

Hybrid Simulation of Energy Generation from Ocean Waves



Nigel Kojimoto
nigel@calwave.org

Thomas Boerner
thomas@calwave.org



Selim Günay
selimgunay@berkeley.edu



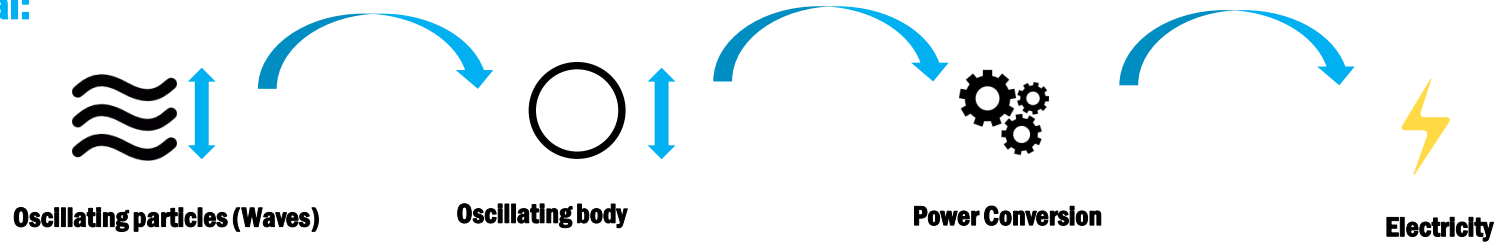
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Outline

- **Introduction** to Wave Energy Conversion
- **Why** is Hybrid Simulation for Wave Energy Conversion?
- **Computational** Domain: Simulation Side
- **Physical** Domain: Constructed Power Take-Off Specimen
- Domain Coupling & **Hybrid Simulation**

Introduction to Wave Energy Conversion

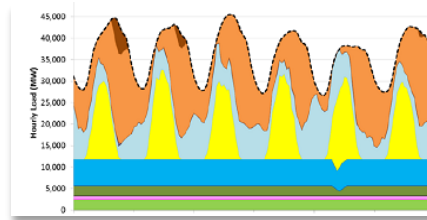
Ideal:



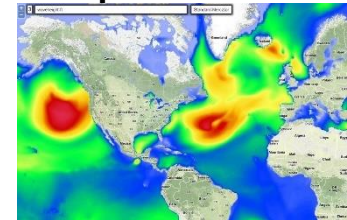
Energy Density



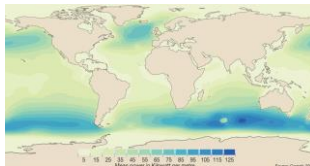
Baseload



Well predictable



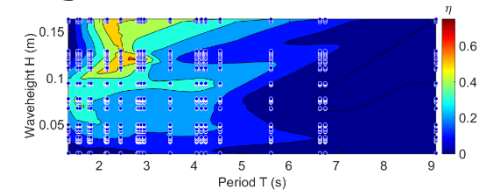
Huge Potential



CO2 Neutral

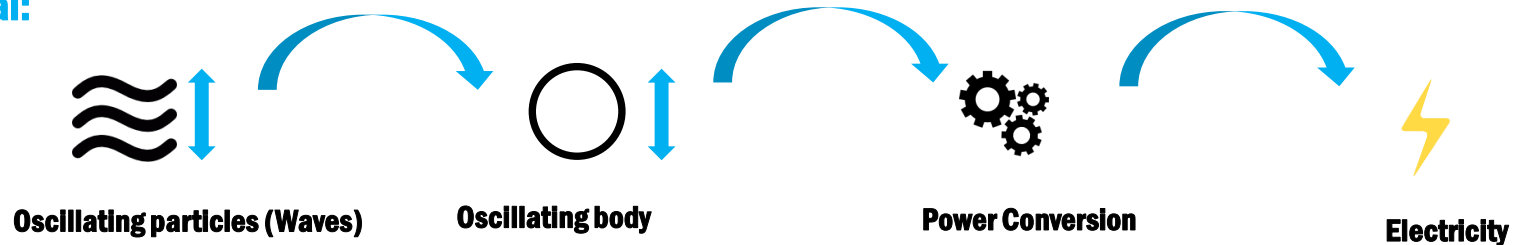


High Efficiencies



Introduction to Wave Energy Conversion

Ideal:

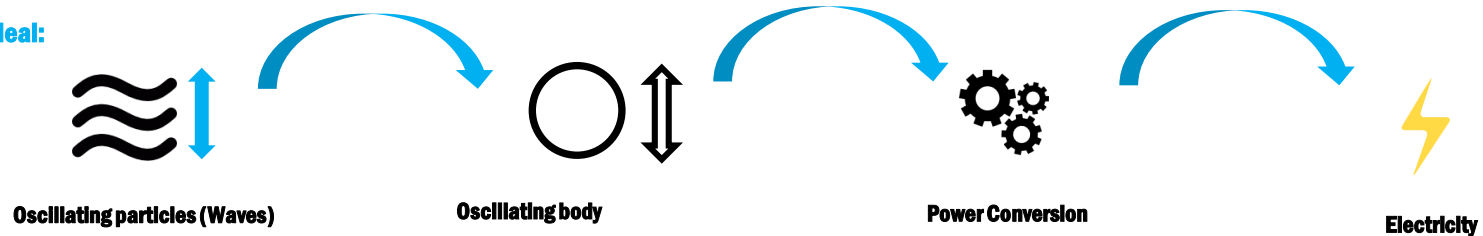


→ Multiple full scale projects **failed** in the past

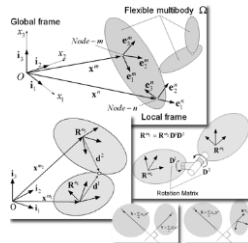
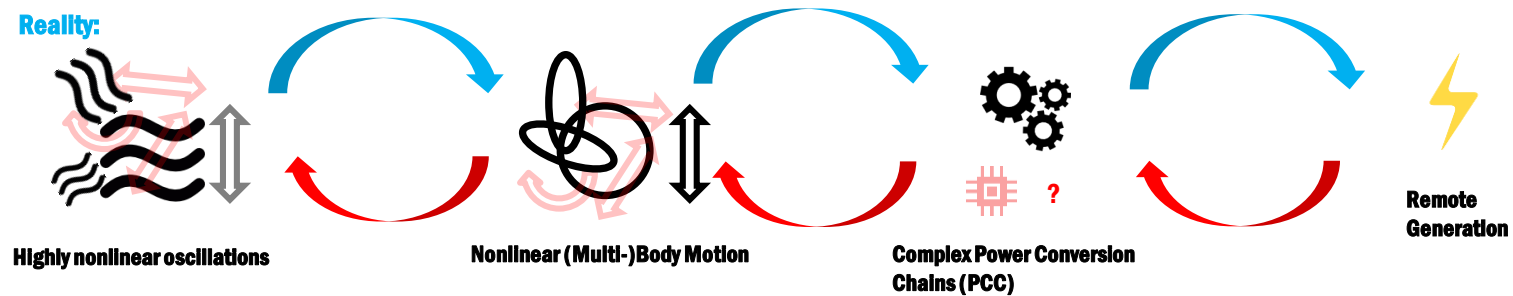
→ Currently no commercial wave power plant in the world

Introduction to Wave Energy Conversion

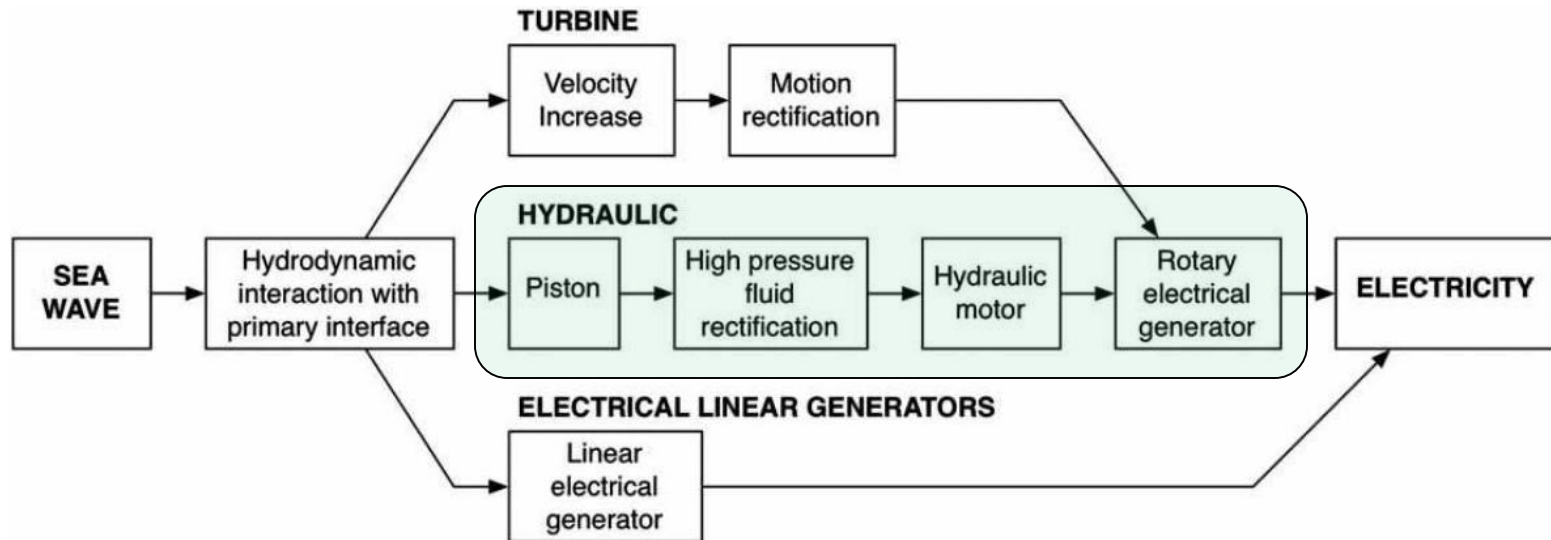
Ideal:



Reality:



Power Conversion Chain



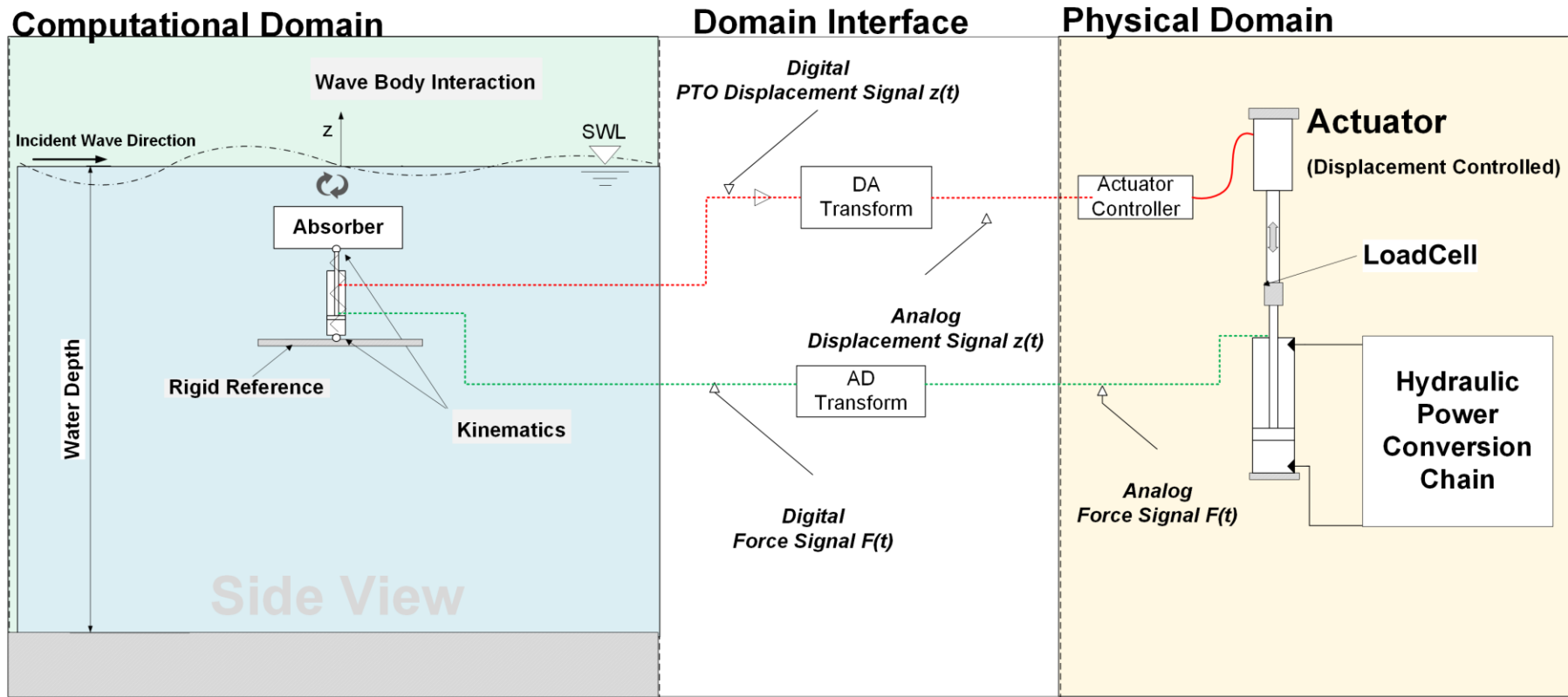
- Hydraulic power conversion chain (PCC) selected

Why Hybrid Simulation?

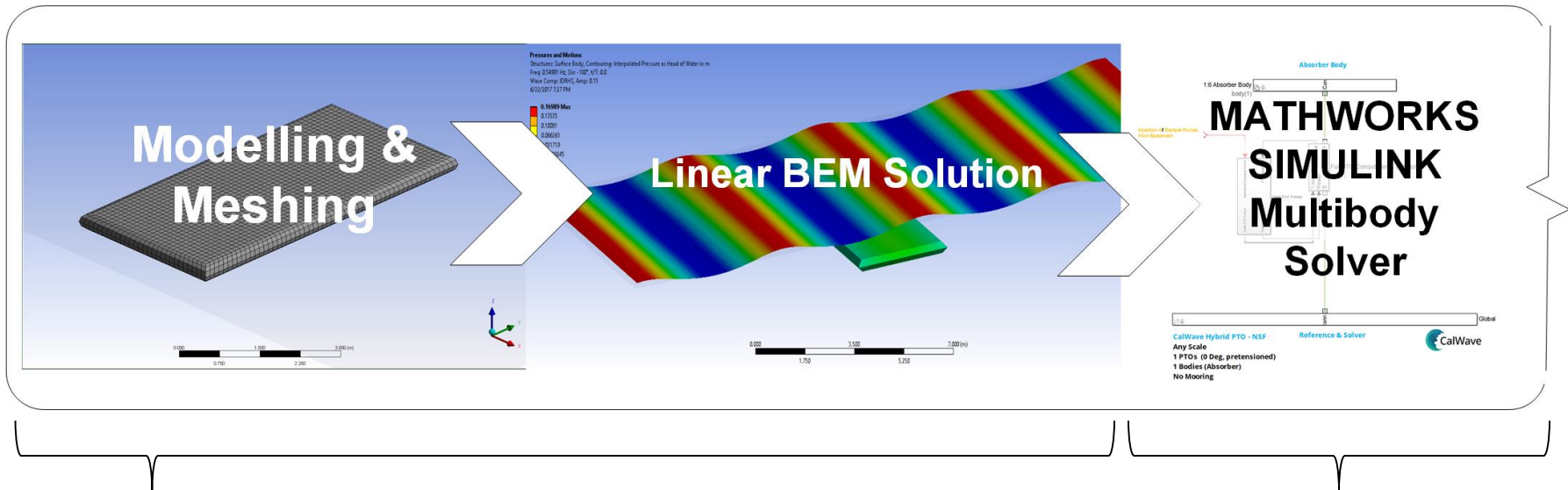
- Full-Scale machines are very **large & expensive**
 - **De-risking of every sub-component required before scaling up but ocean testing for realistic scenarios difficult/impossible**
- Power Conversion Chain behavior & efficiency is **inherently coupled** with the wave absorber behavior
 - **Exp. assessment of entirely uncoupled components not possible**
- Power Conversion Chain requires **complex control and safety mechanisms** to be tuned
 - **Tune and test in safe laboratory environment**



WEC Hybrid Simulation Overview



Computational Domain Overview

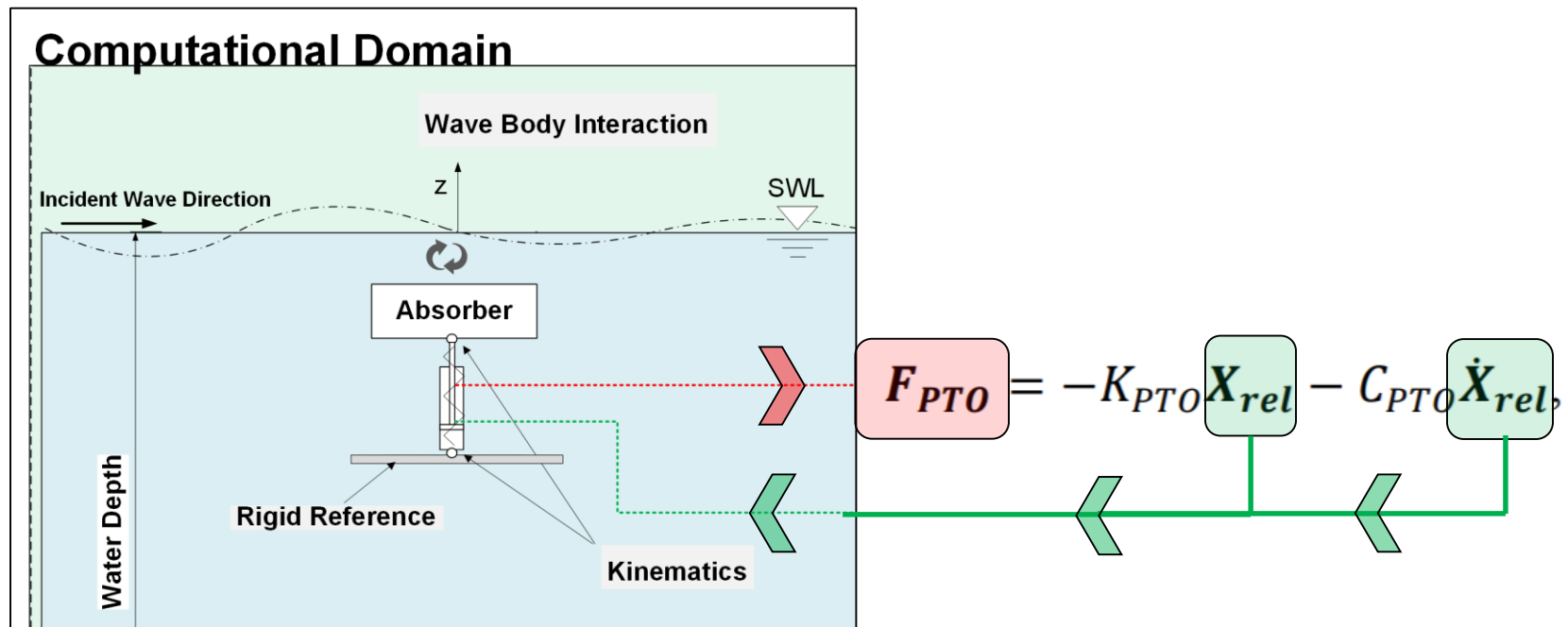


- Pre-Processing
- Fluid-Structure Interaction

- Kinematics
- Real-Time Runtime

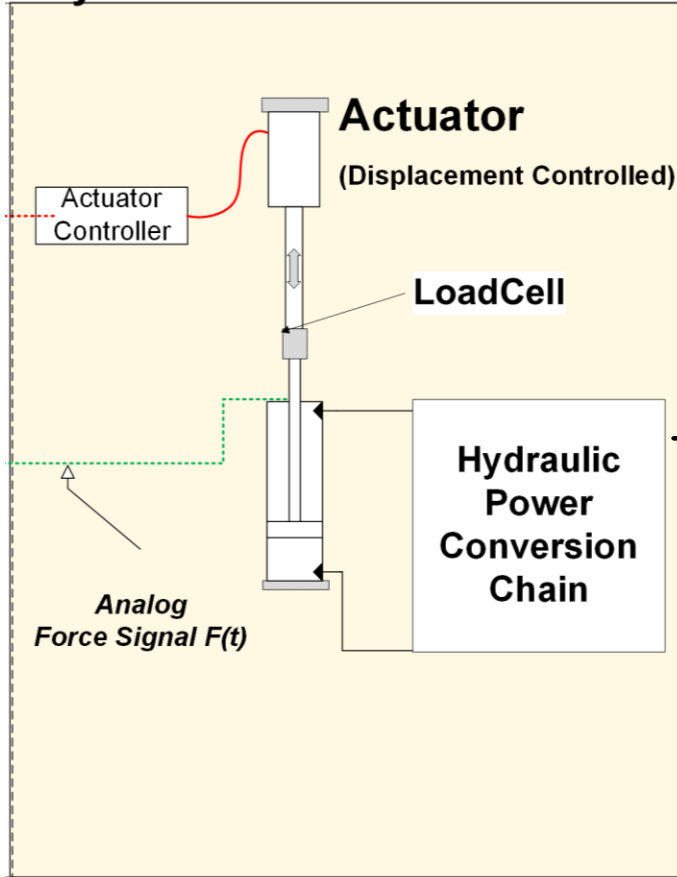
Computational Domain Overview

$$m\ddot{X} = F_{ex} + F_{rad} + \boxed{F_{PTO}} + F_v + F_B + F_m,$$



Physical Domain

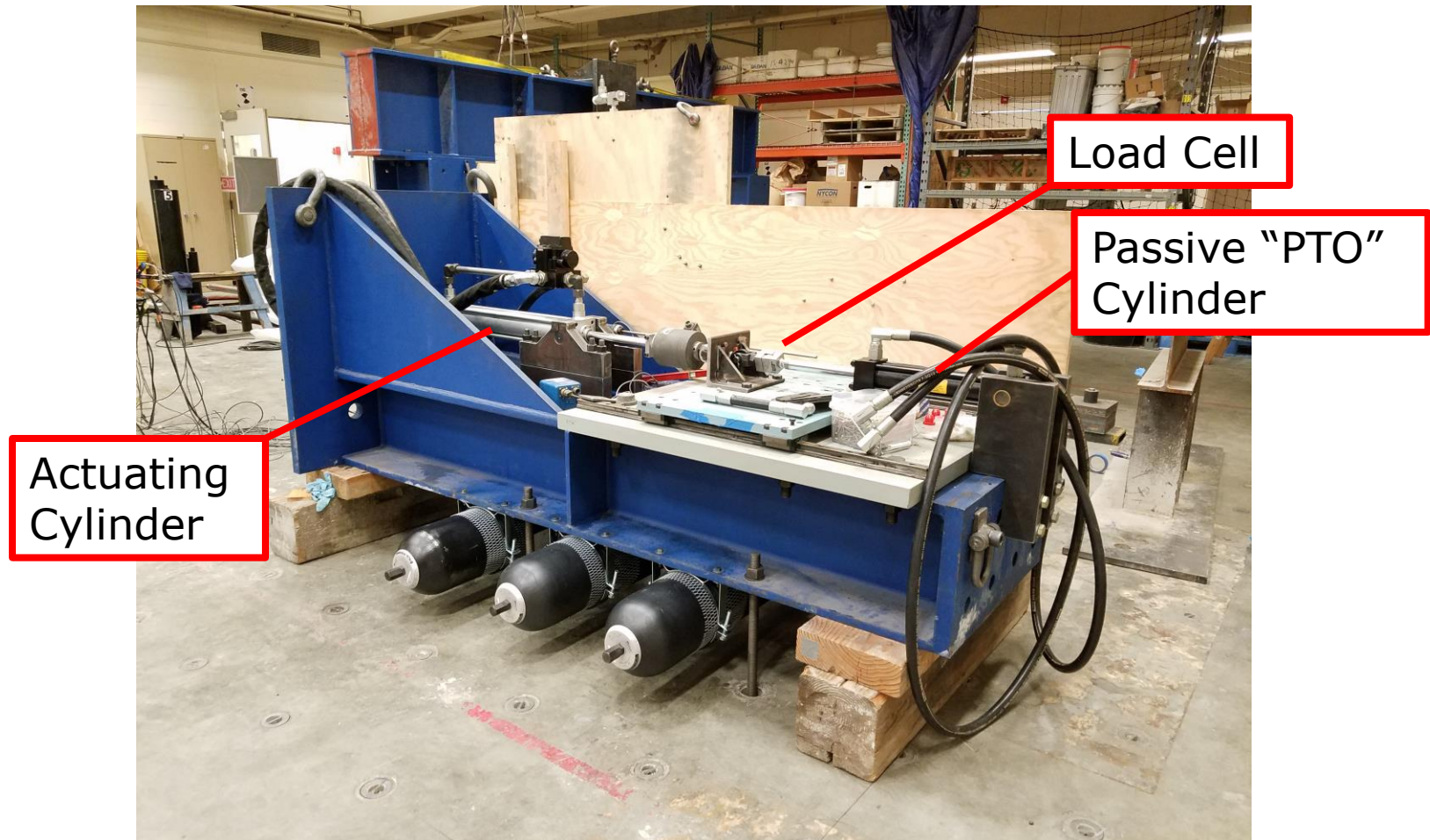
Physical Domain



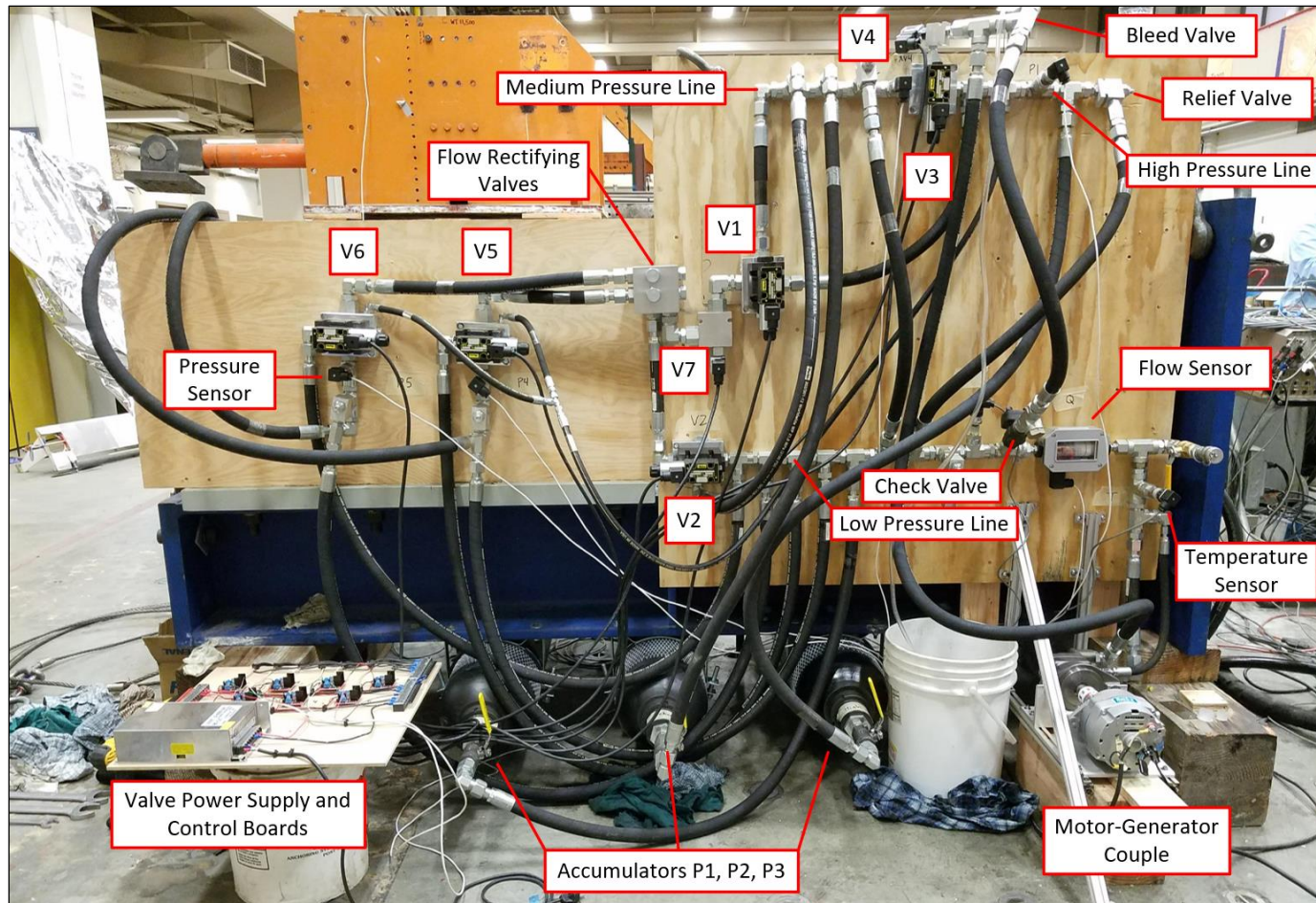
Desirable Power Conversion Characteristics

- **Convert** low speed, high force oscillations into grid compatible electricity
- Include some form of **power smoothing/temporary energy storage**
- **Control force** with respect to velocity for increased power capture efficiencies (*controllable damping properties*)

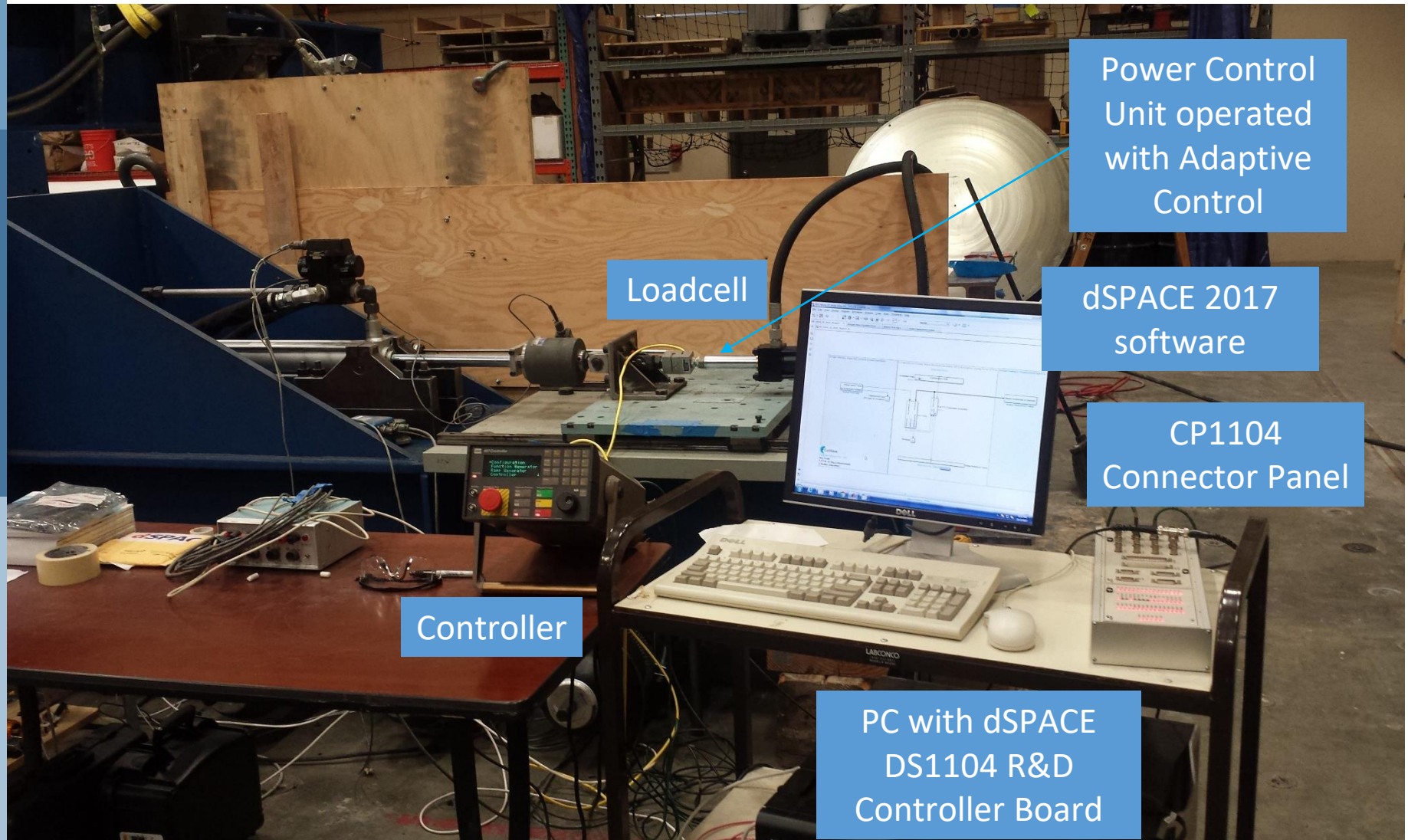
Hybrid Physical Experimental Setup



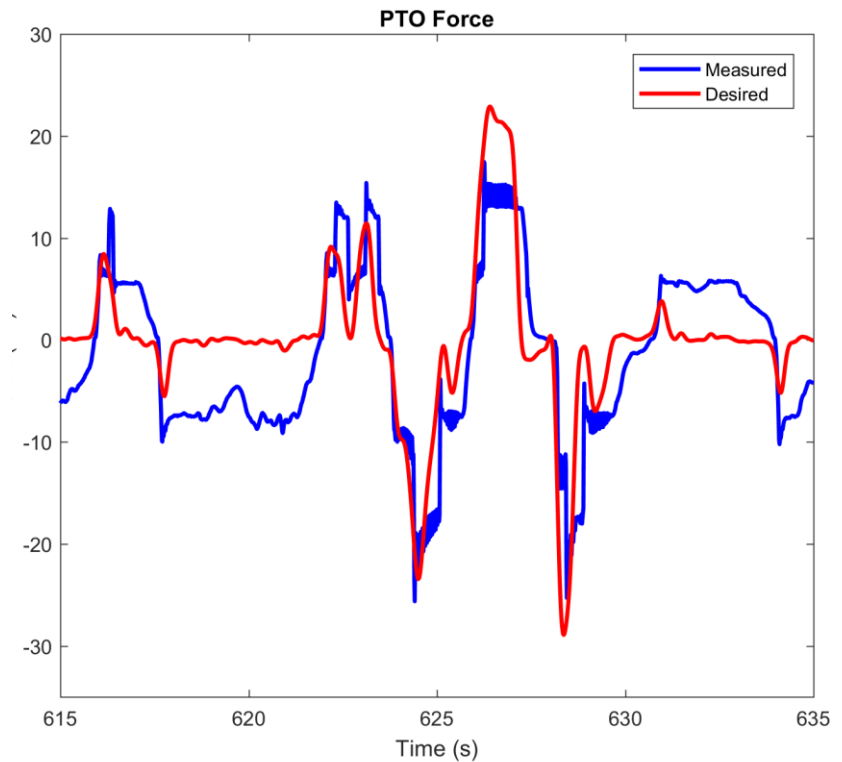
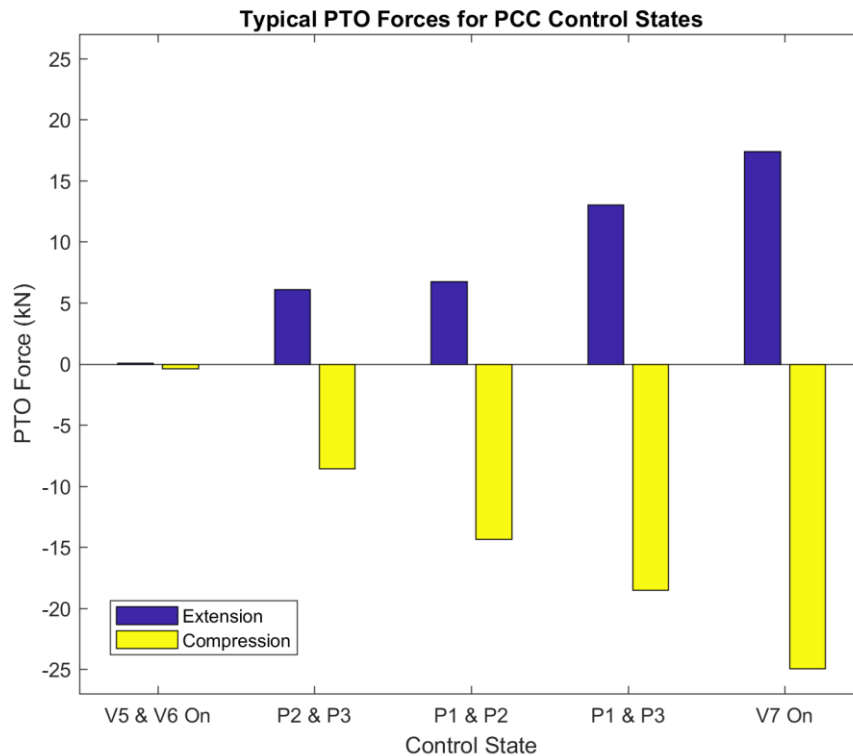
Constructed Hydraulic PCC



Hybrid Simulation System



Preliminary Results



- Wide range of forces achieved
- Preliminary force tracking successful

Next Steps

- Ocean demonstration project funded by DOE
 - Design iteration of PCC
 - Improve component efficiencies
 - Add control states to improve tracking
 - Add restoring force element to PTO (Spring)
 - Reduce computational domain's simulation time for smaller hybrid timesteps
 - Run more wave cases in hybrid experiments

- Apply for NSF STTR Phase II
 - Full Scale PTO Development?

Thank You