ASU BIODESIGN INSTITUTE
ARIZONA STATE UNIVERSITY

DOE Hydrogen Program

Development of Water Splitting Catalysts Using a Novel Molecular Evolution Approach

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The Biodesign Institute at Arizona State University

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Overview

Timeline

- Start - July 1, 2005
- Finish - June 30, 2009
- 70% Complete

Barriers

- Barriers addressed
  - H. System Efficiency
  - J. Renewable Integration

Budget

- Total Project Funding
  - DOE - $1,200,000
  - Contractor - $300,000
- Funding for FY09
  - $300,000 DOE
  - $75,000 Contractor

Partners

- CombiMatrix Corp., Mukilteo, WA
- Prof. Bill Armstrong, Boston College

Objectives

- **Broad Objectives:**
  - **Develop a novel approach to creating molecular catalysts for redox reactions based on high throughput synthesis on electrodes**
  - **Mimick Nature's approach to water splitting**
  - **Reduce the overpotential by 30%**
- **Specific Objectives (FY09):**
  - **Optimize high throughput peptide synthesis on CombiMatrix Arrays**
  - **Optimize the multielectrode measurements of water splitting on the CombiMatrix Arrays**
  - **Demonstrate several rounds of optimization for catalytic activity**

Significance

- **The impact would be an energetically more efficient method for production of hydrogen from renewable electricity sources**

- **This addresses both System Efficiency and Renewable Integration**

General Approach

COMBIMATRIX

- Synthesis of 12,000 different peptides directly on electrodes
- Binding of metal ions or metal complex catalysts to the peptides, mimicking PSII water splitting complex
- Direct electrochemical measurement of current due to electrolysis at each electrode
- Analysis of one library of molecules informs the production of the next library
- Iterative optimization should result in an efficient water splitting catalyst

Milestones (FY09)

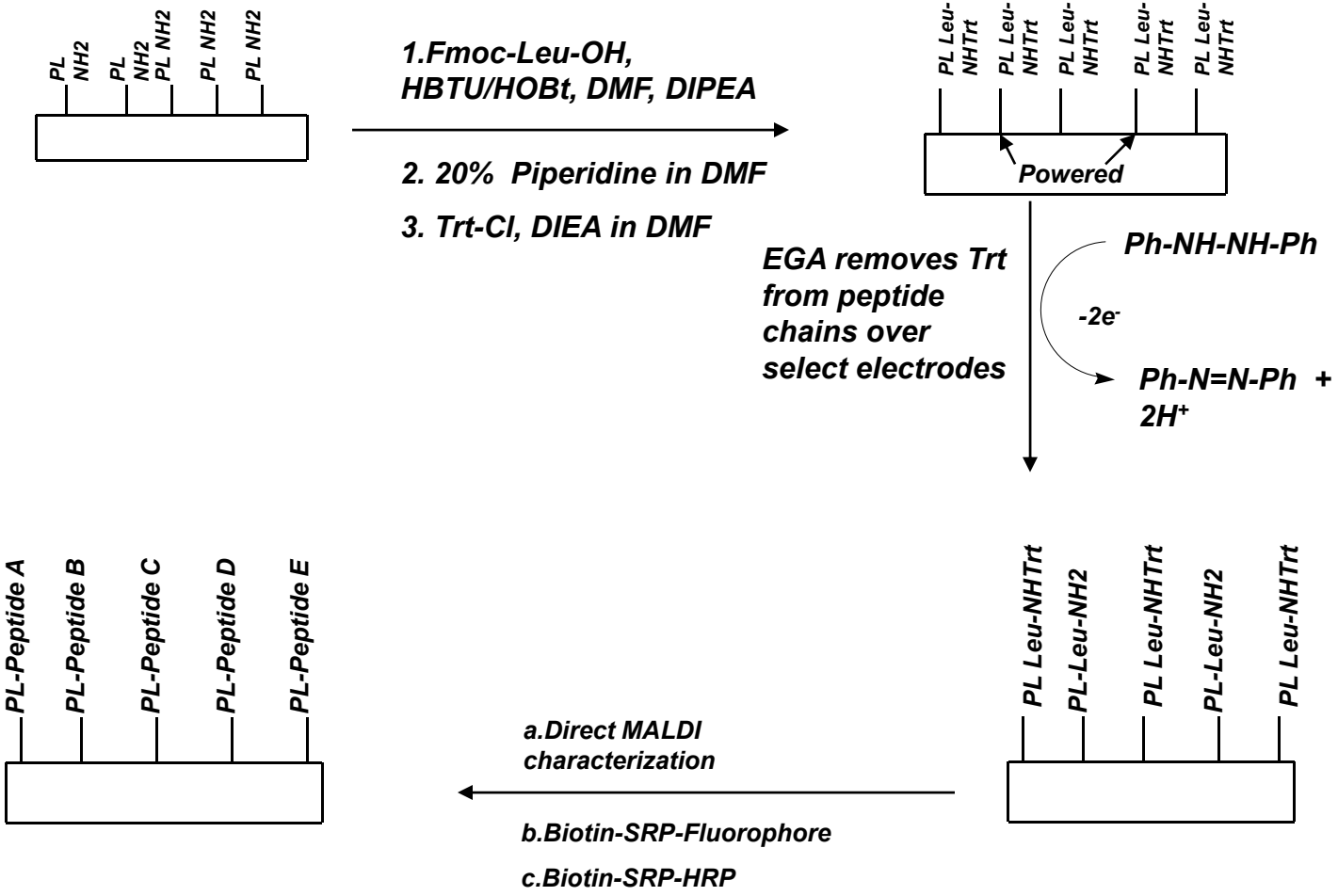
1. Multi-step patterned synthesis of peptides in an array
2. Verification of synthesis via direct MALDI spectroscopy on the surface
3. Automation of array synthesis
4. Background current measurements on the arrays
5. Comparing currents from peptides with and without Mn on the arrays
6. Iterate synthesis and measurement to result in a sequence optimization

Go/No Go to continue pursuing this approach depends on 1) ability to measure catalytic signal above noise and 2) ability to reproducibly synthesize arrays with multiple variable residues

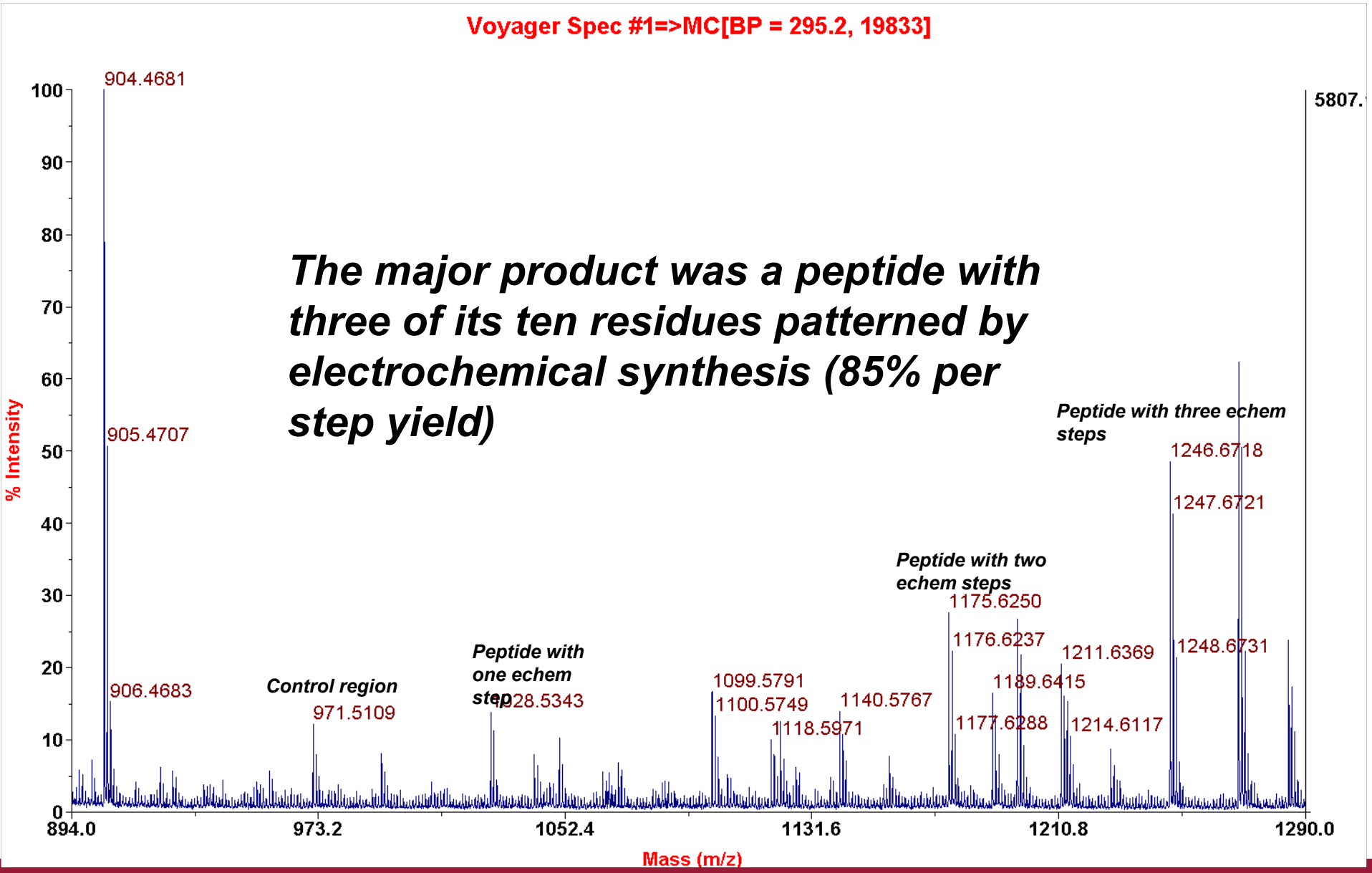
Summary of Past Accomplishments

1. Tested two platforms, light directed on home-built arrays and electrochemically directed via CombiMatrix arrays: elected CombiMatrix arrays
2. Design, synthesis and characterization of initial Mn binding peptides
3. Partnership formed with Mn-complex chemist
4. Developed MALDI method for measuring products of in situ synthesis directly on the surface
5. Partnered with CombiMatrix to modify sensing equipment to measure currents at 12,500 electrodes
6. Demonstrated ability to perform standard solid phase synthesis on the arrays (by nonpatterned methods)
7. Demonstrated ability to remove blocking groups using patterned electrochemically generated acids and create peptide bonds

Accomplishment: Multistep Synthesis

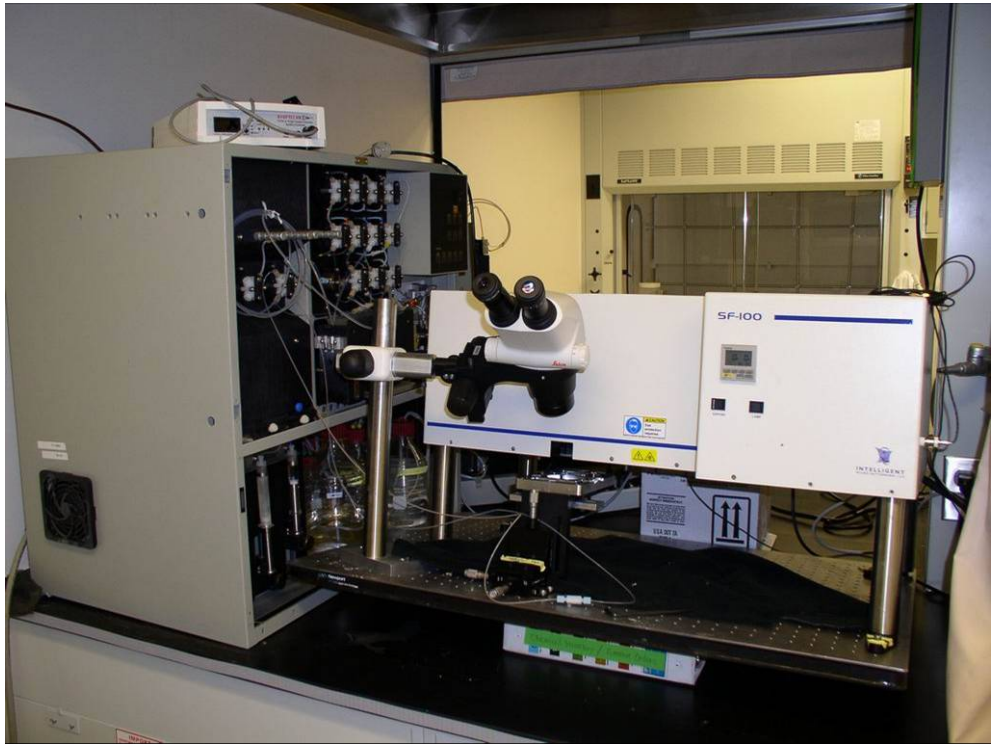


Accomplishment: Synthesis Verification



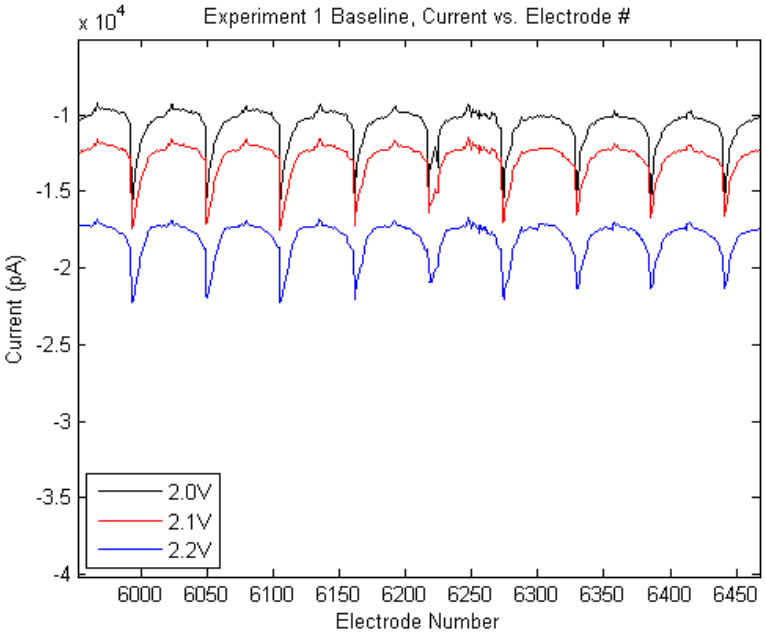
Accomplishment: Automation

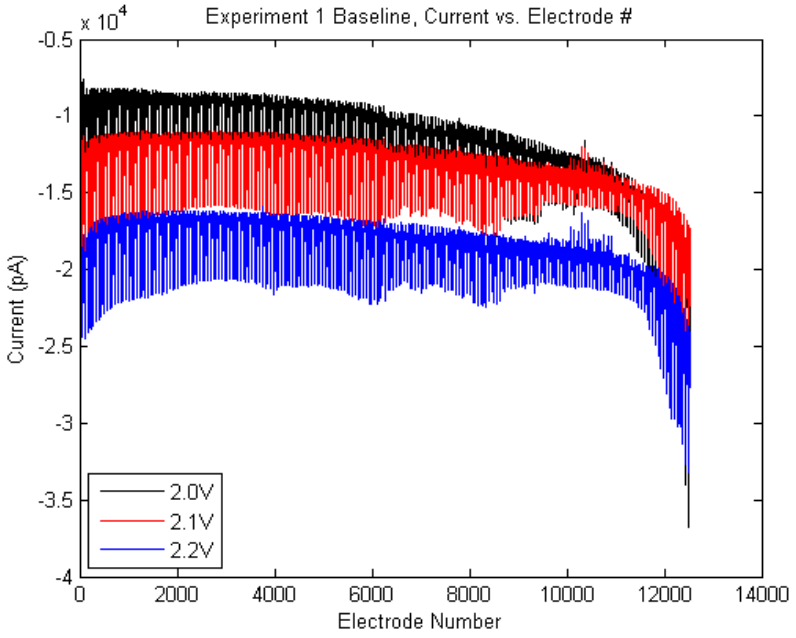
1. Fluidic connection between Pioneer synthesizer and Combimatrix synthesis chamber
2. Software control interface developed between synthesizer and synthesis system



Accomplishment: Array Current Background

Large, but systematic current variations across electrodes

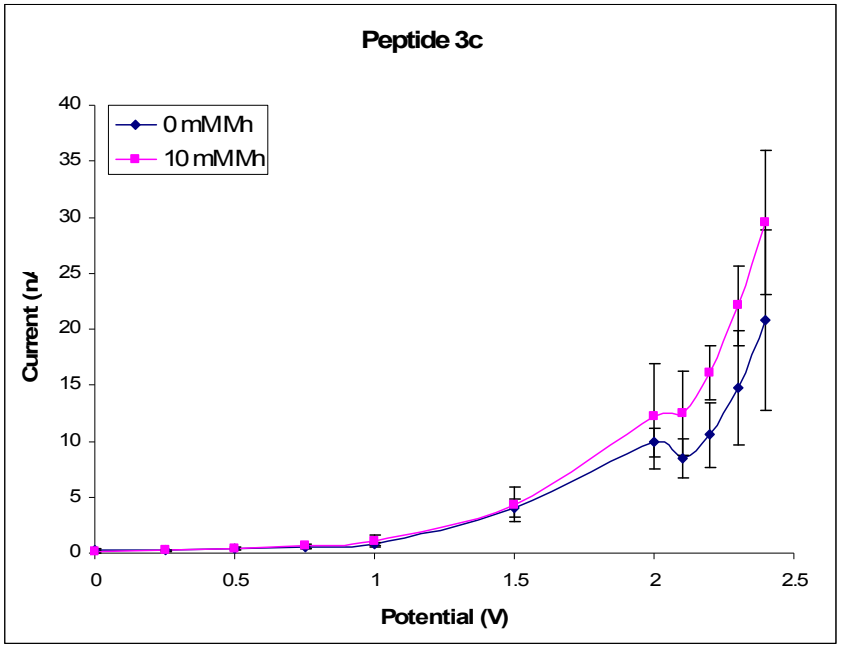




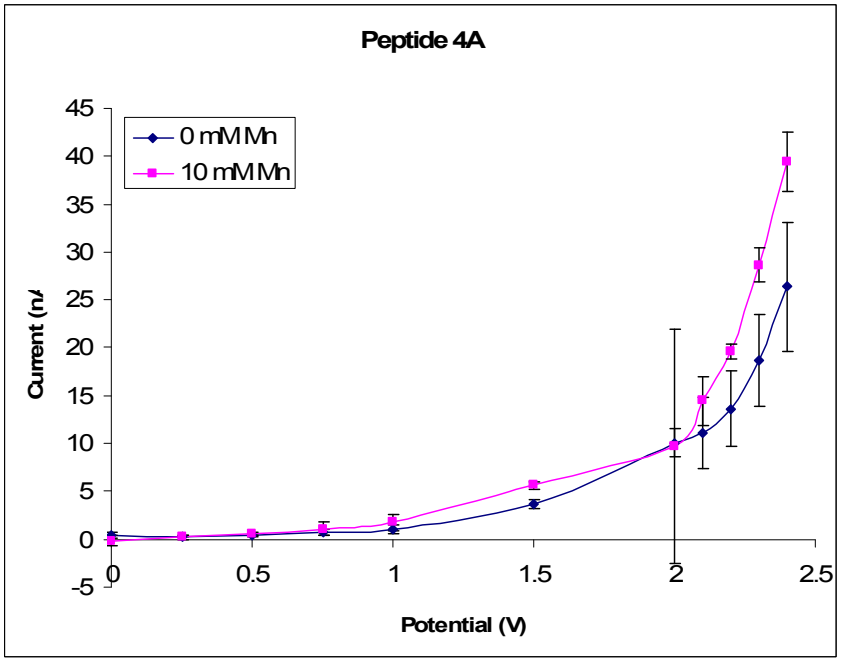
Accomplishment: Comparing +/- Mn peptides

No significant difference between Mn binding peptide and control

Mn binding Peptide



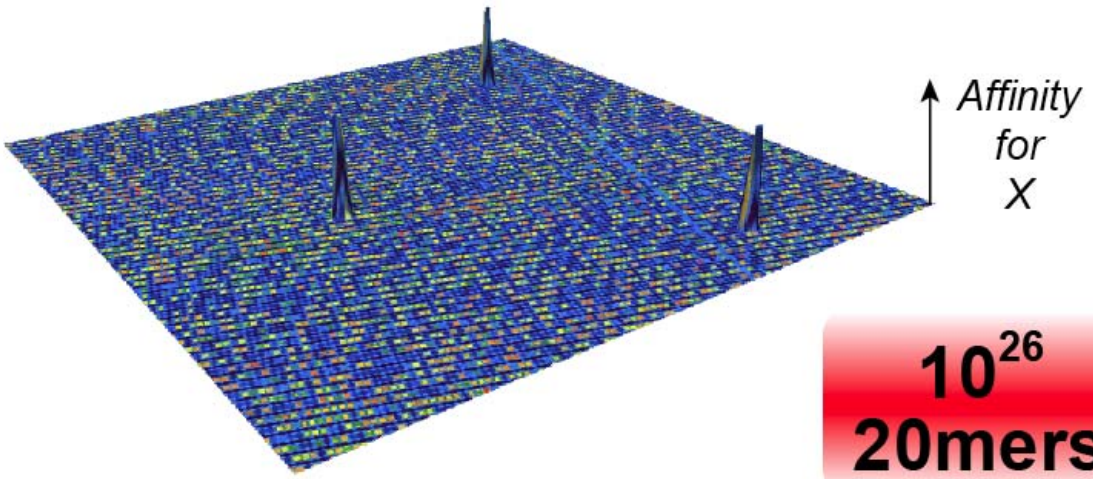
Control Peptide



Milestones (FY09)

1. Multi-step patterned synthesis of peptides in an array	✓
2. Verification of synthesis via direct MALDI spectroscopy on the surface	✓
3. Automation of array synthesis	✓
4. Background current measurements on the arrays	✓
5. Comparing currents from peptides with and without Mn on the arrays	✓
6. Iterate synthesis and measurement to result in a sequence optimization	

Key Additional Finding (Not DOE funded)



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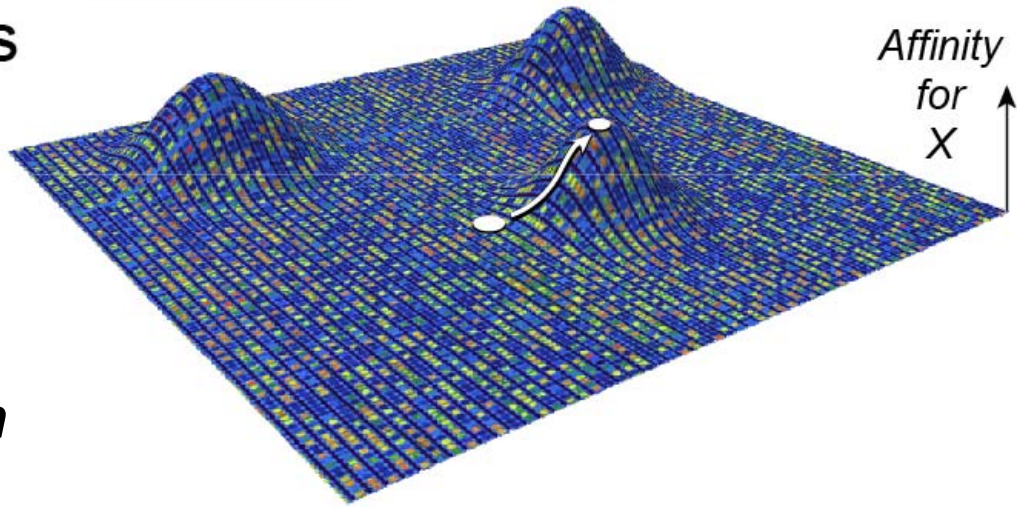
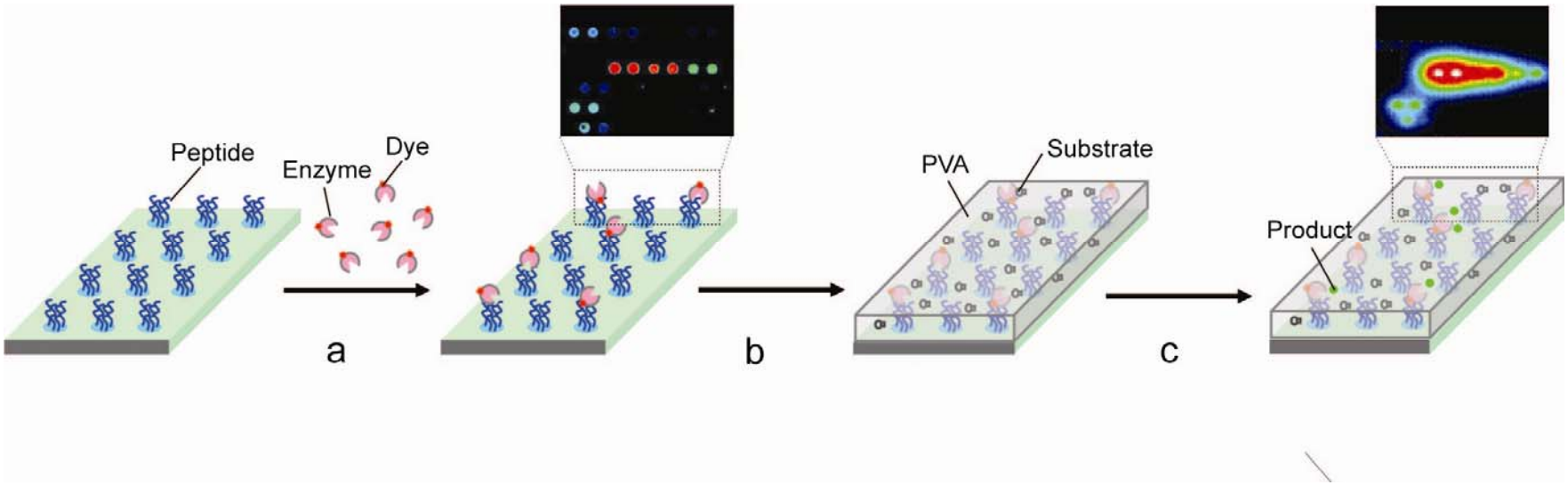
Requires Large Libraries

Peptide space is smooth and can be searched through iterative mutation



Sparse Sampling Effective

Key Additional Finding (Not DOE funded)



Peptides can be used to stabilize or modify activity of existing catalysts

Collaborators

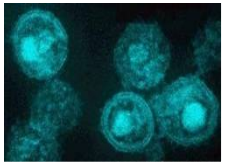
- **CombiMatrix**
  - Industry partner
  - Funded through equipment purchase
  - Provides software/hardware development assistance
  - Outside DOE hydrogen program
- **Professor William Armstrong**
  - Boston University
  - Currently unfunded
  - Will provide Mn-complex catalysts
  - Outside DOE hydrogen program

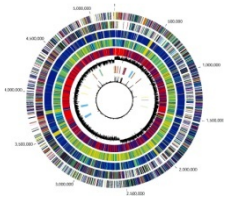
Future Work

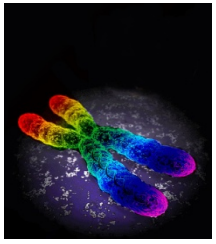
- FY09 is final year of DOE funding (official end June 09, but no cost extension to December granted)
- Perform an Iterative optimization:
  1. Start with one of our peptides known to bind Mn
  2. Select 3-4 residues thought to be key to catalysis
  3. Synthesize array with all possible variants
  4. Measure currents vs. voltage
  5. Pick best
  6. Repeat for 3 additional residues
  7. Etc.

Summary

- After choosing the electrochemical patterning platform, synthesis was optimized to about 85% yield
- Still limited by issues with side chain reactivity
- Using a modified CombiMatrix sensing instrument, have made electrochemical measurements at 12,500 electrodes
- Current Mn binding peptides do not show high enough catalysis to measure on the electrode arrays
- Goal is not to create an array and attempt and optimization in remaining 8 months







The Biodesign Institute at ASU

- Eradicating Cancer
- Rapid Vaccine Discovery System
- Defending Against HIV
- Diabetes Detection and Management
- Preventing Pneumonia in Newborns
- Treating Childhood Mitochondrial Diseases
- Using Nature to Clean Water
- Energy from Waste