The 349'ers

Fuel Cell Design for Unmanned Underwater Vehicles

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IPRO 349
Professor Ramani

History Of Fuel Cells

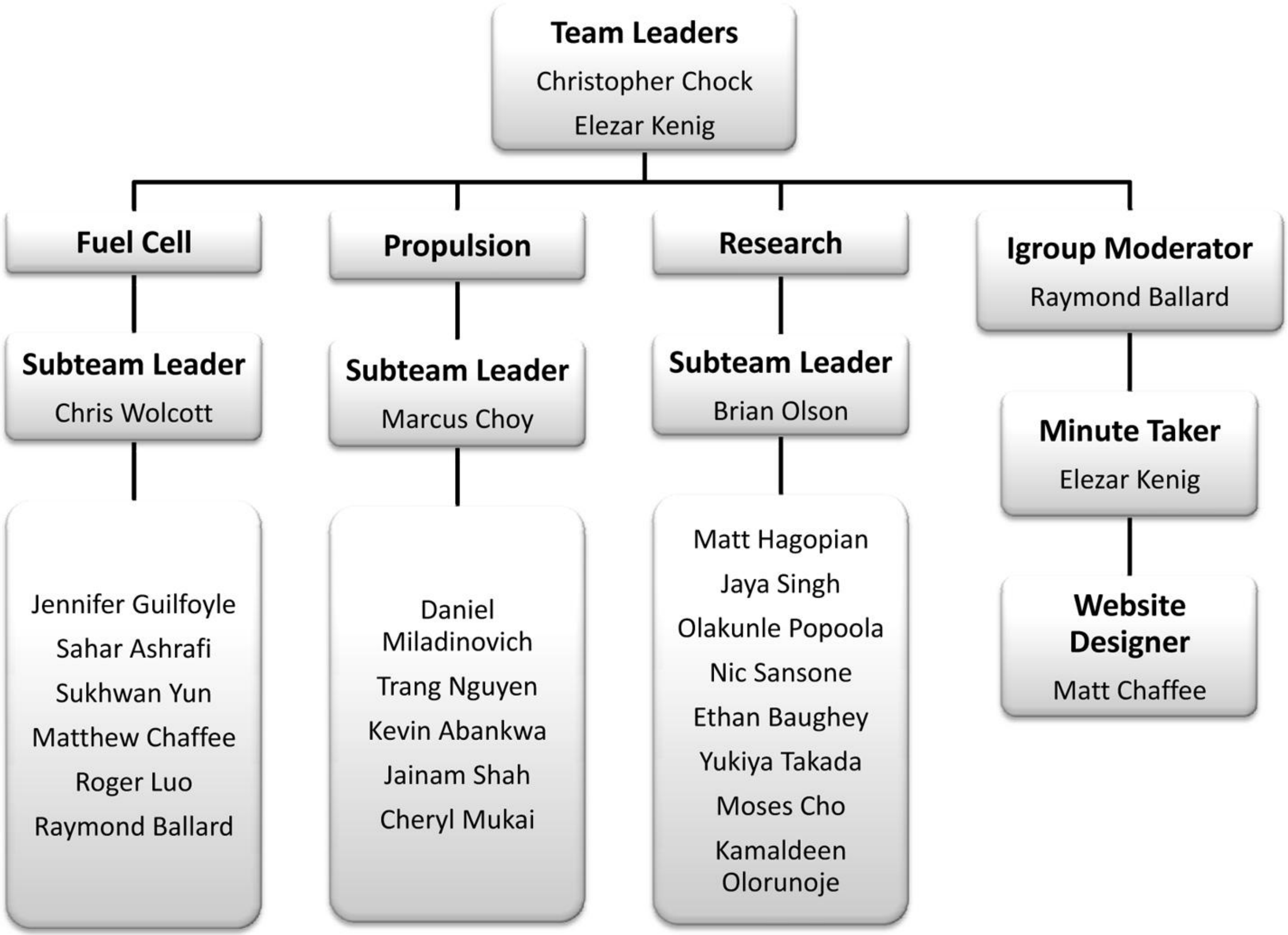
- 1839 - Sir William Grove discovers fuel cells
- 1889 - First practical fuel cell
- 1932 - First successful fuel cell device
- 1959 - Five-kilowatt fuel cell system
- 1959 - 20 HP fuel cell-powered tractor

Statement of Problem

- Manned Vehicles Limitations
  - Depth
  - Safety
  - Maneuverability
  - Duration
- Fuel Cells
  - Energy Density
  - Silent/Stealth
  - Air independent
  - Low Maintenance

Project Goals

- Draw out plans for a UUV
- Design and test a prototype fuel cell
- Develop a UUV based off of fuel cell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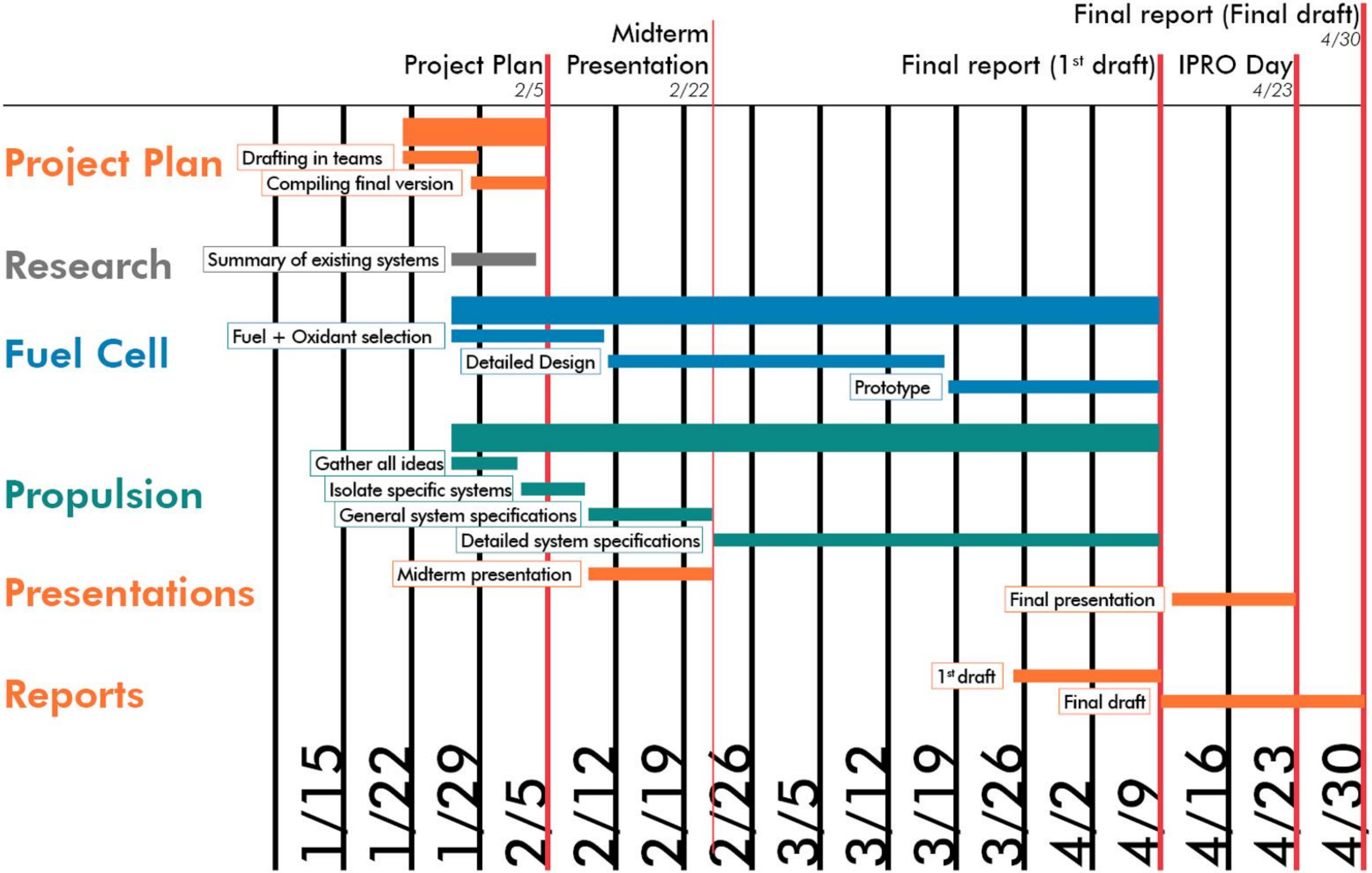
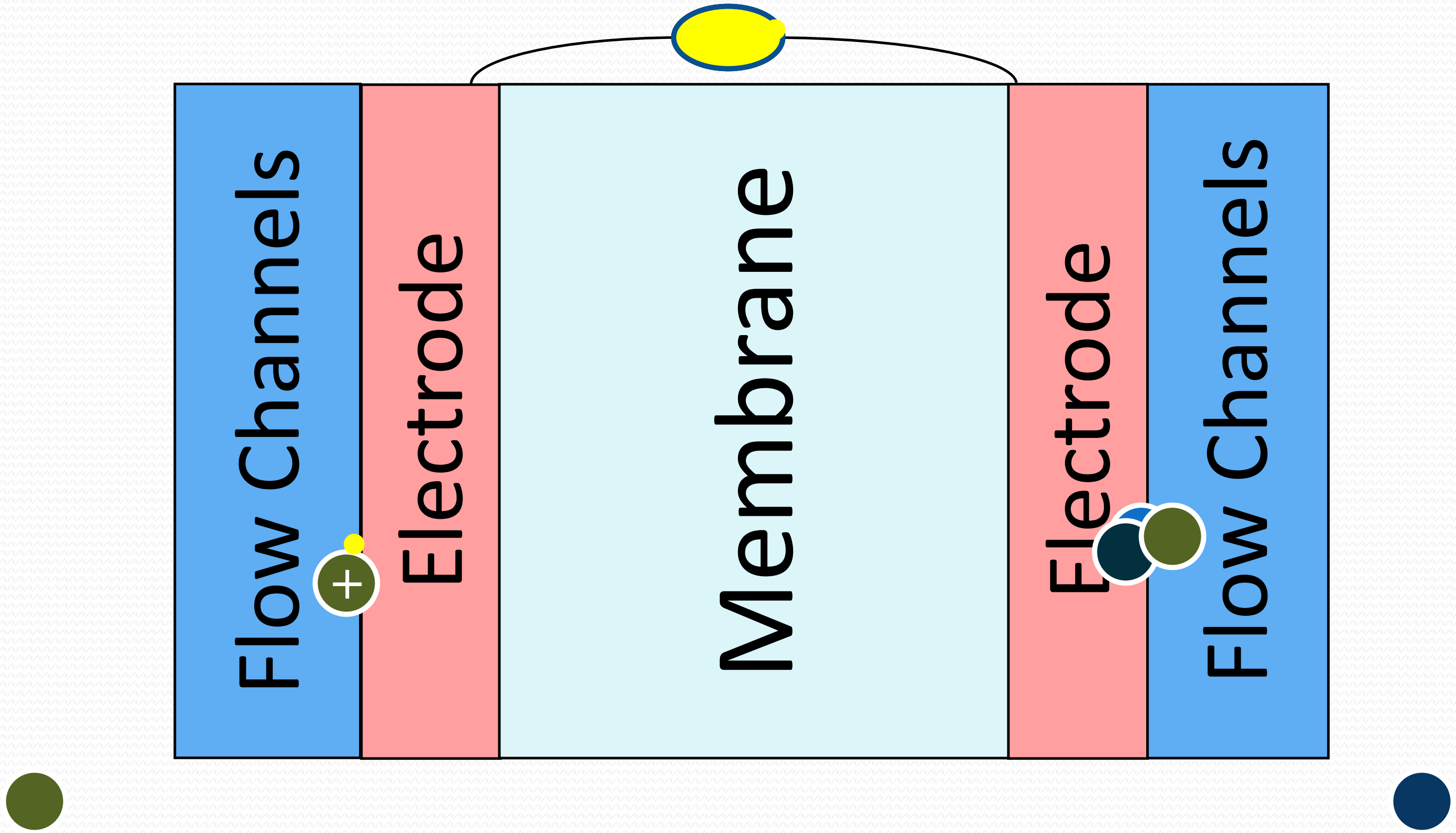
IPRO 349: Fuel cells for Undersea Vehicles



Fuel Cell Team

How A Fuel Cell Works

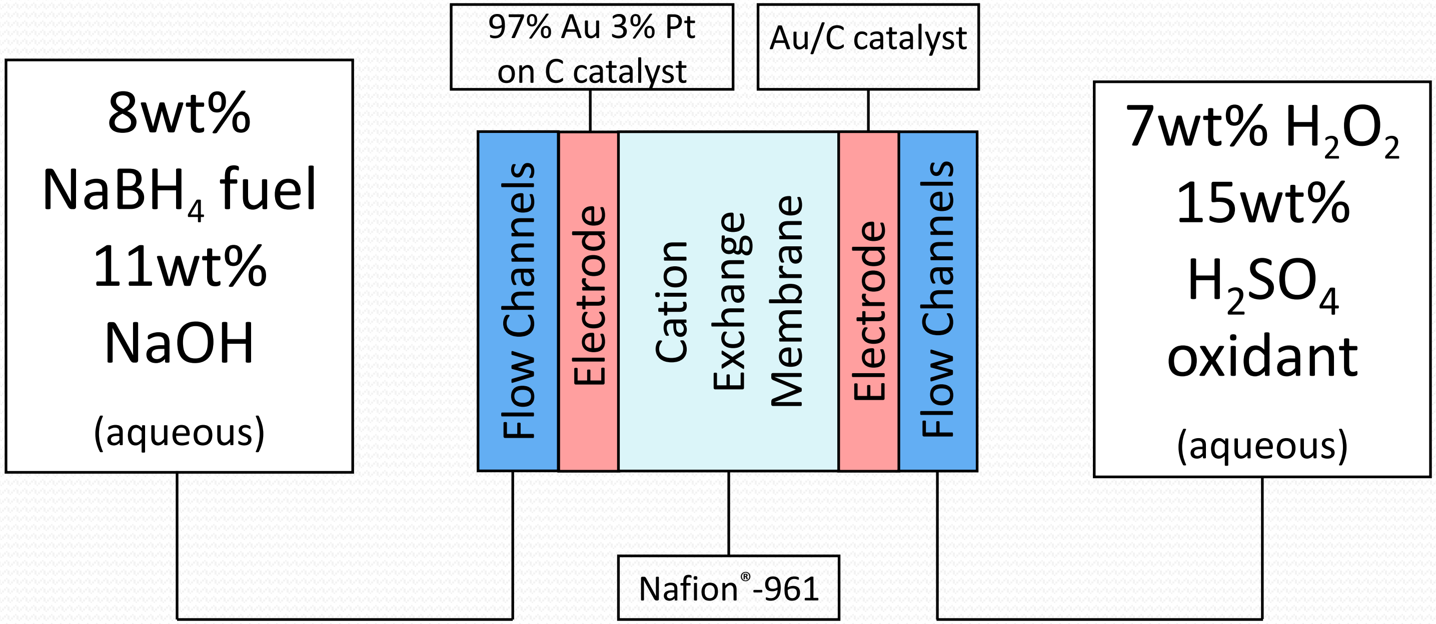


Choosing a Chemistry

- Fuels
  - Carbon Fuels
    - Methanol
    - Ethanol
    - Ethylene Glycol
    - Etc.
  - Hydrazine
  - Sodium Borohydride
- Oxidants
  - Oxygen
  - Perchlorates
  - Hydrogen Peroxide

Proposed Fuel Chemistry

Overall Theoretical Cell Voltage 3.01 V



$BH_4^- + 8OH^- \rightarrow BO_2^- + 6H_2O + 8e^-$

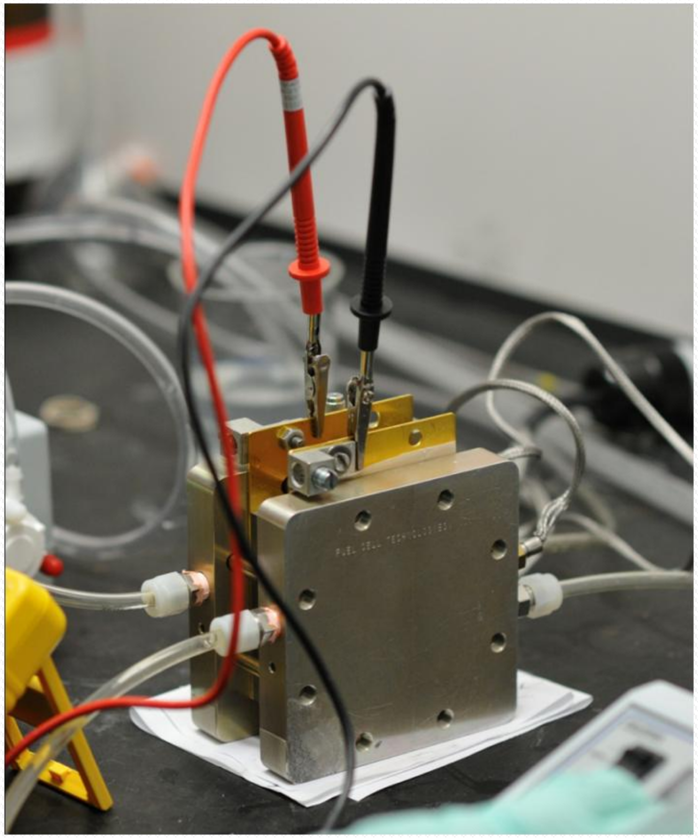
Half Reaction Potential = -1.24 V (vs. SHE)

$H_2O_2 + 2H^+ + 2e^- \rightarrow H_2O$

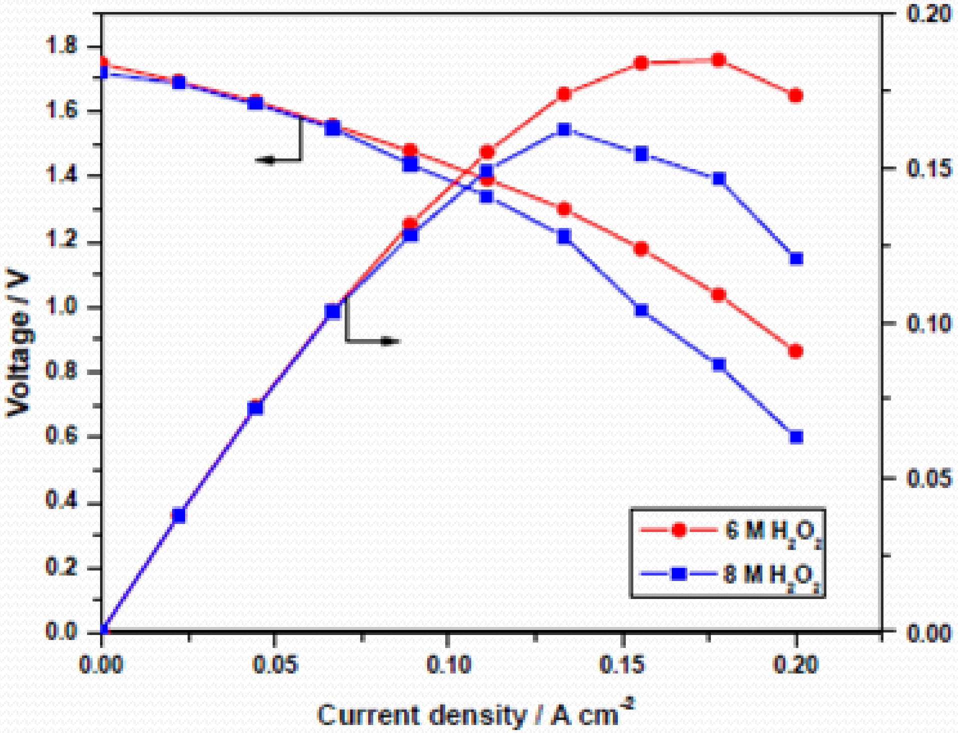
Half Reaction Potential = 1.77 V (vs. SHE)

Goals

- Build a prototype fuel cell



- Design fuel cell system based on performance from literature

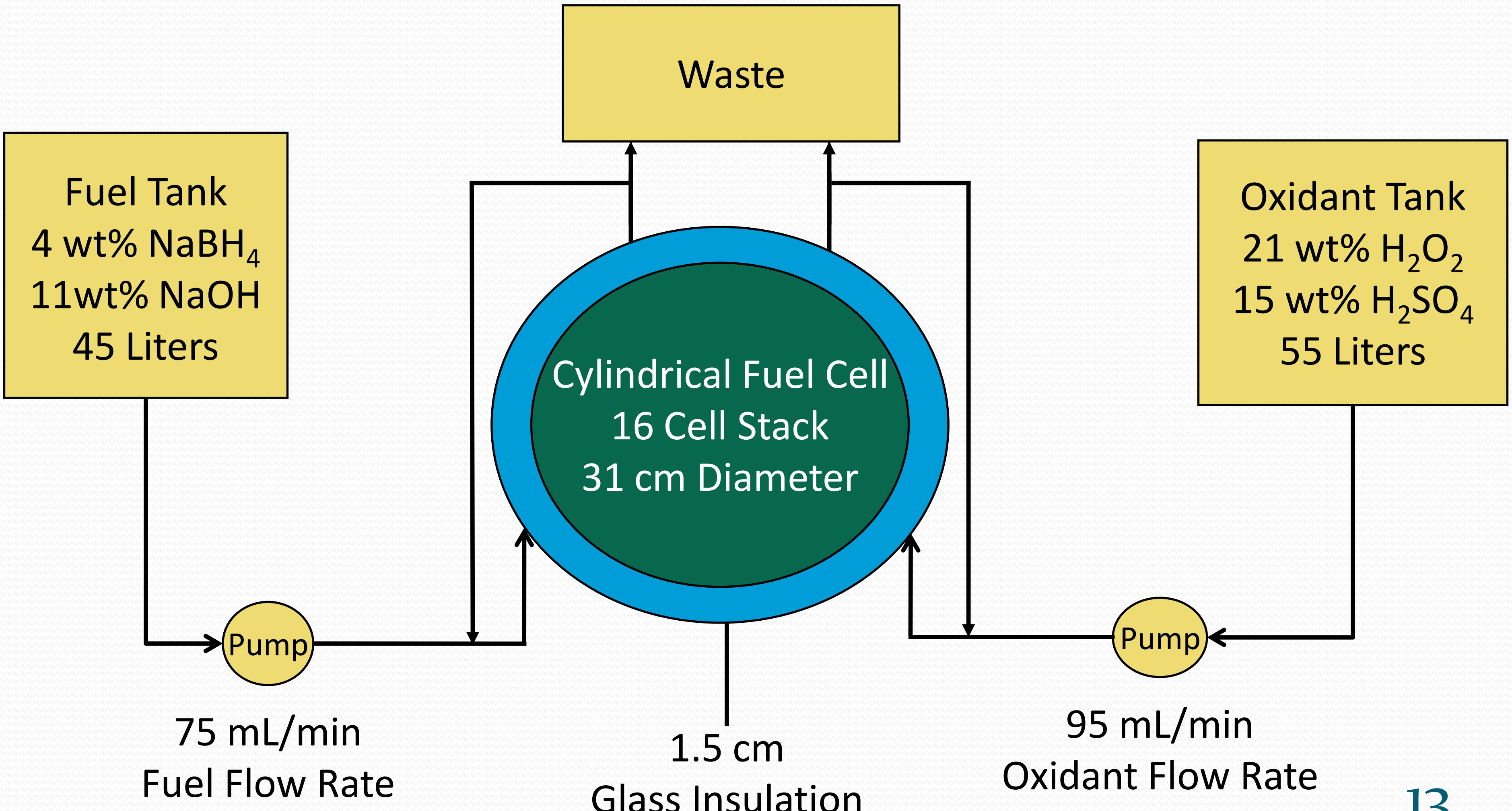


[1]Shukla et al., *Energies* **2009**, 2, 190-201

Differences from Ideal

- Experimental
  - Cathode (oxidant side) catalyst 97wt% Au 3wt% Pt on C
  - 4% NaBH4
  - Nafion 117/112 Membrane
- Design
  - 21 wt% H_2O_2
  - Anode (fuel side) catalyst Pt/C
  - Nafion 117 Membrane

Design Based on Literature



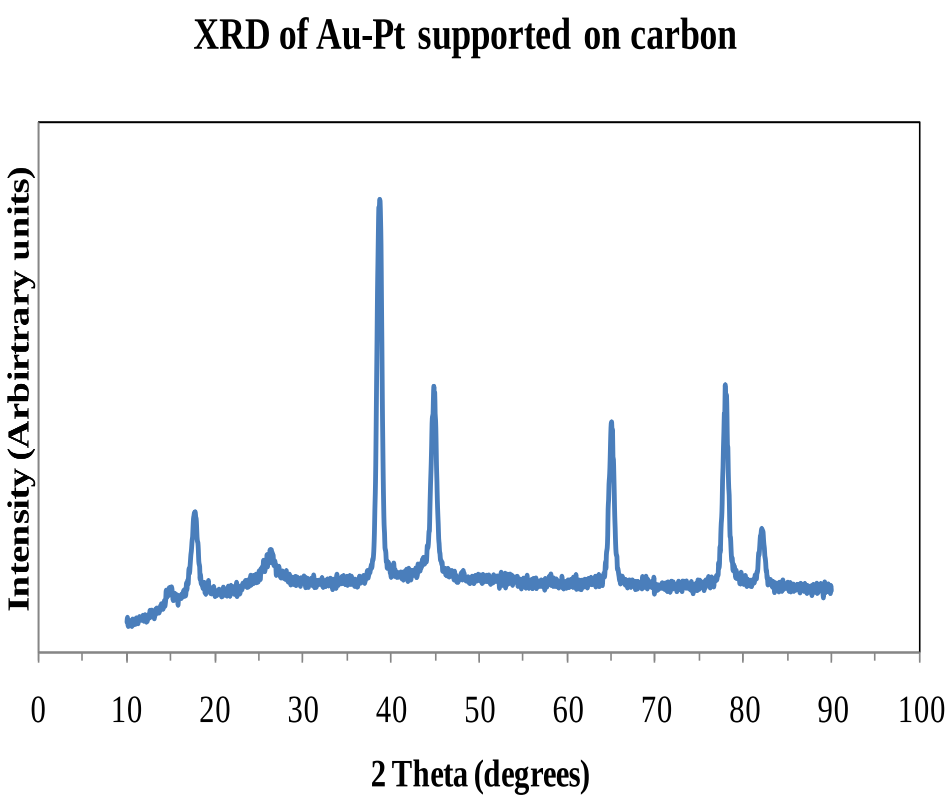
Design Based on Literature

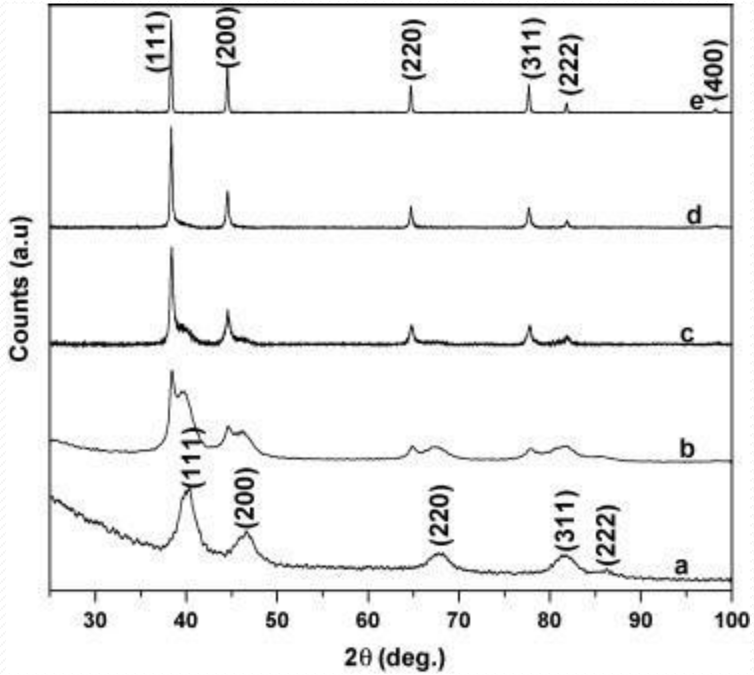
Fuel Cell Design Results

Number of cells	16
Cell operating voltage	1.5 V
Fuel cell length	29 cm
Fuel cell volume	23 L
Fuel cell power output	2 kW
Fuel cell voltage	24 V
Range	70 km

Fuel Cell Prototype

Catalyst Results





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a: 100% Pt on carbon catalyst

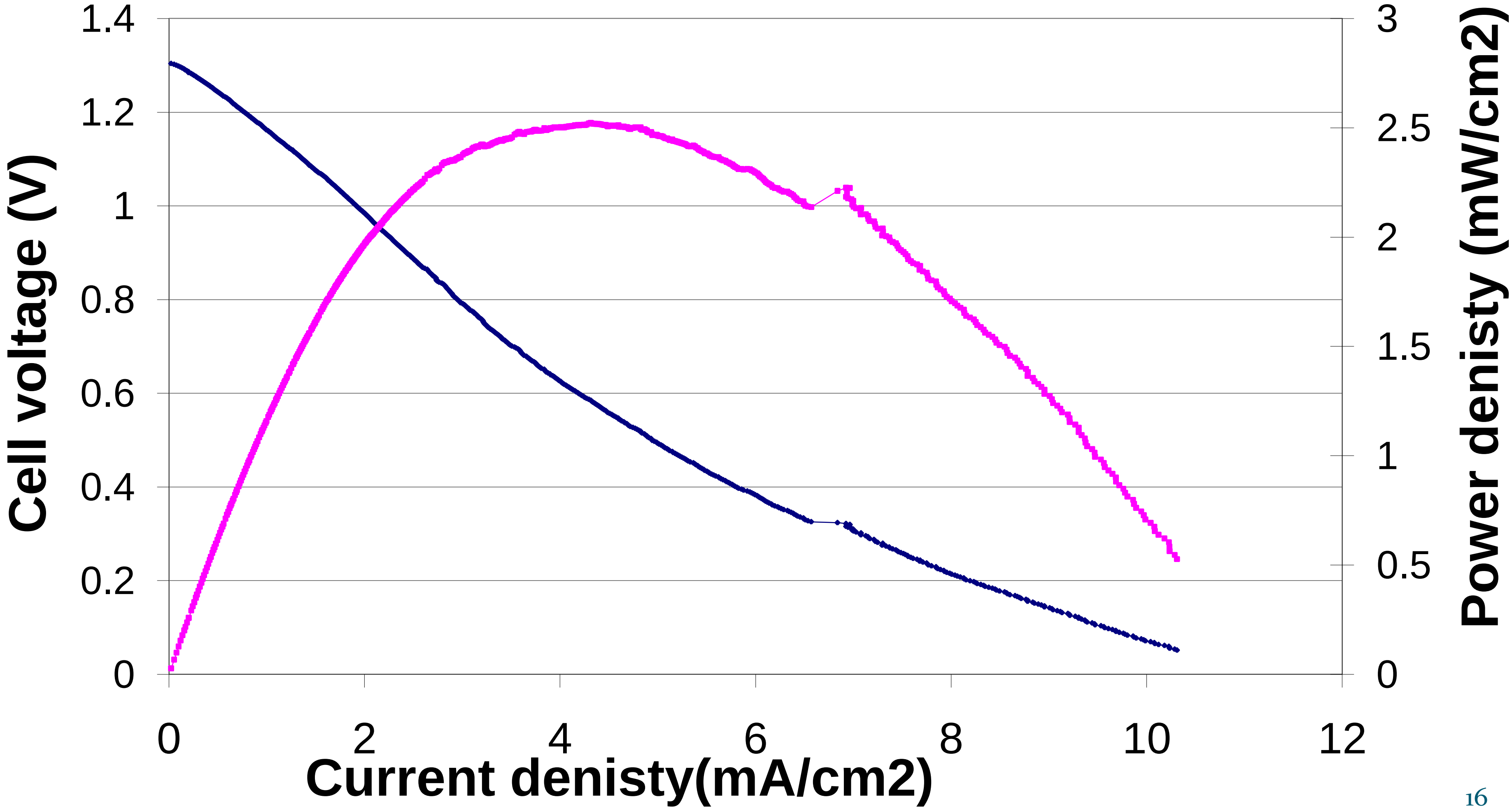
b:25% Au/75% Pt on carbon catalyst

c:50% Au/50% Pt on carbon catalyst

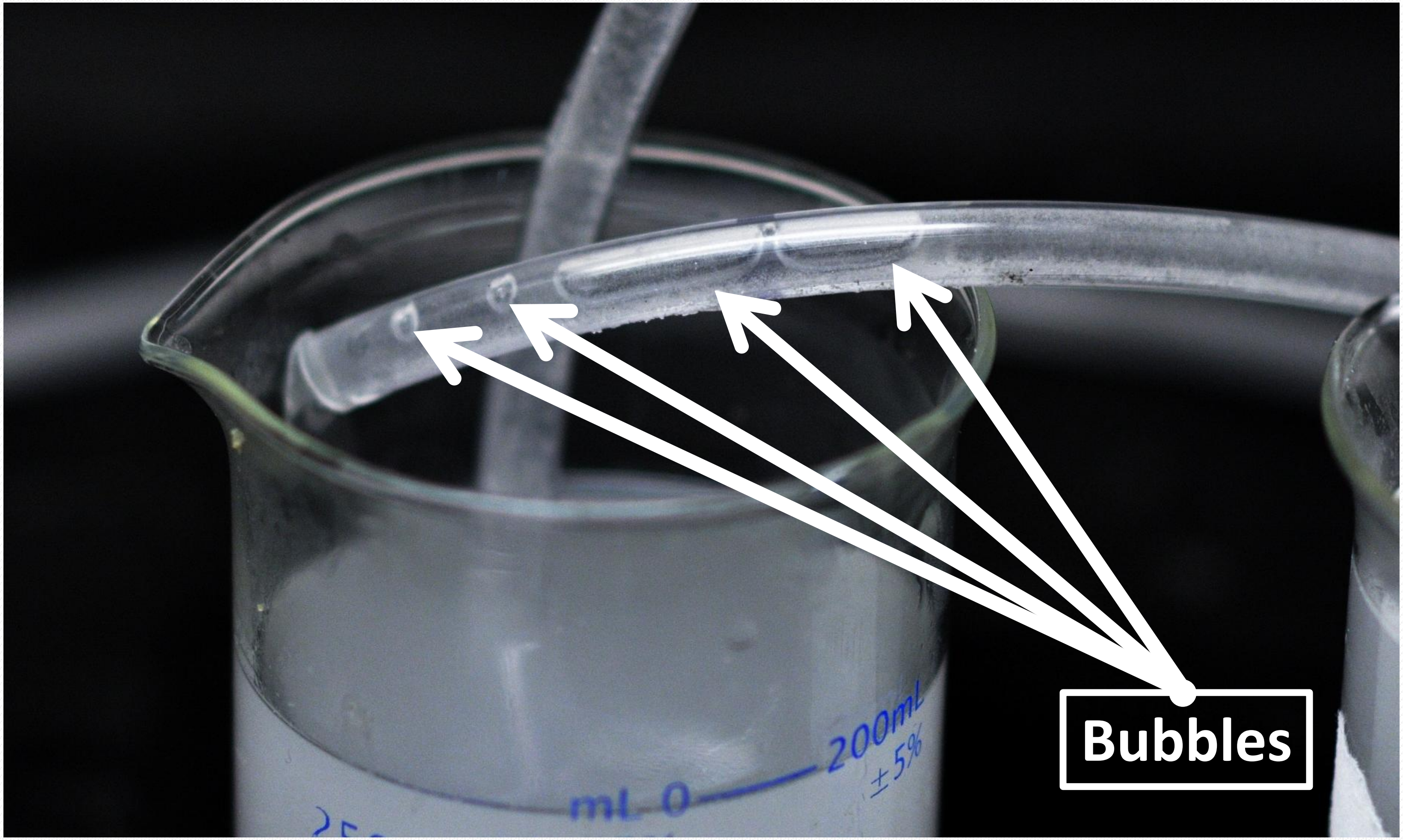
d:75% Au/25% Pt on carbon catalyst

e:100% Au on carbon catalyst

Prototype Performance



Fuel Cell Operation



Future Work

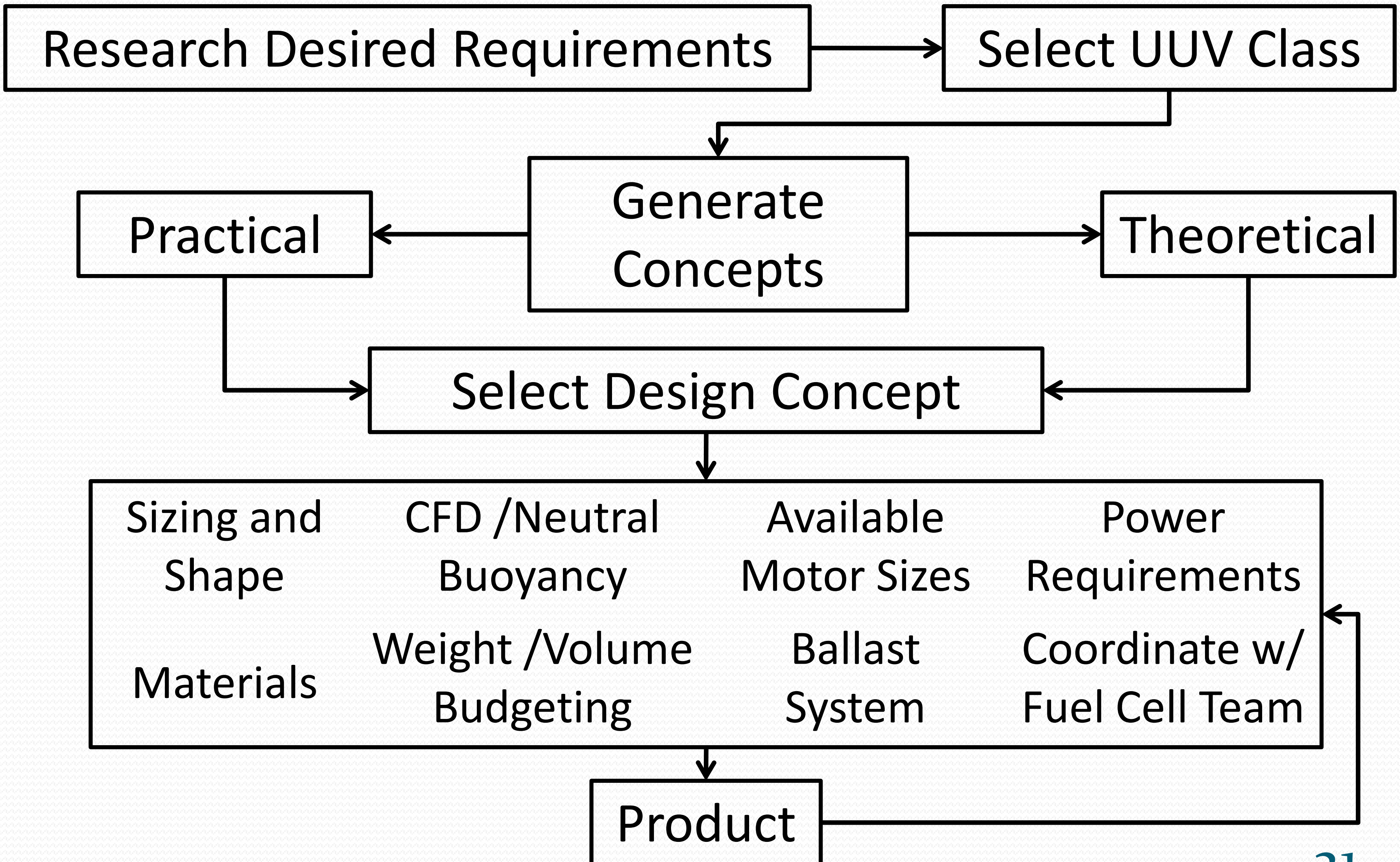
- Continue to work to improve prototype performance
- Problems in sodium transport across a Nafion membrane
  - Ongoing area of research
  - Anion exchange membrane potentially best solution

Mechanical Team

Goals and Tasks

- Overall design for UUV
  - Sizing, shaping, materials
  - Volume and weight budgeting
  - Power requirements

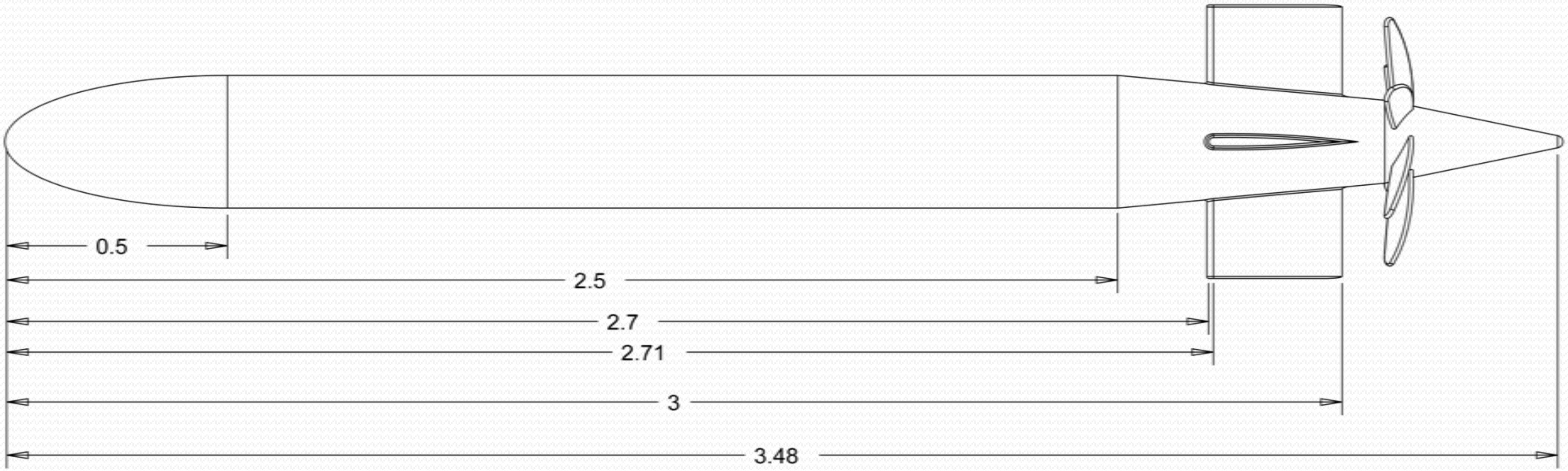
Design Process

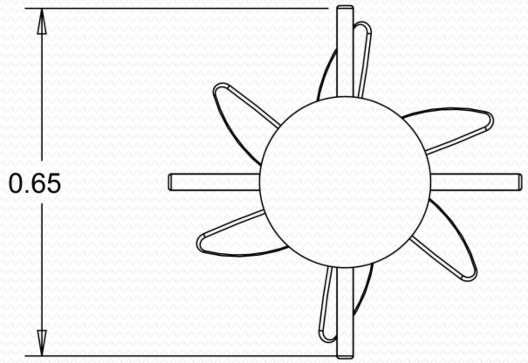


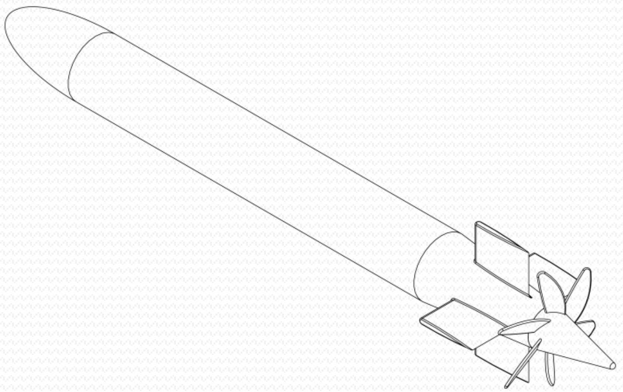
Design Requirements

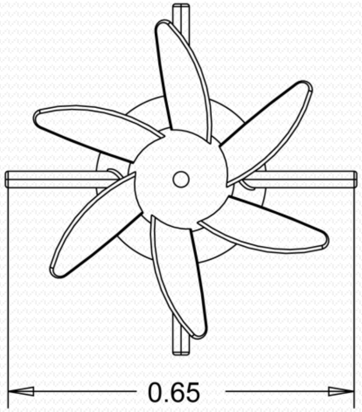
- Medium weight vehicle class
- Quiet and ultra quiet operation
- Powered by fuel cells
- Average sea water properties

Sizing and Shaping:

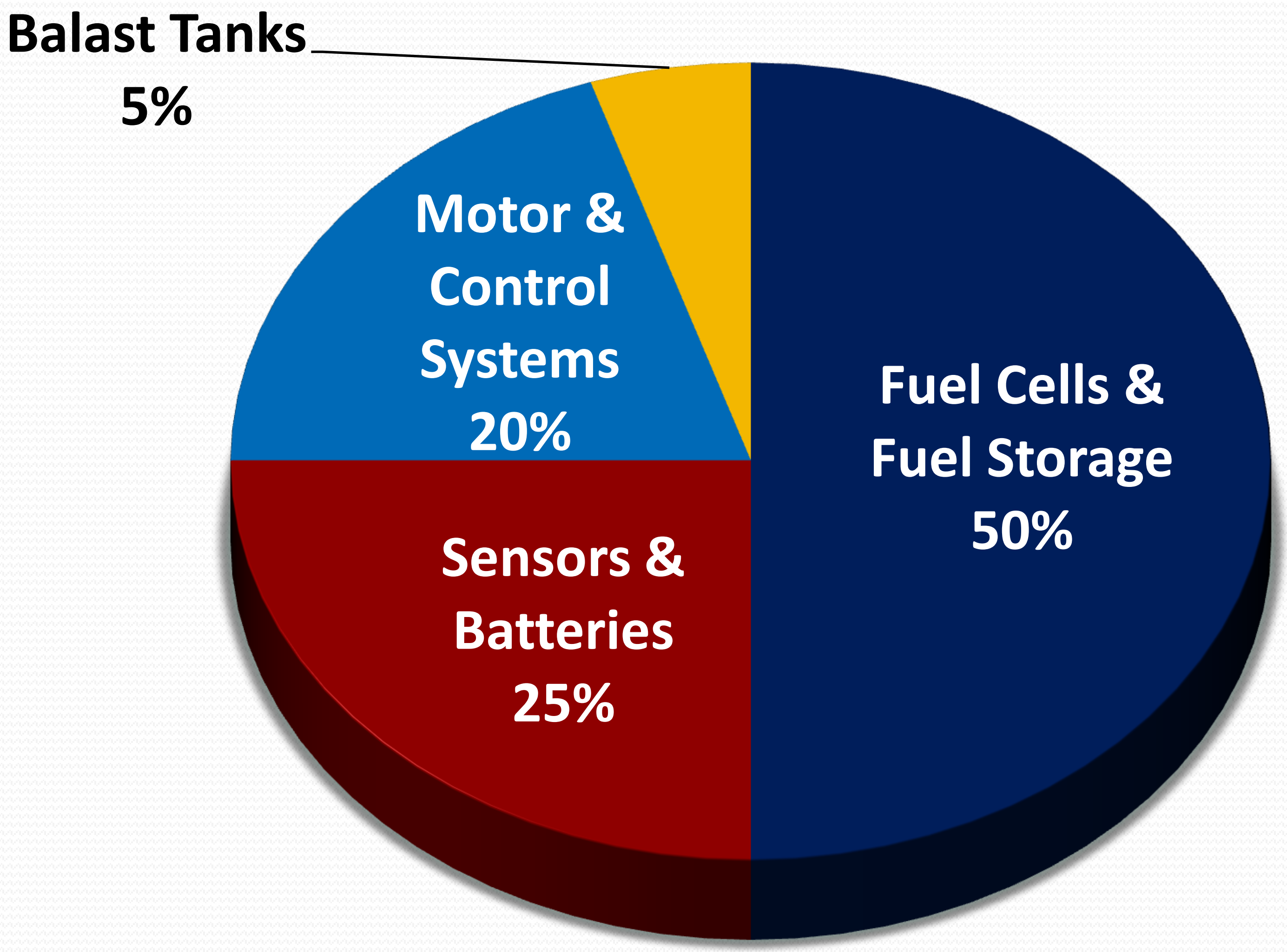




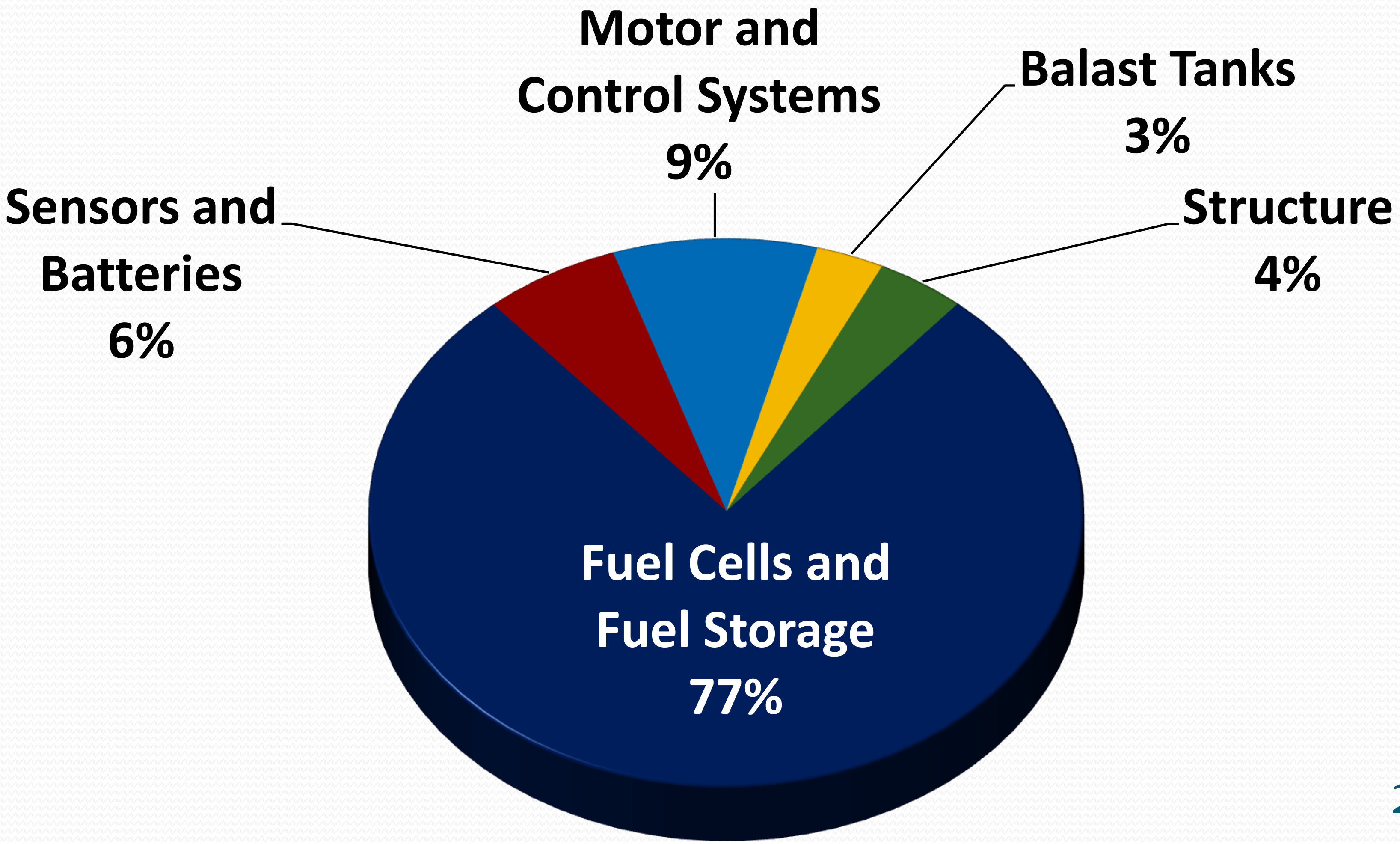




Volume Budget



Mass Budget


Motor and Control Systems 9%
Balast Tanks 3%
Structure 4%
Sensors and Batteries 6%
Fuel Cells and Fuel Storage 77%

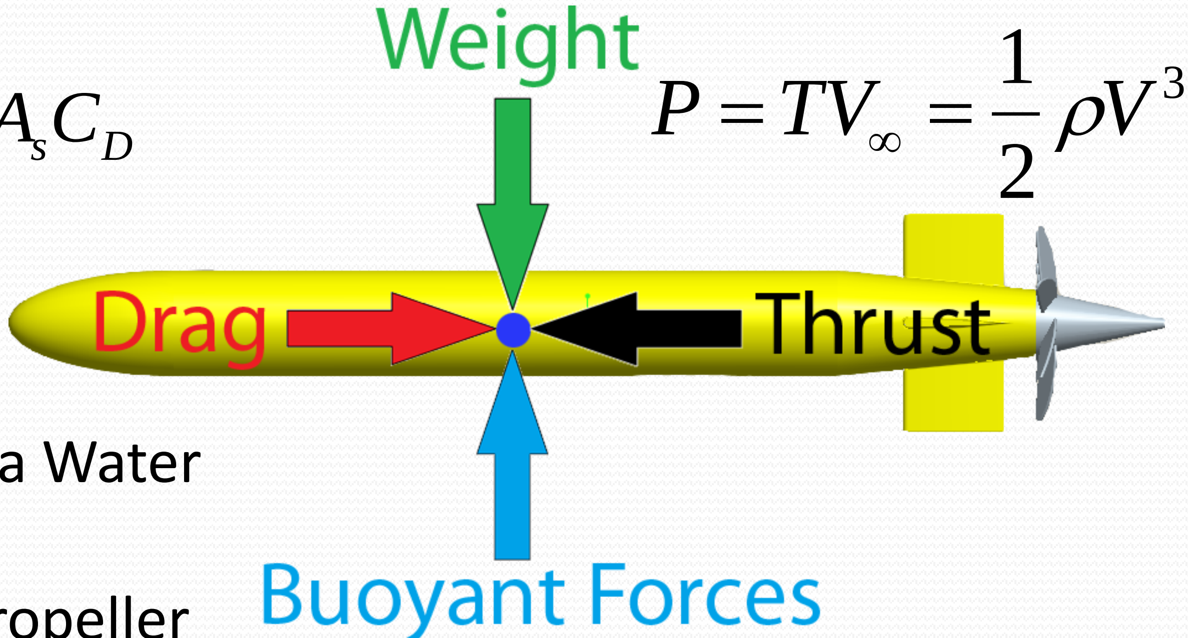
Materials Selection

Material	Pros	Cons
Steel	Strong, common material, cheap, customizable	Vulnerable to elements, heavy.
Aluminum	Strength:weight ratio, cheap	Alloy are susceptible to corrosion
Titanium	Corrosion resistant, strength:weight ratio	Expensive

Power Requirements:

$$T = D = \frac{1}{2}\rho V_{\infty}^{2} A_s C_D$$

$$P = TV_{\infty} = \frac{1}{2}\rho V^{3} A_s C_D$$



T =Thrust

ρ =Density of Sea Water

A_s =Surface Area

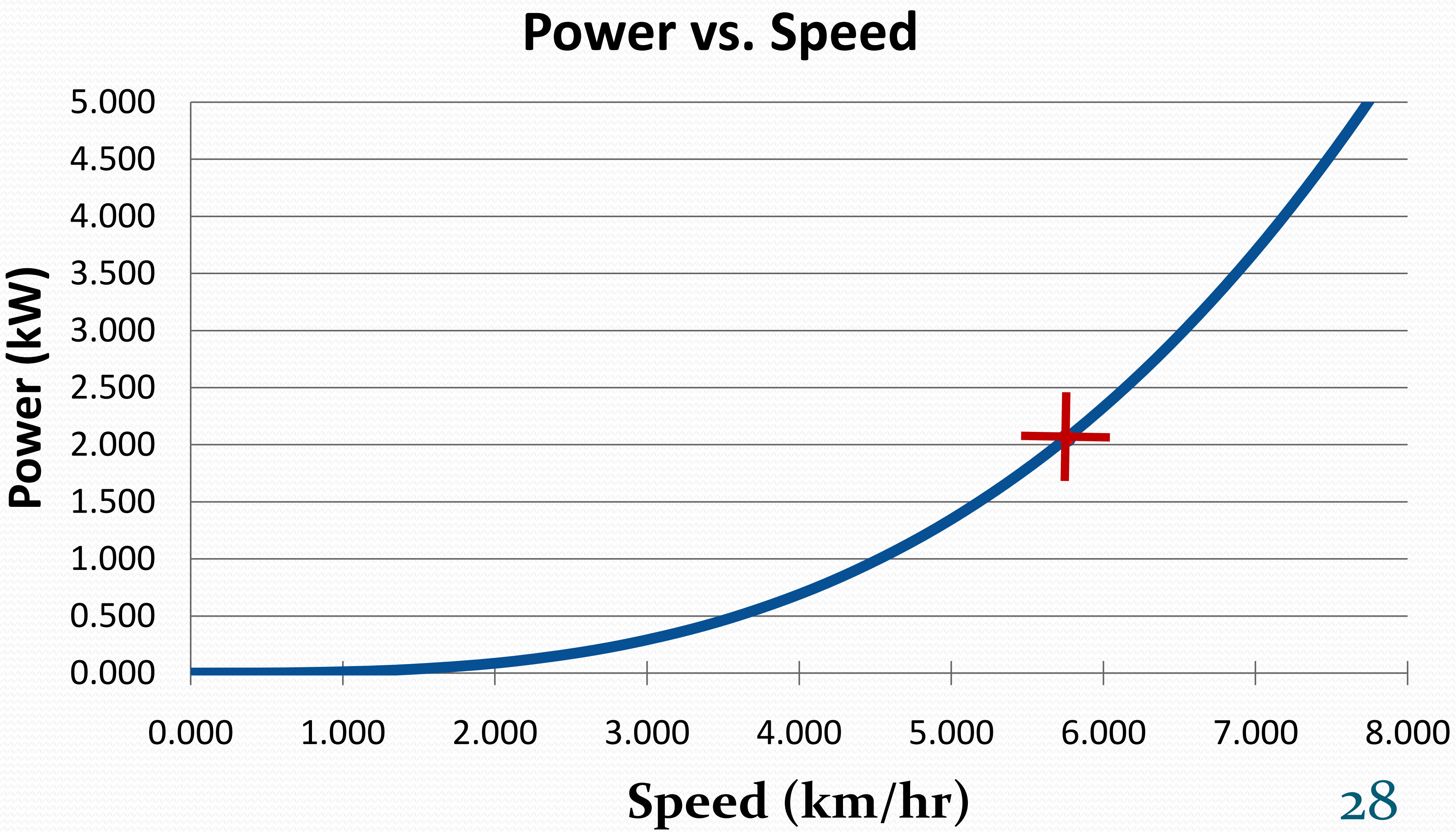
V_{∞} =Velocity of Propeller

C_D =Coefficient of Drag

P=Power

D=Drag

Power Requirements:



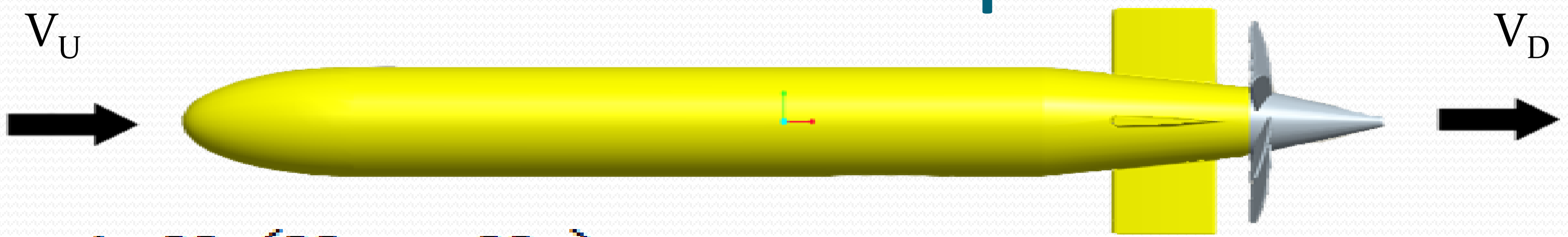
Motor Selection

Model	Power (kW)	Speed (rpm)	Efficiency (%)	Volts
LEM 130 model 95s	3.02	6624	87	12-48
LEM 200 model D135	14.39	3780	90	12-84
PMG 132	2.2-7.2	1080-3480	90	24-72
BLCV-70-1 (brushless)*	2.2	3012	~	156

Specifications PMG 132 24V	
Voltage	24 V
Current	110 A
Power	2.2 kW
Speed	1080 rpm
Torque	20.5 N-m

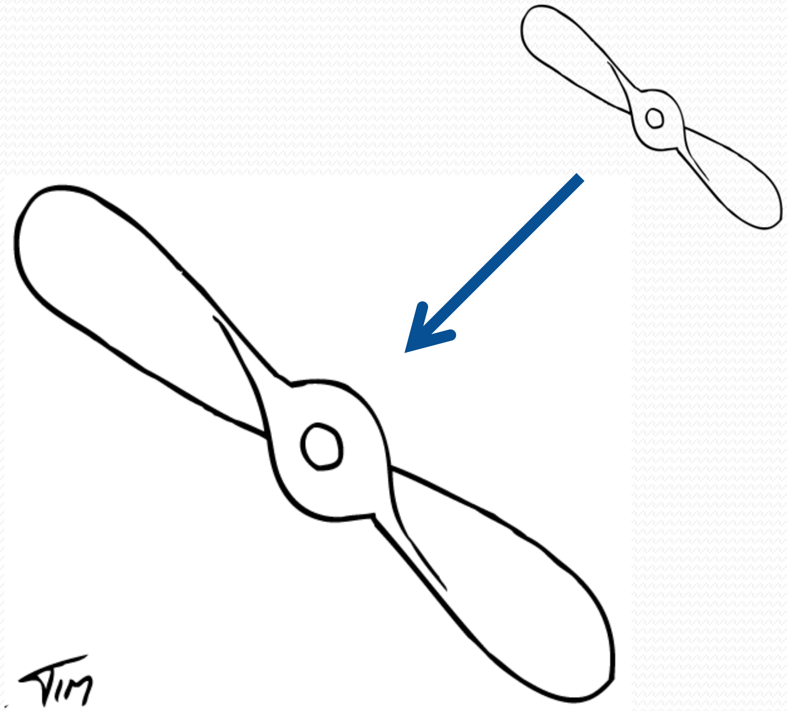
Dimensions	
Body Length	120 mm
Body Diameter	222 mm
Shaft Length	43 mm
Shaft Diameter	19 mm

Future work: Power Requirements



$$T = \rho A_P V_P (V_D - V_U)$$

$$P = \frac{1}{2} \rho A_P V_P ({V_D}^2 - {V_U}^2)$$



http://www.timtim.com/public/images/drawings/large/001516_Propeller.gif

T =Thrust

P = Power

A_P =Area of Propeller

V_U =Upstream Velocity

V_P =Velocity of Propeller

ρ =Density of Sea Water

V_D =Downstream Velocity

Summary

Major Obstacles Encountered

- Lack of prior knowledge
- Availability of information
  - Non standard systems
- Integration between sub-teams
- Coupled systems for iterative design
- Size and weight constraints

Ethical Considerations

- Environmental Impacts
  - Vehicle
    - Titanium hull – nonreactive
    - Interior components - no impact upon corrosion
  - Fuels
    - Low concentrations
    - Breaks down easily

Conclusions

- What we’ve done
  - Conceptual design
  - Proof of concept of fuel cell power source

- What work can still be done
  - In depth power estimates
  - Fix membrane problems
  - More prototyping

Questions?