Disinfection

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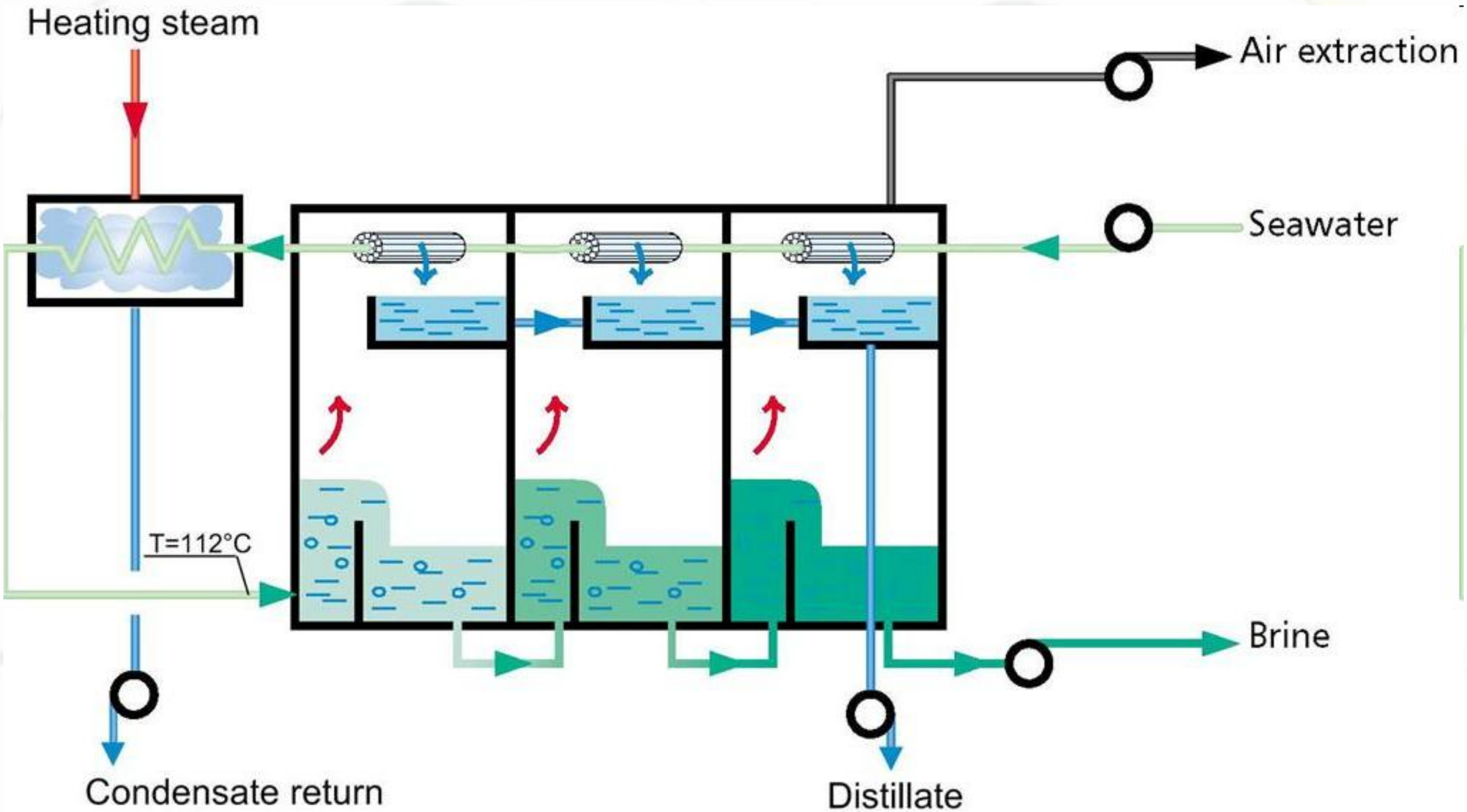
Desalination - Seawater Flashing



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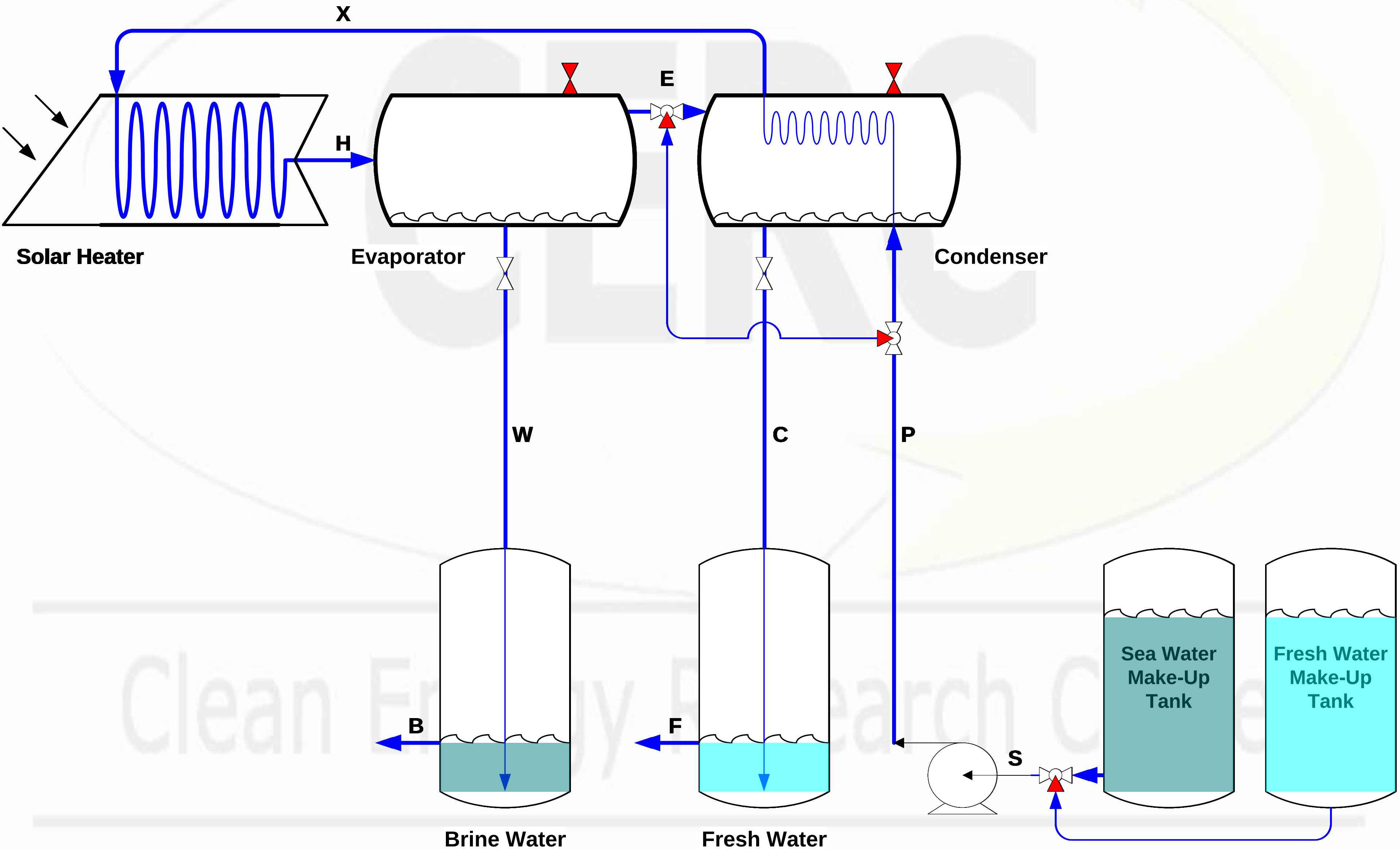
A. Solar Flash Desalination

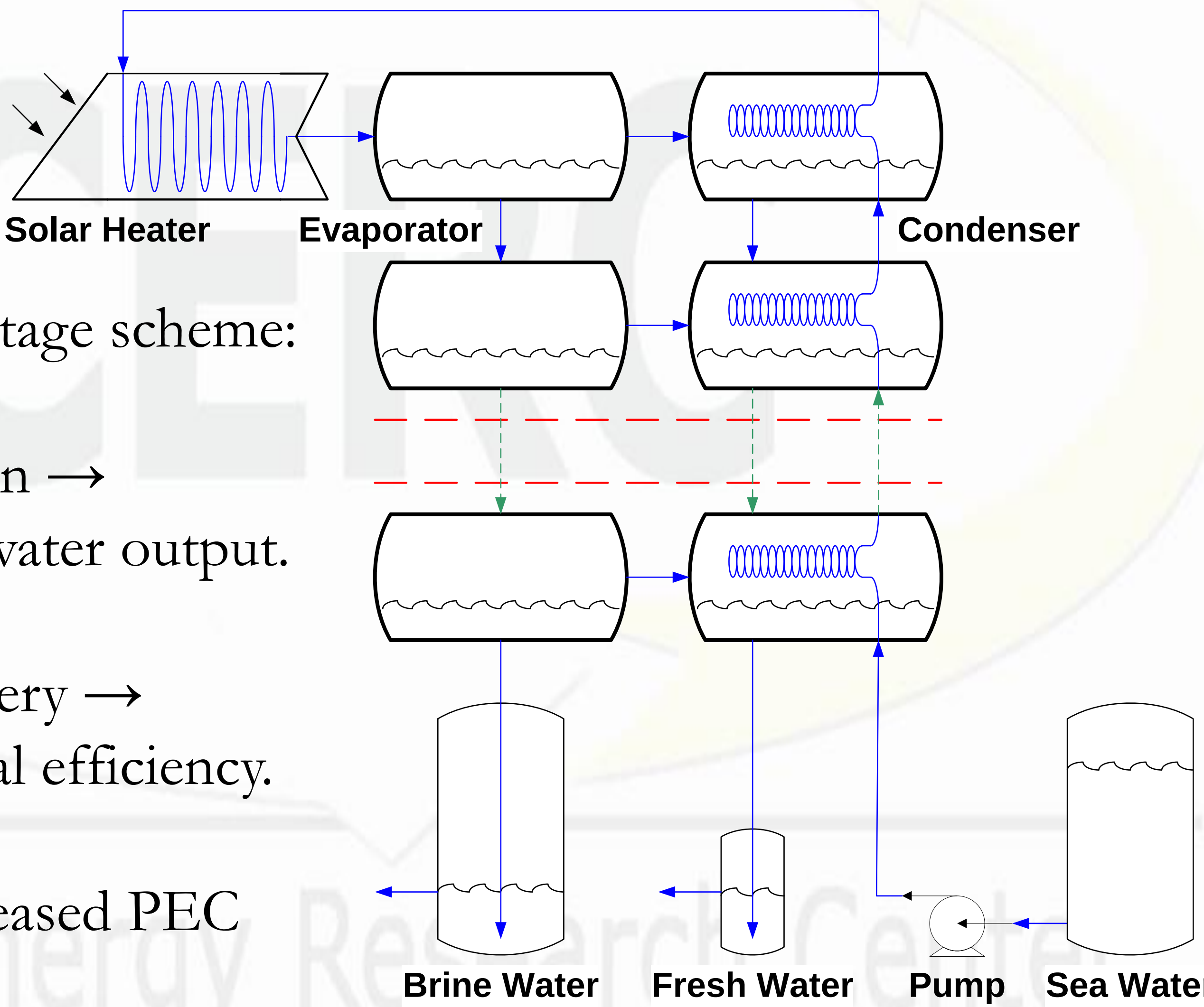
- Develop an economically viable and environmentally friendly desalination system
  1. Lower its energy demand
  2. Use renewable energy

- Modify the most common desalination technique, multi–stage flash:
  1. Create system vacuum passively
  2. Use solar energy.

Single Stage – System Design/Operation



Multi-Stage Configuration



Implementing multi-stage scheme:

1. More evaporation → increased fresh water output.

2. More heat recovery → increased thermal efficiency.

3. #1 + #2 → decreased PEC

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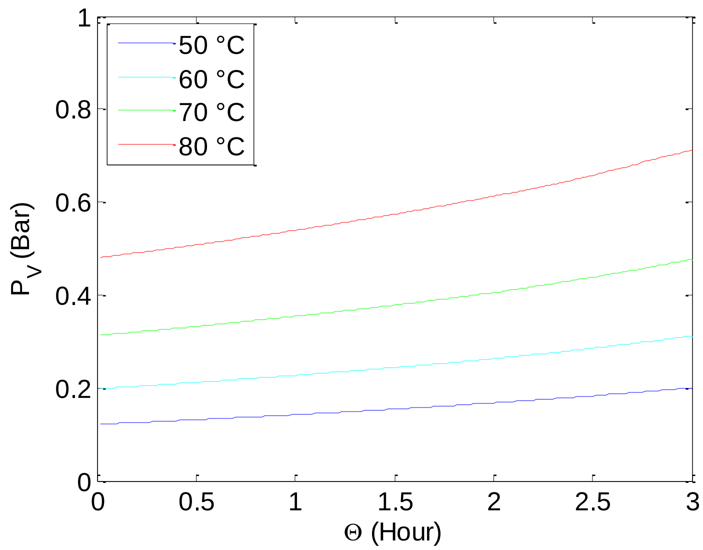
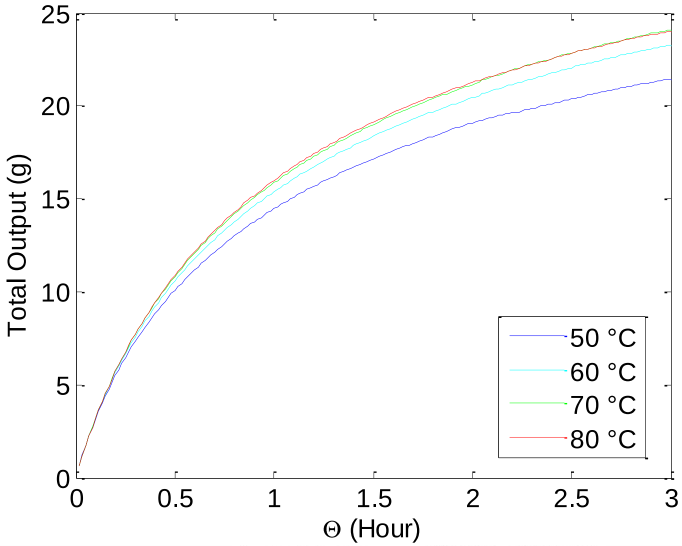
Design Stage

- A model was developed to theoretically simulate the proposed desalination system.
- The model assumed total steam condensation and quasi steady state operation accounting for the build up of non–condensable gases.
- The model used the Rachford–Rice method for the flash calculations and Bernoulli's fluid equation for the hydrostatic balance relations.
- The model is composed of: Physical and thermodynamic relationships + Empirical correlations + mass and energy balances + geometrical formulas + physical property correlations + integrative equation of state





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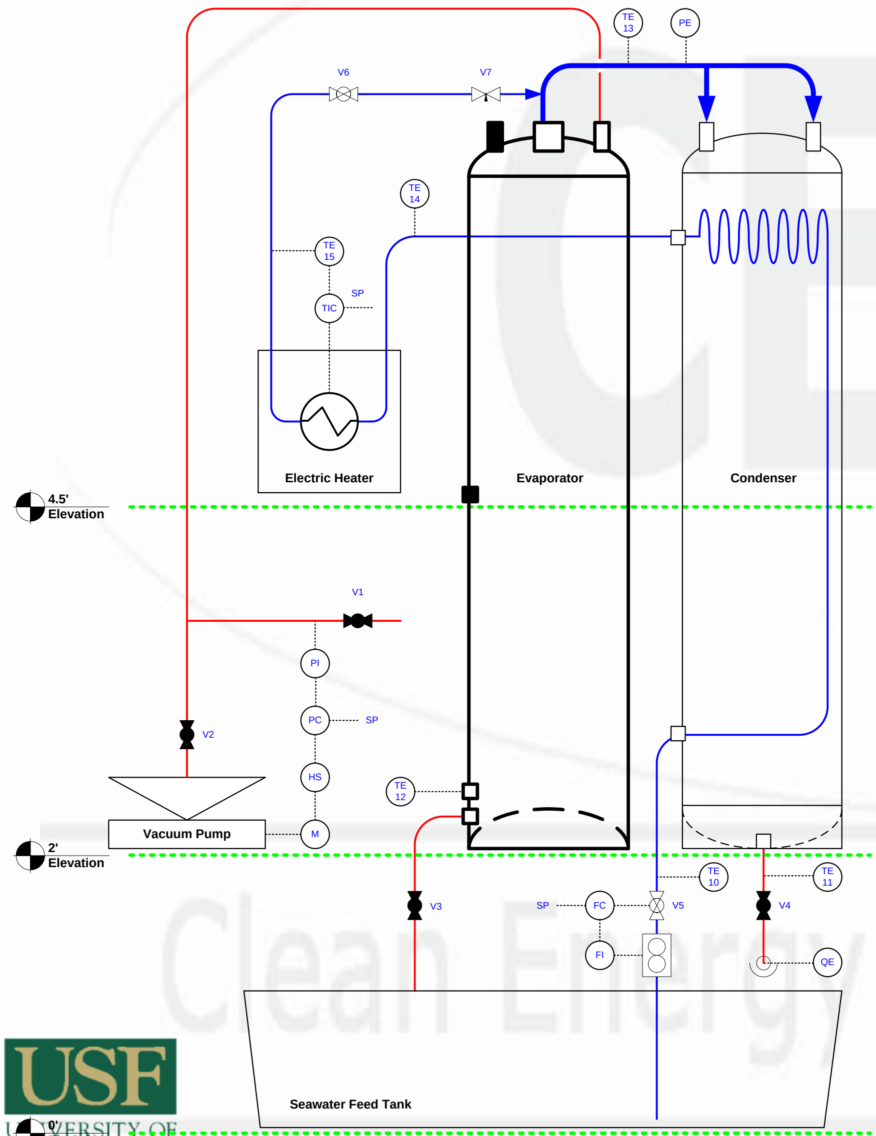
Prototype Assembly



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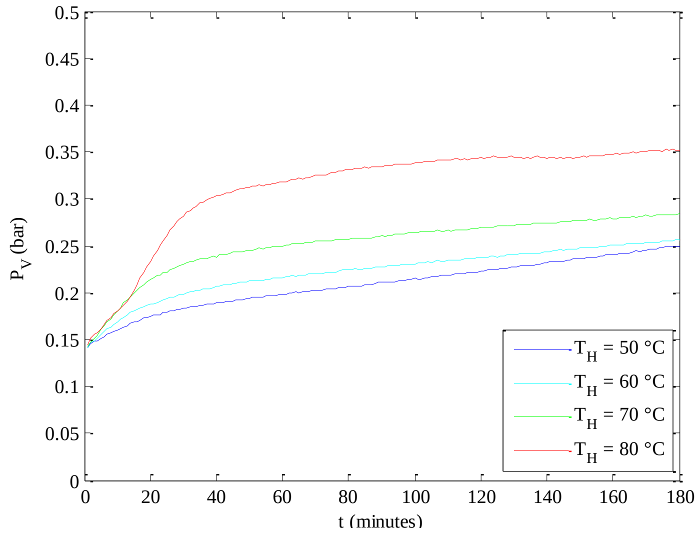
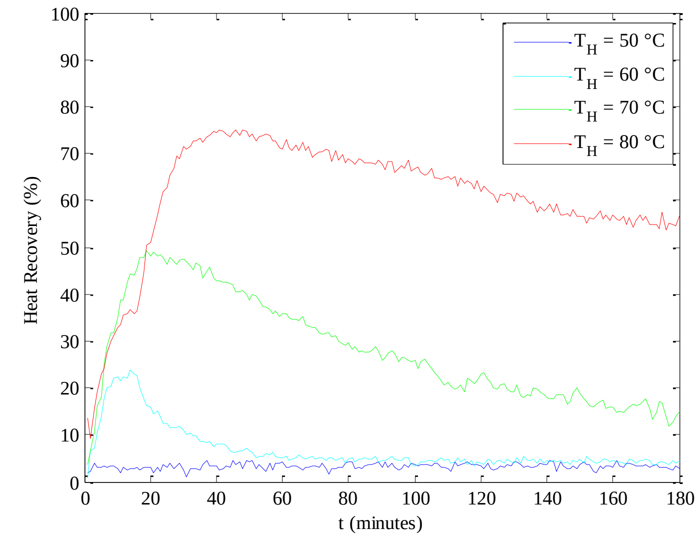
Experimental Analysis

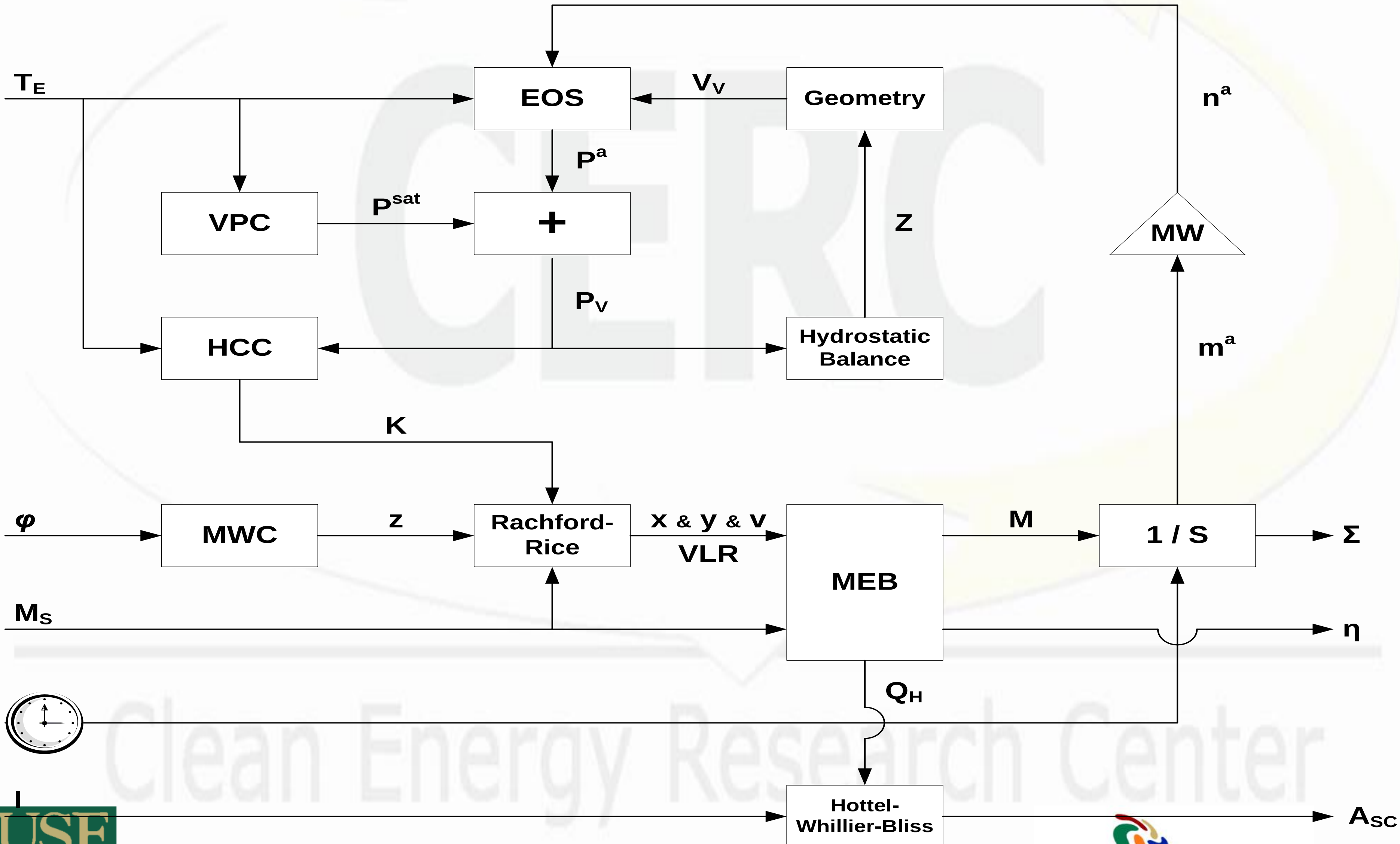
	T_H (°C)			
	50	*60*	*70*	*80*
Number of experiments	3	3	3	3
Duration (hour)	3	3	3	3
Initial vacuum (psi)	2	2	2	2
Average seawater flow (gpm)	0.128	0.122	0.117	0.100
Fresh water produced (gal)	0.01	0.09	0.54	1.25
Average heat input (W)	986	1195	1111	643
Solar collection area (m^2)	2.76	3.12	3.34	2.65
Energy Consumption (W-hr/1000 gal)	424	40	7	2

- The average prime energy consumption of an MSF desalination process is 0.36 W-hr/1000 gal
- The average cost of water desalted by an MSF desalination process is $ 3.41 /1000 gal





Model Development



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Solar Desalination - Milestones

- System Set Up – Completed
- Background Review – Completed
- Design Proposal – Completed
- Theoretical Analysis – Completed
- Prototype Assembly – Completed
- Experimental Simulation – Completed
- Model Development – Fall 2009 Anticipated
- Feasibility Study – Spring 2010 Anticipated
- Prototype Development - 2011

B. Photocatalytic Water Disinfestion A Viable Alternative

- Photocatalysis can kill a wide range of pathogens, including chlorine-resistant *Cryptosporidium* and *Giardia*
- It has the potential to use solar energy directly to drive the disinfection reaction
- It does not require expensive chemicals and the byproducts are generally benign

WATER RESEARCH 42 (2008) 1523–1530
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WATER RESEARCH

Photocatalytic inactivation of *Cryptosporidium parvum* with TiO_2 and low-pressure ultraviolet irradiation

*Hodon Ryu, Daniel Gerrity, John C. Crittenden, Morteza Abbaszadegan**

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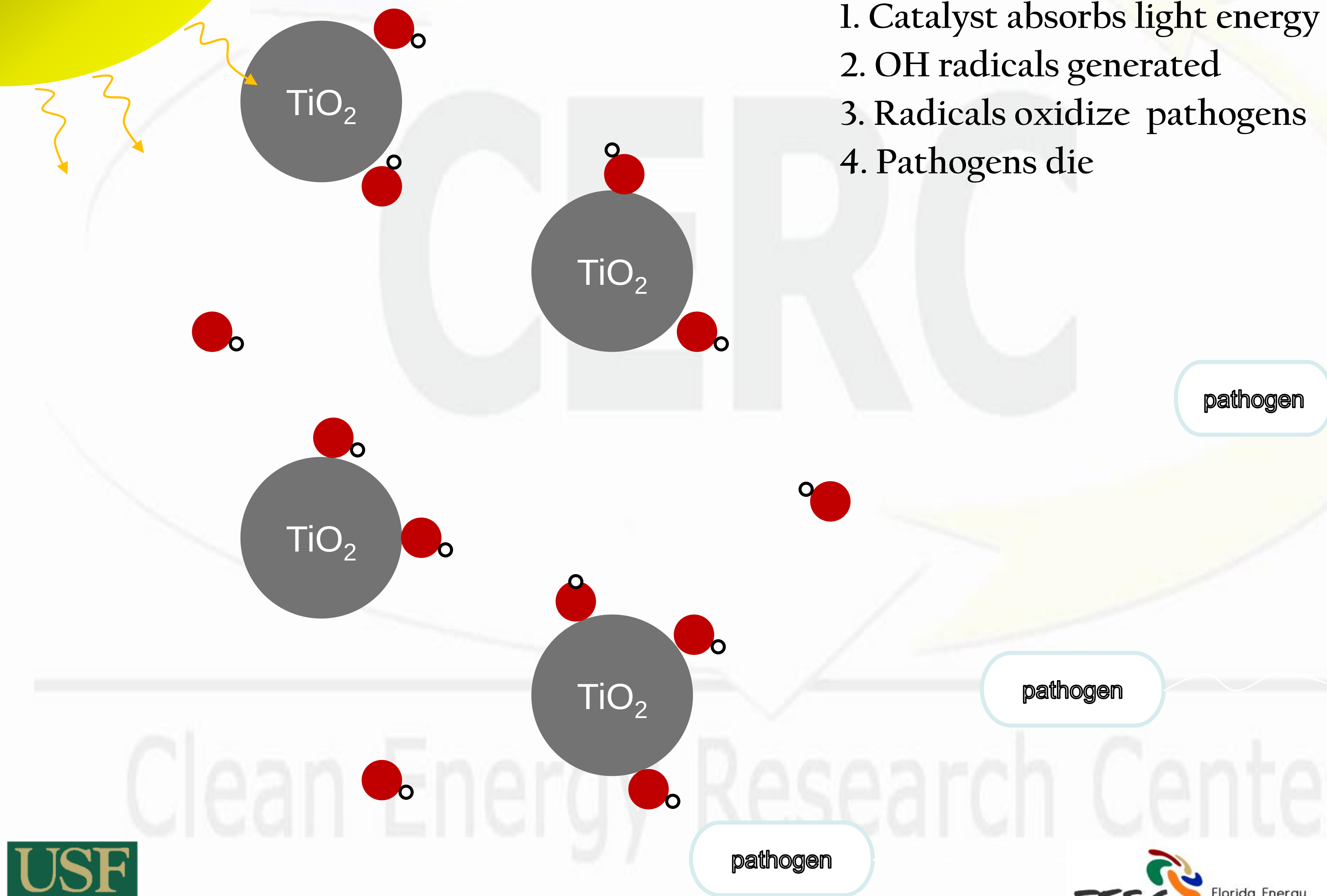
Available online at www.sciencedirect.com
ScienceDirect
Journal of Photochemistry and Photobiology B: Biology 88 (2007) 105–111
Journal of Photochemistry and Photobiology B:Biology
www.elsevier.com/locate/jphotobiol

Disinfection of drinking water contaminated with *Cryptosporidium parvum* oocysts under natural sunlight and using the photocatalyst TiO_2

Fernando Méndez-Hermida [a,d], Elvira Ares-Mazás [a], Kevin G. McGuigan [b], Maria Boyle [b], Cosima Sichel [c], Pilar Fernández-Ibáñez [c,*]

Simplified schematic of photocatalytic disinfection

1. Catalyst absorbs light energy
2. OH radicals generated
3. Radicals oxidize pathogens
4. Pathogens die



Problem Statement

There are currently no design methodology for design of photocatalytic systems which prevent full-scale development and use. Current attempts are based on traditional chemical disinfection models, which

1. are empirically-based and fundamentally non-representative and;
2. do not allow for system optimization and the incorporation of biological information about pathogens

Research Objectives

- The long-term goal is to optimize photocatalytic disinfection, so that water can be disinfected quickly, safely and inexpensively

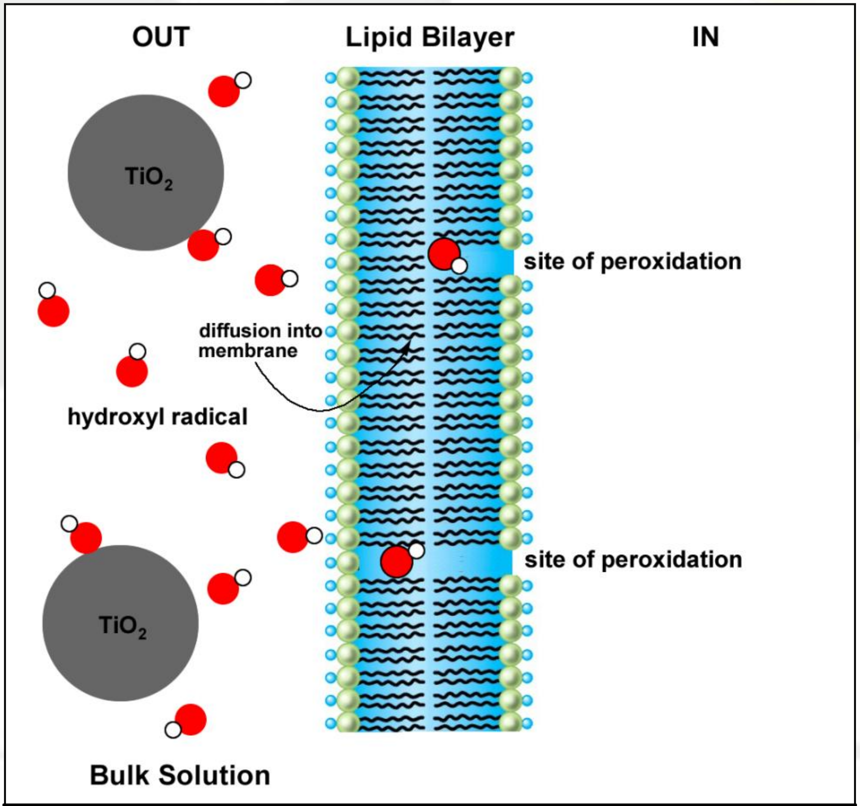
- Specific goals:

1. Build a mechanistic model which can form the basis for engineering designs of photocatalytic disinfection systems
2. Set up a solar lab-scale reactor based on the new disinfection model
3. Test the accuracy of the model to predict reaction rates under different operating conditions

- The rationale is that modeling the mechanism will allow us to find ways to improve photocatalytic disinfection

Proposed Mechanistic Model

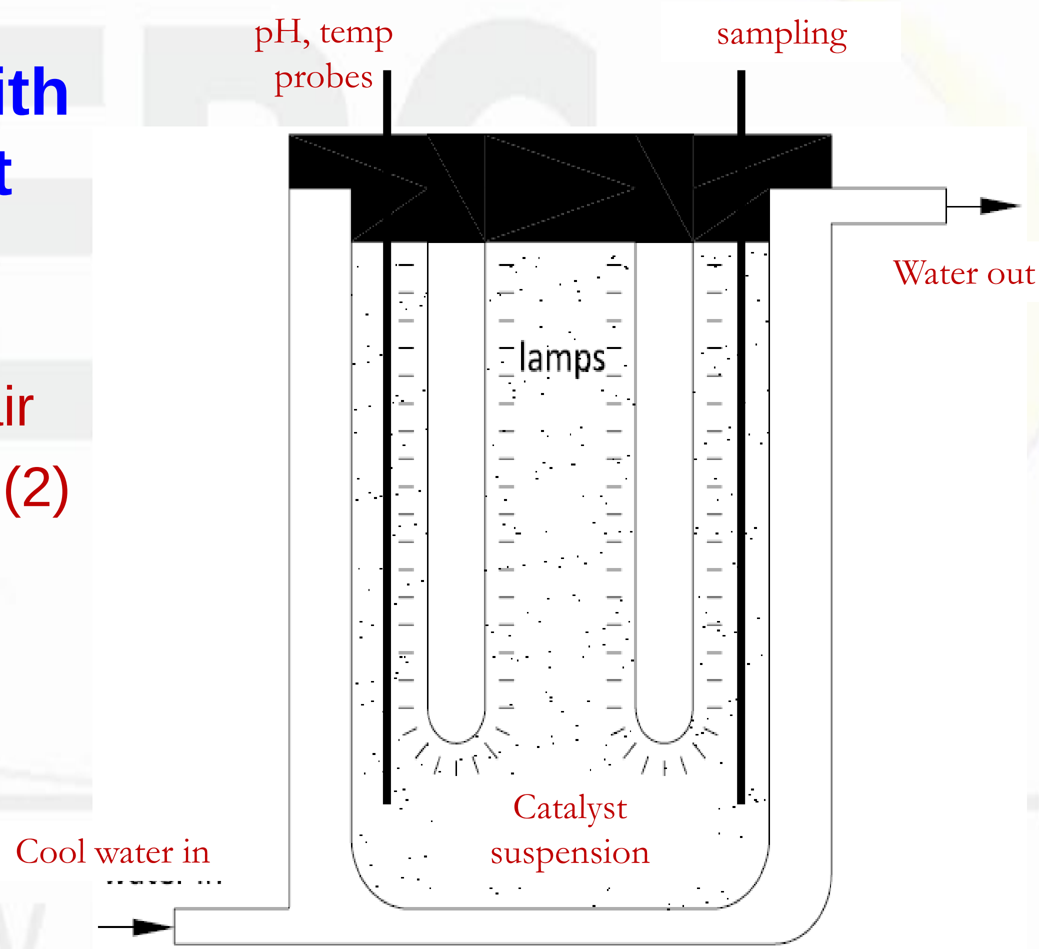
- Based on the peroxidation of membrane lipids of microorganisms
- Can incorporate biological information about organisms which may confer difference in resistance to disinfection
- Can be used for batch and plug-flow reactors in real engineering design
- First comprehensive mechanistic model to be proposed



Conceptual model of membrane peroxidation

Experimental Setup

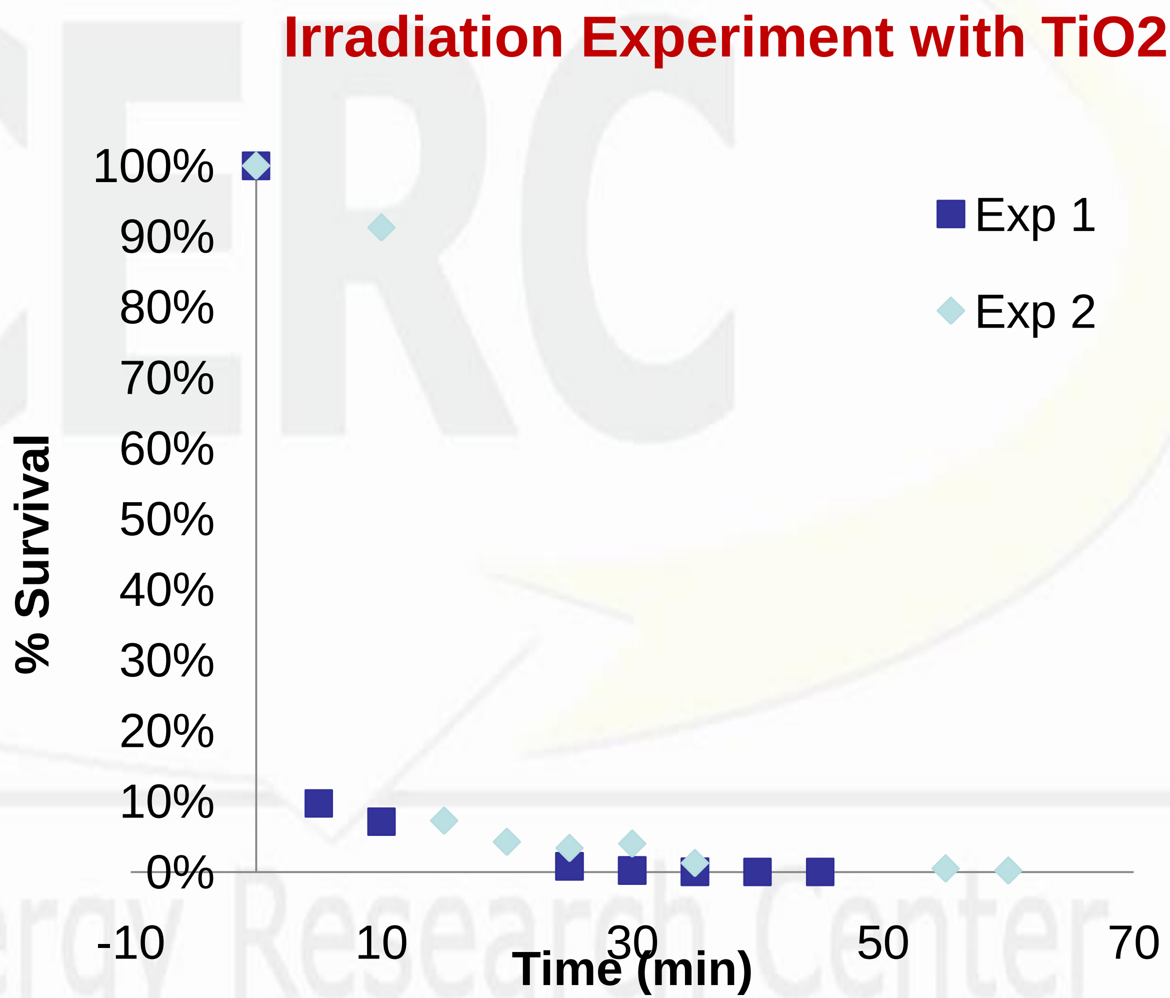
- **Batch reactor with black (ultraviolet) light**
  - Jacketed-beaker for temperature control
  - Aerated with oxygen or air
  - Accommodates two (2) lamps per reactor



Schematic of batch reactor

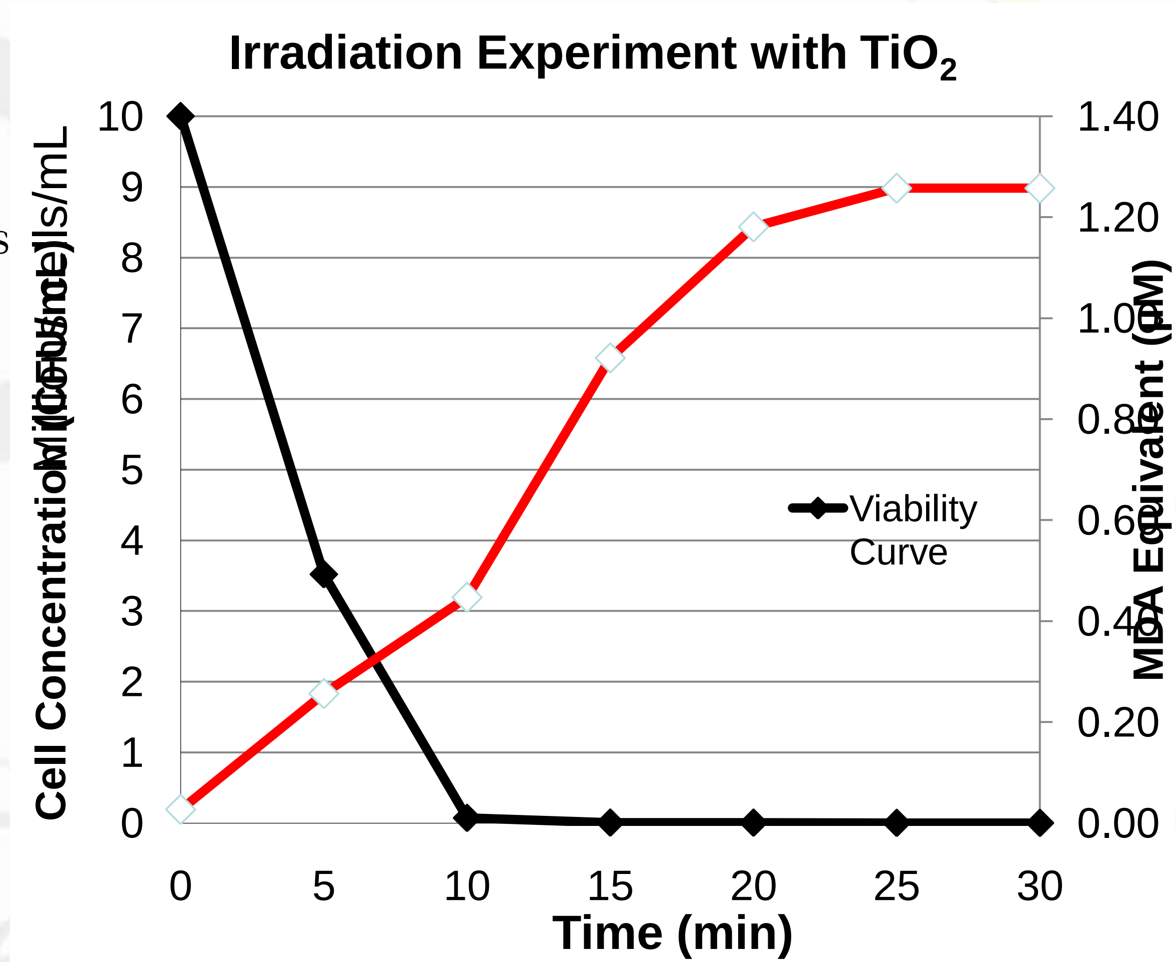
Preliminary Results

- *E coli* used as common water pathogen (indicator) for experiments
- Initial results show that photocatalysis is capable of inactivating the pathogen
- The kinetics appear similar to previous studies



Preliminary Results

- The production of MDA has been confirmed in preliminary experiments
- MDA production is evidence of lipid peroxidation
- Model will focus on linking peroxidation to inactivation



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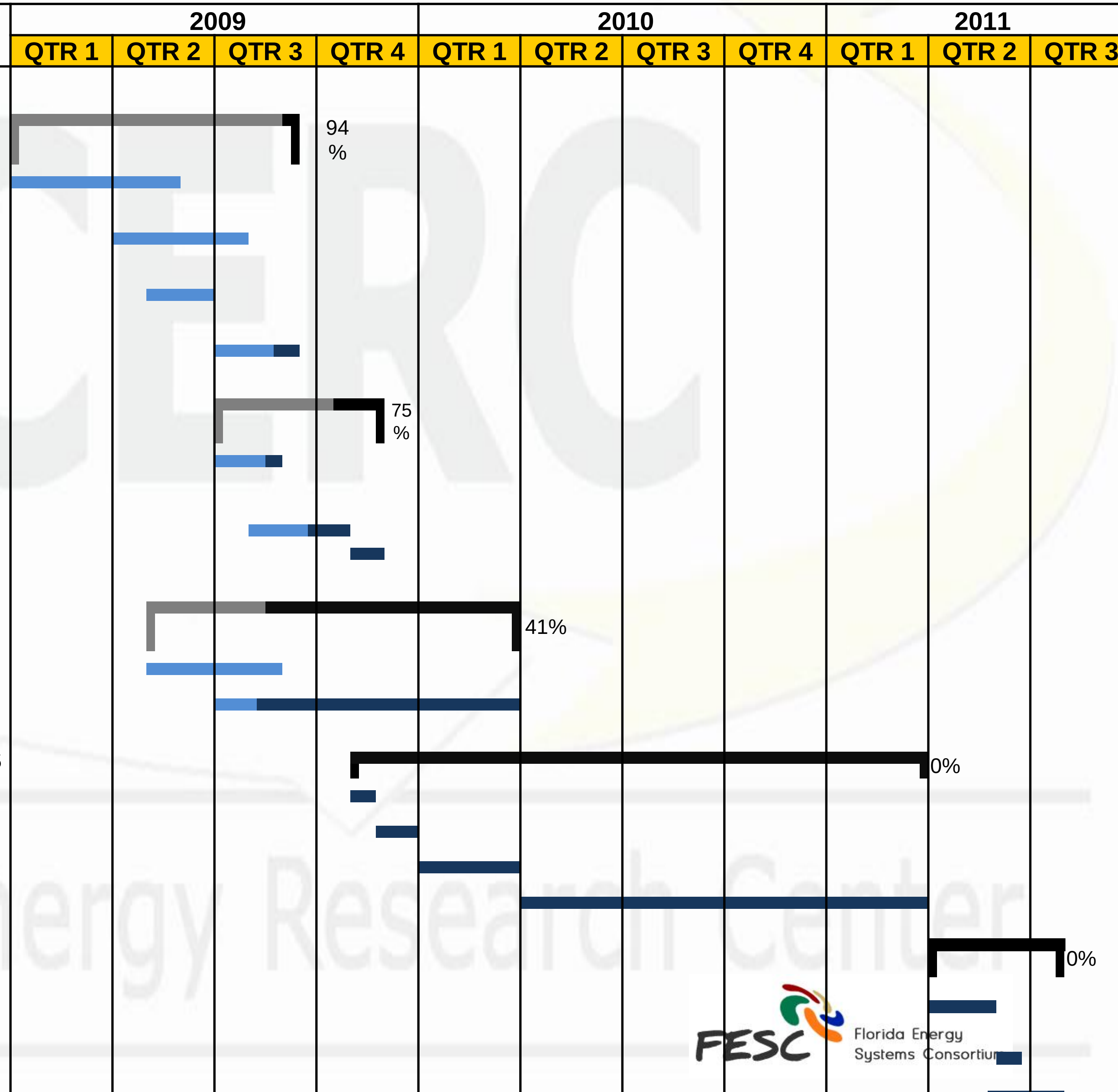
Proposed Pilot Setup

- Will be designed based on information from batch studies
- Will use borosilicate glass tubes in parallel
- Set up for solar photocatalytic disinfection

TASK#	TASK DESCRIPTION
TASK 1	**LITERATURE REVIEW**
	Review available literature on water disinfection
	Review history of disinfection model development
	Review inactivation pathways of photocatalysis
	Prepare review paper for publication
TASK 2	**MODEL DEVELOPMENT**
	Establish the steps in photocatalytic inactivation
	Develop mathematical relationships
	Test model with preliminary data
TASK 3	**BENCH-SCALE (BATCH) EXPERIMENTS**
	Set up bench-scale experiments
	Run batch experiments
TASK 4	**PILOT SET UP AND EXPERIMENTS**
	Design pilot-scale system
	Build solar pilot-scale reactor
	Perform preliminary tests and modify
	Run flow-through experiments
TASK 5	**DATA COMPILATION & FINAL REPORT**
	Analyze data
	Compare models



THANK YOU