PHS Sustainability

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NAU NORTHERN ARIZONA UNIVERSITY

Project Description

Ponderosa High School (PHS) tasked us with:

- Analyzing and improving upon the existing off-grid renewable energy system
  - Wind turbine, solar panels, and 24-volt battery storage
  - Adding additional lighting components
- Manufacturing a bike that converts human pedaling to energy generation


Fig 1. Inside the greenhouse

Importance

- Strengthens community
- Contributes to sustainable infrastructure in Flagstaff
- Hands on teaching platform
  - Encourages STEAM education and careers
- System upgrades improve PHS greenhouse for future generations


Fig 2. PHS mosaic mural

Clients

Fig 3. Client: Les Hauer

Les Hauer – PHS Principle

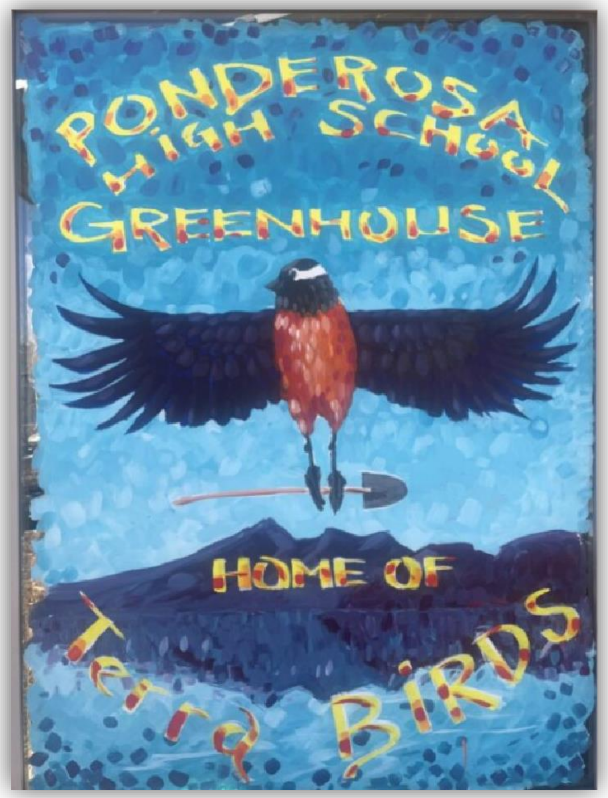


Fig 4. Client: PHS Terra Birds

PHS Terra Birds – Student led program that promotes sustainability

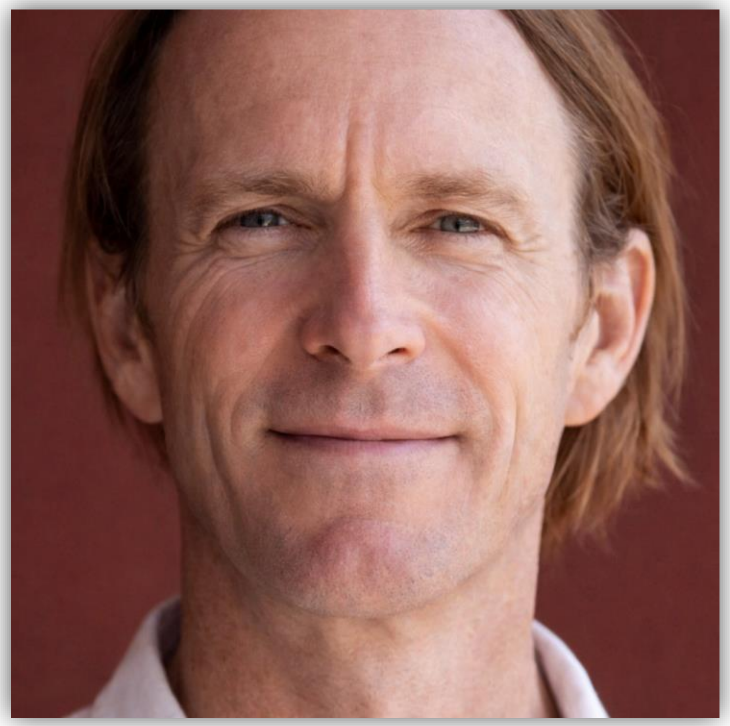
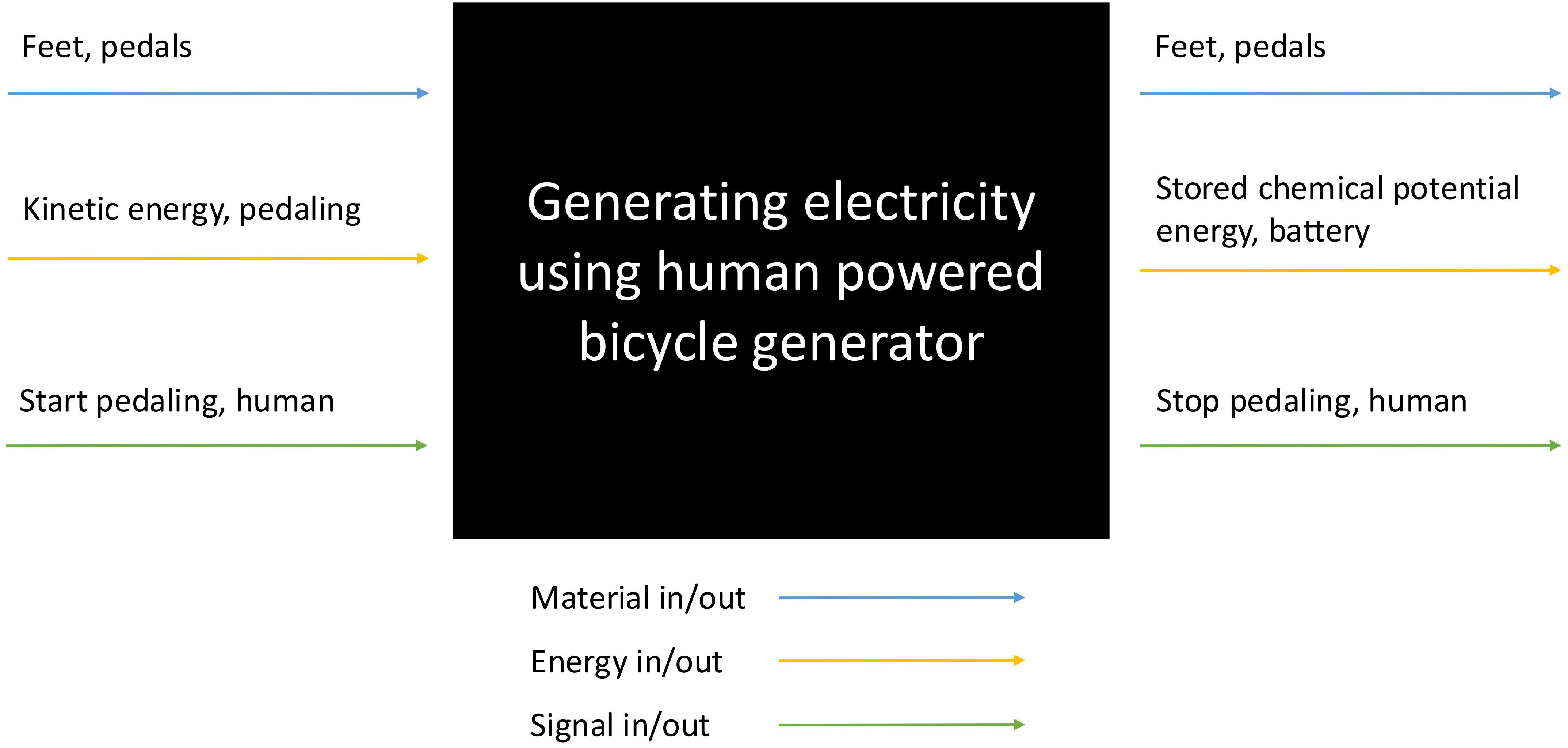


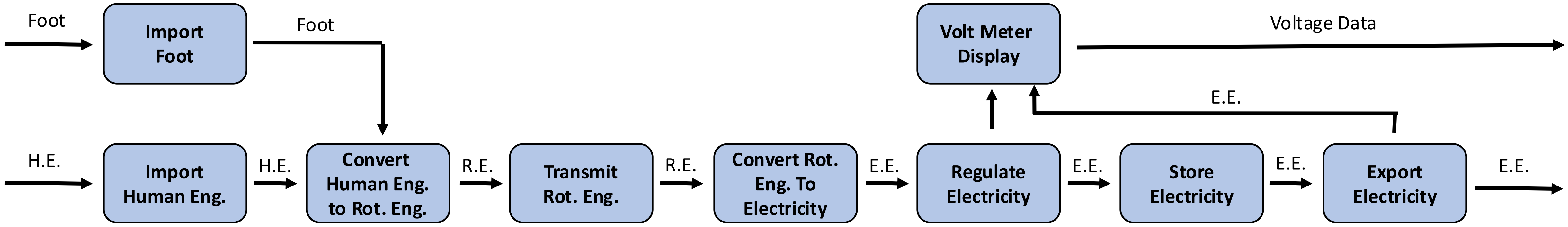
Fig 5. Client: John Taylor

John Taylor – Math Teacher & Greenhouse Consultant

Black Box Model for Bicycle



Decomposition Model for Bicycle



Concept Generations: Sub Assembly

Morphological Matrix

- Based off Customer and Eng. Requirements

Sub Assembly Categories:

- Competition/Energy Display
- Motors
- Materials/Design of Stand
- Point of Connection

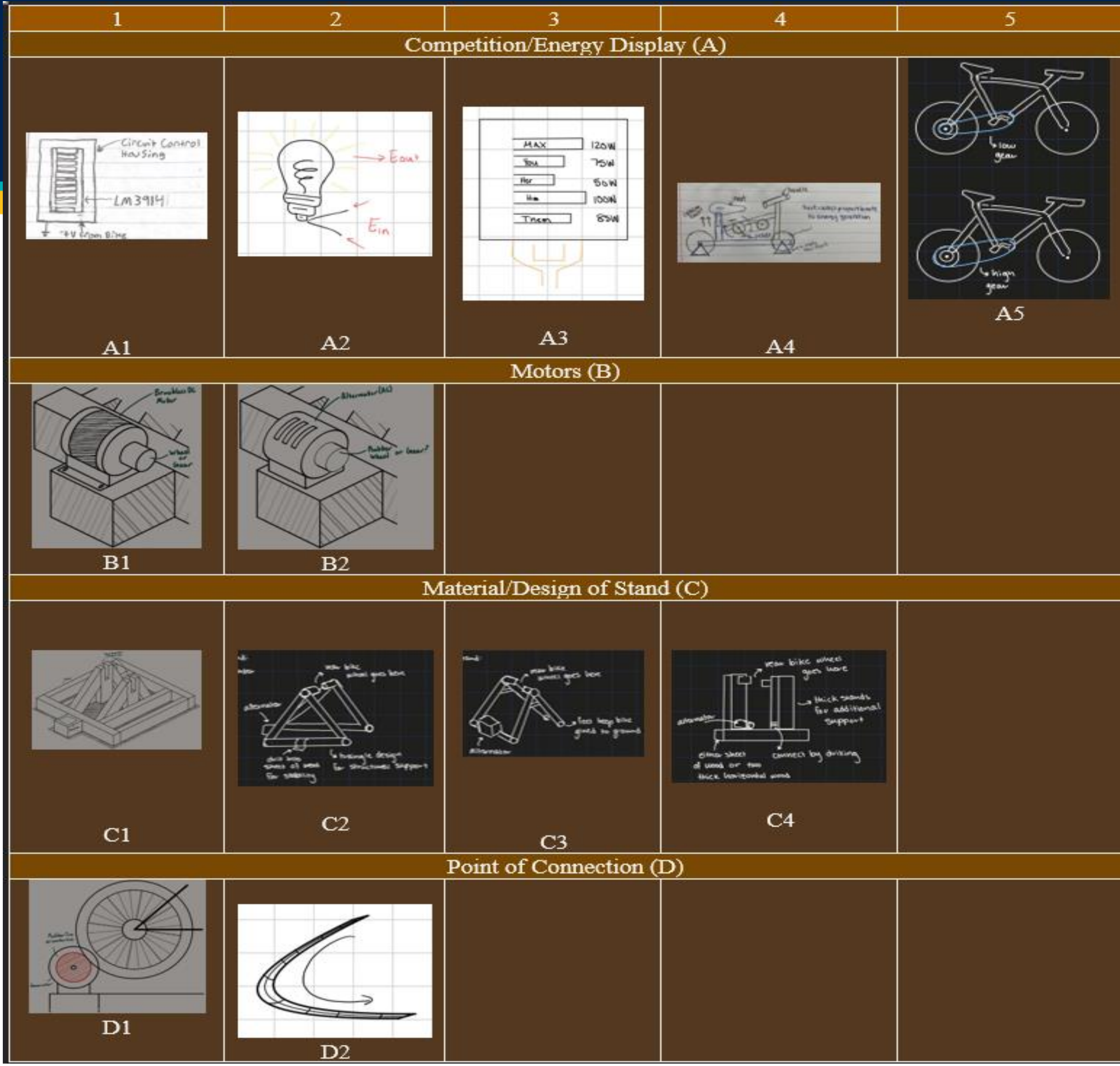
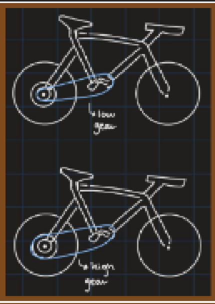
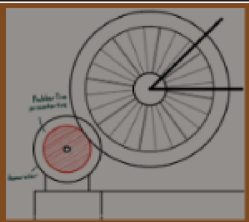
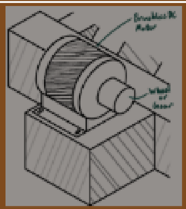
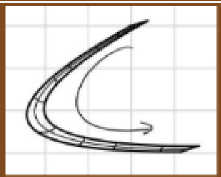
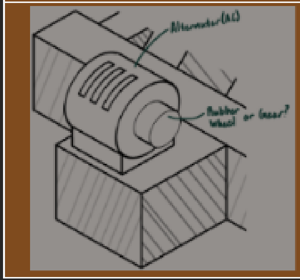


Table 1. Morphological Matrix

Concept Generations: Sub Assembly Advantages/Disadvantages

	Advantage: Edu. Value about resistance/gear ratios Disadvantage: Maintenance		Advantage: Easy to remove wheel Adjustable Disadvantage: Potential for Slipping Degradation due to friction
	Advantage: Direct Energy Generation Cost Effective Disadvantage: Less Effective		Advantage: Friction Consistant Disadvantage: Expensive Potential Belt Failure
	Advantage: Higher Energy generation Disadvantage: Pricier		

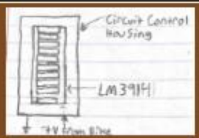
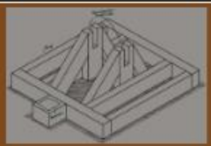
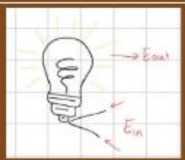
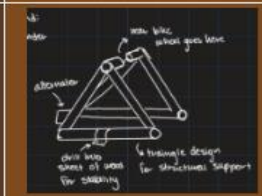
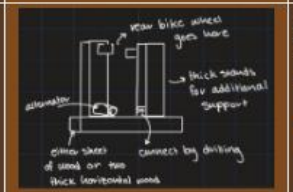
	Advantage: Edu. value Disadvantage: Uses Energy		Advantage: Cheap Stable Disadvantage: Environmental Decay
	Advantage: Edu. value Disadvantage: Uses Energy		Advantage: Structurally Strong Long Lasting Disadvantage: Pricy Human Error
	Advantage: Student competition Disadvantage: Use Energy		Advantage: Premade, easy assembly Disadvantage: Expensive
	Advantage: Edu. value Disadvantage: Maitenance		Advantage: Cheap Disadvantage: Maintenance/Durability

Table 2. Advantages/Disadvantages of Sub Assembly

Concept Generations: Top Level

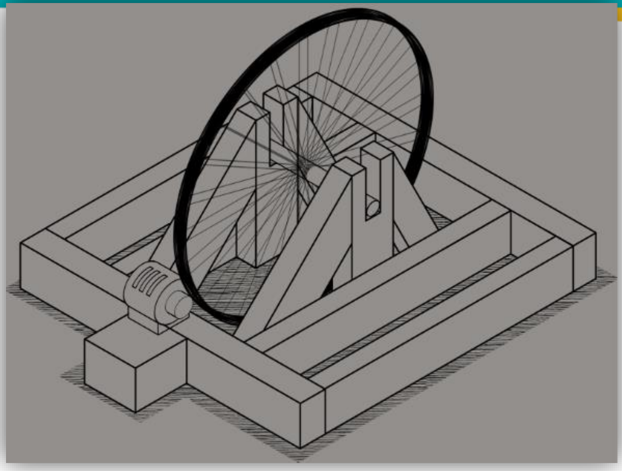


Fig 6. Design #1

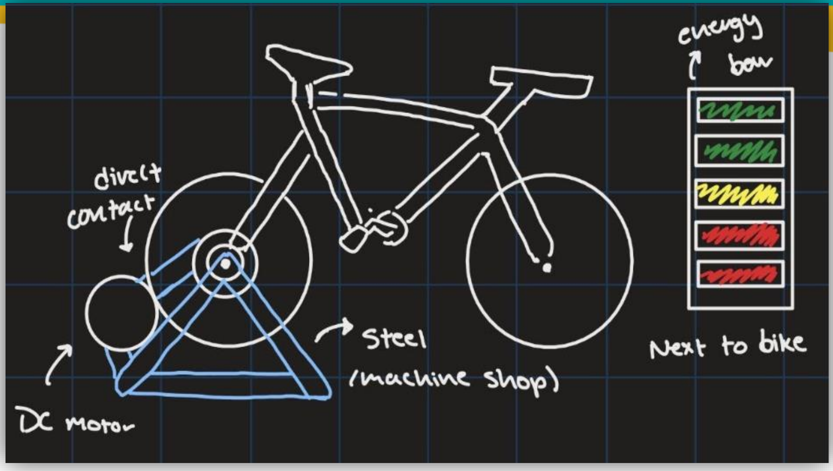


Fig 7. Design #2

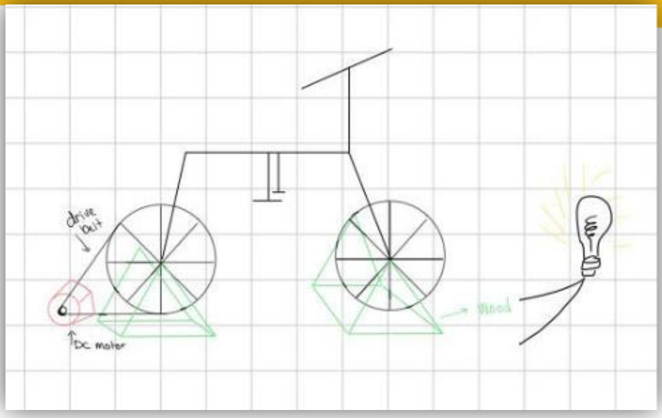


Fig 8. Design #3

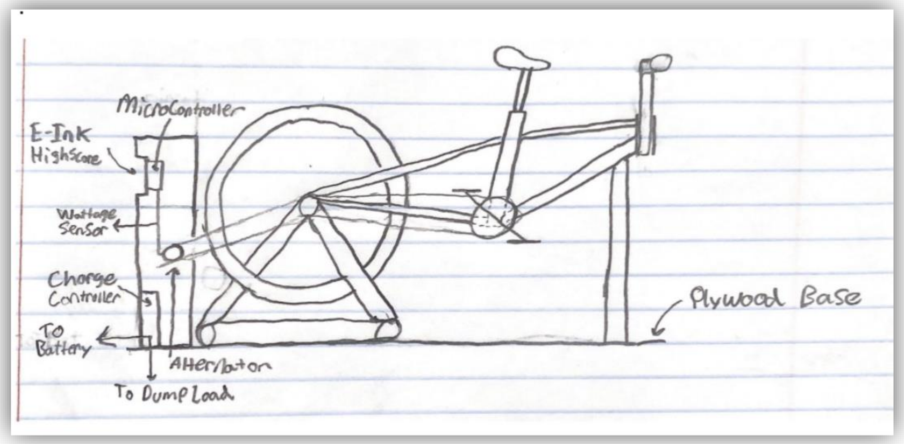


Fig 9. Design #4

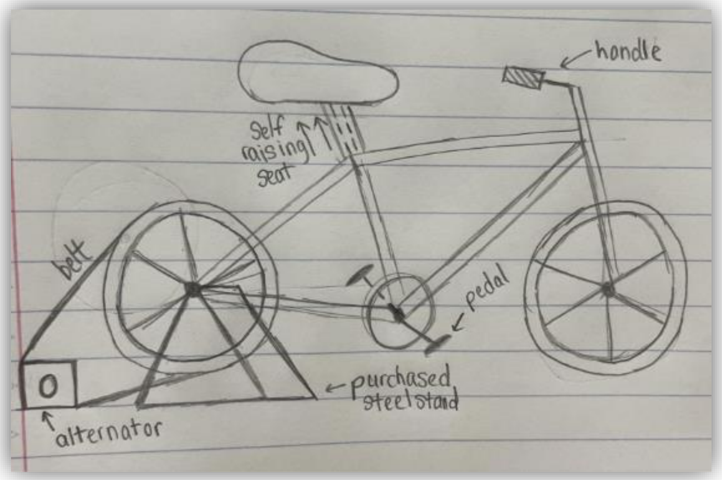


Fig 10. Design #5

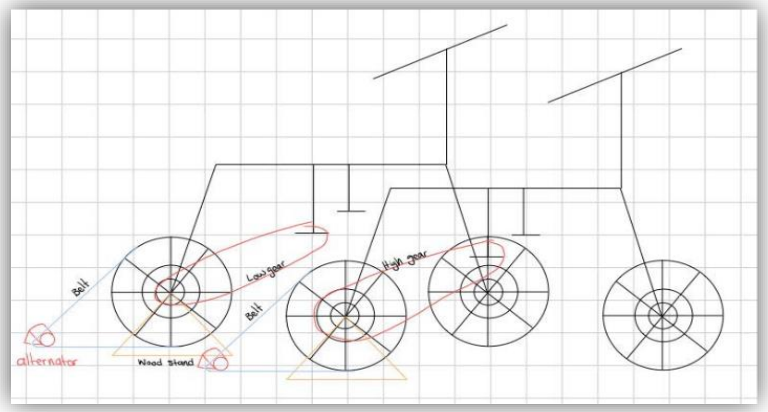


Fig 11. Design #6 (Datum)

Eng. Calculations: Human Powered Bicycle Generator

Question

- How does gear selection affect electrical power output for a recreational cyclist?

Constants

- Sustainable pedaling cadence (ω) 45-75 RPM
- Sustainable Tan. Pedal Force (F) 125-250 N
- Bicycle Crank Length (r) 0.19 m
- Wheel Radius (R) 0.356 m
- Alternator Roller Radius (r_{alt}) 0.025 m
- 7-Speed Cassette (n) G1-G7
- Chainring (N) 34 teeth
- Alternator Efficiency (η_{alt}) 70%
- Drivetrain Efficiency (η_{drive}) 96%
- Direct Contact Efficiency ($\eta_{contact}$) 96%
- Charge Controller Efficiency (η_{charge}) 95%

Equations

- $G_{bike} = \frac{N}{n}$
- $G_{alt} = \frac{r}{r_{alt}}$
- $\omega_{alt} = \omega G_{bike} G_{alt}$
- $\tau\ [N * m] = Fr$
- $P_{mech}\ [W] = \tau\omega$
- $\eta_{sys} = \eta_{alt}\eta_{drive}\eta_{contact}\eta_{charge}$
- $P\ [W] = P_{mech}\ \eta_{sys}$

Tools

- MATLAB

Human-Powered Bicycle: Results

Results

- G4 (18 teeth) and G3 (15 teeth) produce optimal (140W) output to batteries
- System Efficiency (η_{sys}) is 61%
- Model assumes linear force-cadence tradeoff; physical testing required

Literature Comparison

- Typical sustained power output for recreational cyclists is 75 to 150 W [24]
- Professional cyclists sustain 350-400 W [28]
- Peak power output occurs at moderate resistance [24][28]

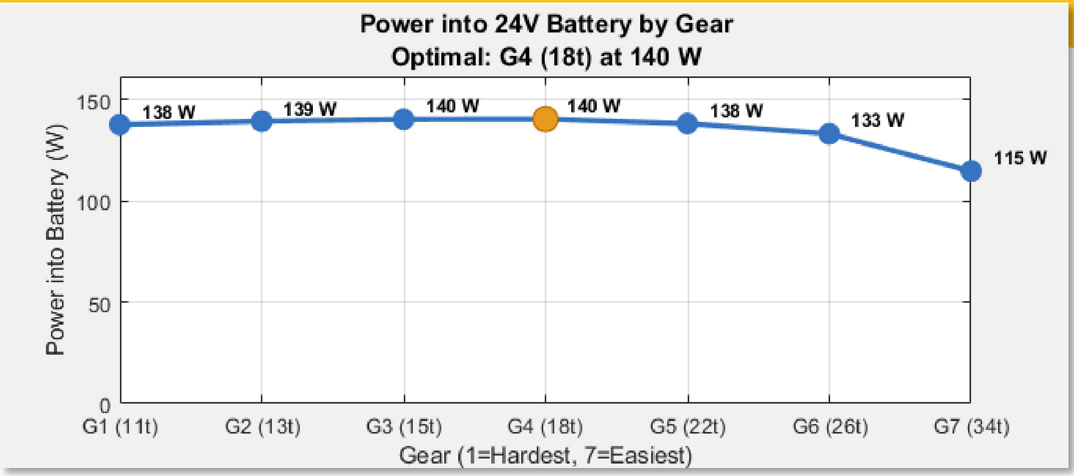


Figure 12. Power by Gear

Gear	Teeth	ω (RPM)	F (N)	ω_{alt} (RPM)	P (W)
G1	11	45	250	1978	137.5
G2	13	48	239	1771	139.2
G3	15	50	228	1619	140.1
G4	18	54	212	1454	140.3
G5	22	60	190	1305	138.0
G6	26	65	168	1201	133.0
G7	34	75	125	1067	114.6

Table 3. Gear Performance

Concept Evaluation: Pugh Chart

Top three design variants from Pugh Chart:

- Design #1 -
- Design #3 -
- Design #4 -

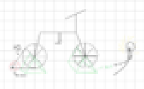
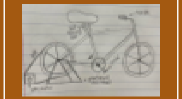
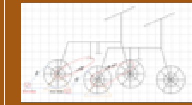
Design Criteria	#1  Figure 11	#2  Figure 16	#3  Figure 13	#4  Figure 18	#5  Figure 19	#6  Figure 15 (datum)
Competition	S	+ Bar	S	+ High Score	S	Datum
Cost	+ Direct Contact	- Steel	+ DC motor	- High Score	- Steel	Datum
Net Power	+ Direct Contact	- DC Motor and bar	- Lightbulb and DC	- Electronics	S	Datum
Educational Value	S	+ Bar Visual	+ Light Visual	+ Screen	+ Raised Seat	Datum
Maintenance	+ removable	S	S	S	S	Datum
Aesthetics	S	+ Visual	+ Visual	+ Visual	S	Datum
Total '+'	3	3	3	3	1	Datum
Total '-'	0	2	1	2	1	Datum
Total 'S'	3	1	2	1	4	Datum

Table 4. Pugh Chart

Concept Evaluation: Decision Matrix

Top design from Decision Matrix

- Design #4

All three designs scored similarly

- Best stand: Design #1
- Best Competition: Design #4

Top Customer Requirements:

- Educational Value
- Net Power
- Competition

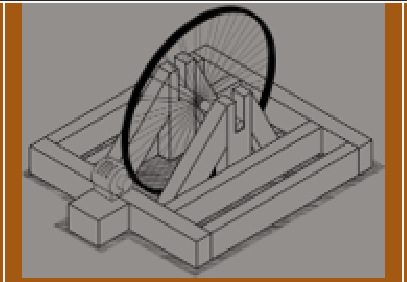
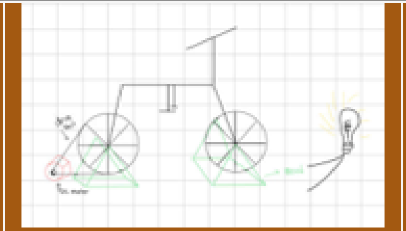
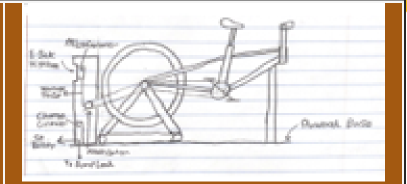
		 Design #1		 Design #3		 Design #4	
Criterion	Weight	Unweighted Scores	Weighted Scores	Unweighted Scores	Weighted Scores	Unweighted Scores	Weighted Scores
Competition	0.15	5	0.75	8.5	1.275	10	1.5
Cost	0.10	10	1	9	0.9	8	0.8
Net Power	0.25	10	2.5	9	2.25	8	2
Edu. Value	0.25	6.5	1.625	7.5	1.875	10	2.5
Maintenance	0.20	10	2	7.5	1.5	5	1
Aesthetics	0.05	7	0.35	8	0.4	10	0.5
Total	1	Sum:	8.125	Sum:	8.2	Sum:	8.3

Table 5. Decision Matrix

Concept Evaluation: CAD model

Rough model of human powered bicycle:

- Alternator
- Removable bike stand
- Wood material

Additional components for the bike:

- High score display screen
    - student competition
- Two bikes
    - high gear and low gear comparison

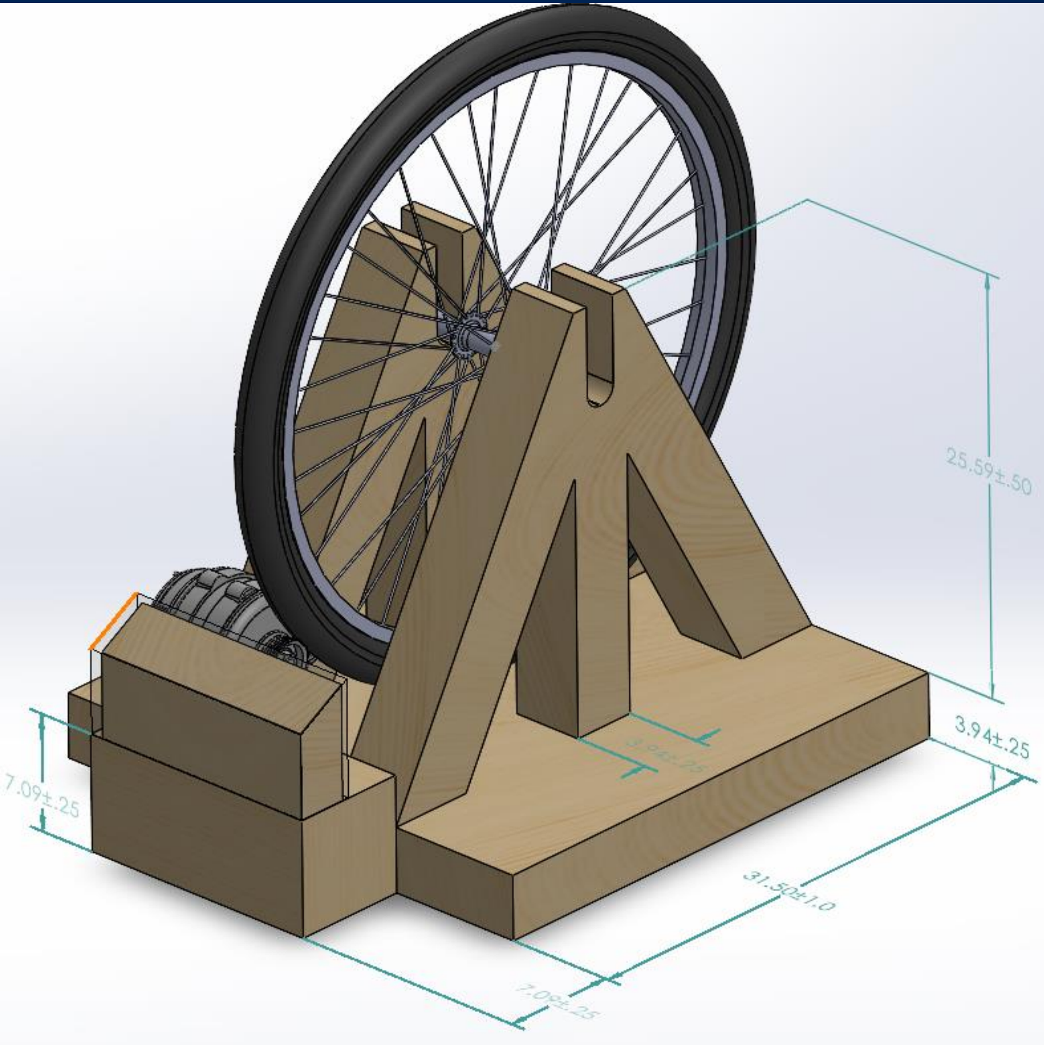


Fig 13. Cad model of human powered bicycle

Greenhouse System Overview

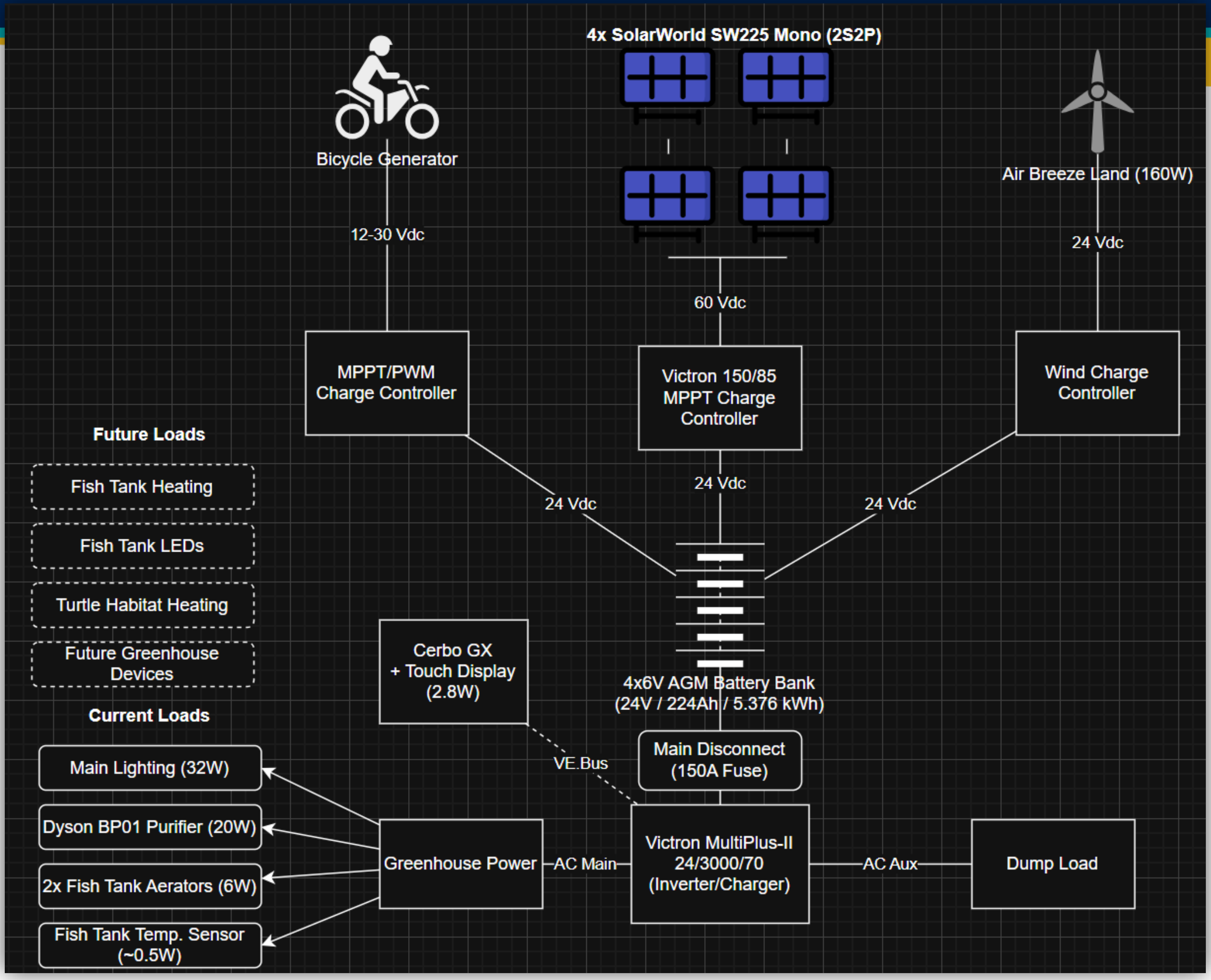


Fig 14. Diagram of Greenhouse System

Greenhouse Eng. Calculations: Wind Energy

Equations

Weibull Distribution

$$f(V) = \frac{k}{c}(\frac{V}{c})^{k-1}e^{-(\frac{V}{c})^k}$$

Wind Turbine Power Coefficient

$$C_p = \frac{P}{(\frac{1}{2})(\rho A V^3)}$$

Rotor swept area

$$A = \pi(R^2)$$

Available Wind Power

$$P_{available} = (\frac{1}{2})\rho A V^3$$

Extracted Power

$$P_{extracted} = C_p P_{available}$$

Energy from Power Over Time

$$E = P_t$$

Expected Power

$$E(P) = \int_0^\infty P(V)f(V)dV$$

Results

At V = 14.6 m/s:

Available Wind Power = 13474.02 W

Extracted Turbine Power = 5389.61 W

Expected Power Output: 244.6645 W

Engineering Analysis Tools

MATLAB

MATLAB SIMULINK

Ansys

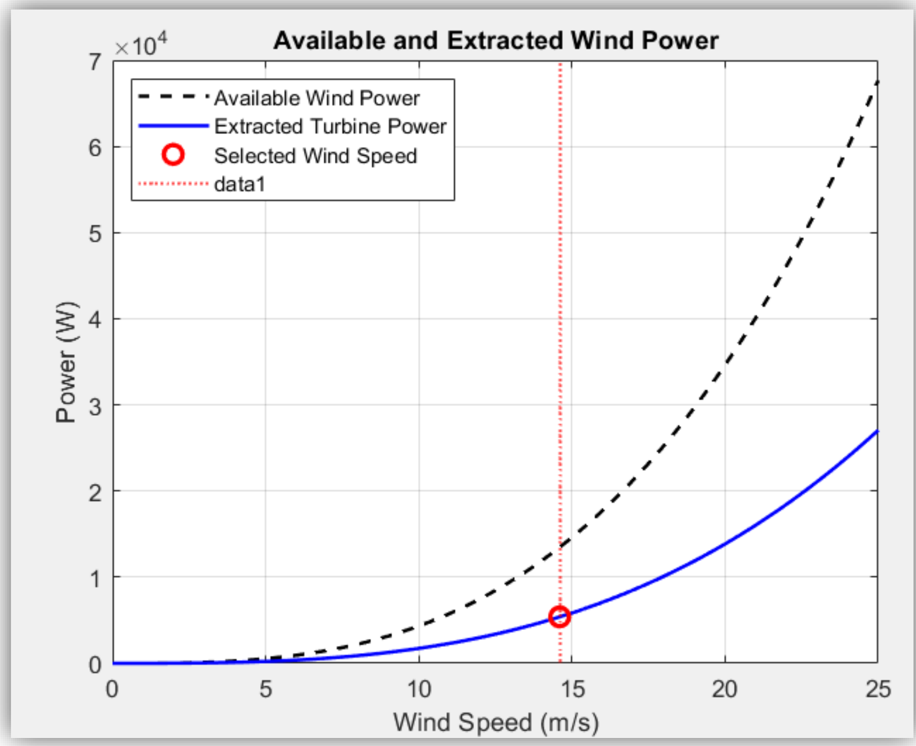


Figure 15. Instantaneous Power

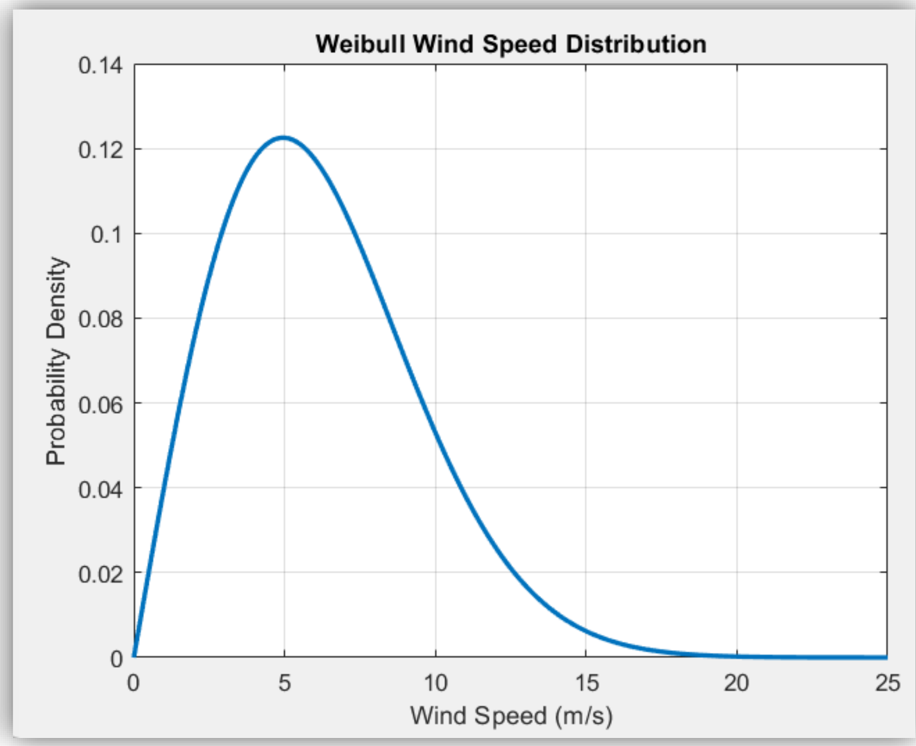


Figure 16. Variable Wind Speed

Greenhouse Eng. Calculations: Solar Energy

Equations

Energy Based on Solar Panel Area

$$Energy[kWh] = A \bullet I \bullet \eta \bullet t$$

A = Panel Area [m^2]

I = Solar Irradiance [kW/m^2]

η = Panel Efficiency

t = Average Sun Exposure per day [hr]

$$5.38[kWh] = 6.40[m^2] \bullet 1[kW/m^2] \bullet 0.14 \bullet 6[hr]$$

Yearly Energy:

$$1962.24[kWh] = 365[Days] \bullet 5.38[kWh]$$

Energy Based on Solar Panel Rated Power

$$Daily\ Energy[kWh] = N(RP \bullet PSH \bullet \eta_s)$$

N = Number of Panels

RP = Rated Power of Panels [kW]

PSH = Peak Sun Hours [hr]

η_s = System Efficiency

$$5.47[kWh] = 4(0.285[kW] \bullet 6[hr] \bullet 0.80)$$

Yearly Energy:

$$1997.28[kWh] = 365[Days] \bullet 5.47[kWh]$$

Results

Energy(Panel Area)= 5.38 kW

Energy(Rated Power) = 5.47 kW

Expected Power Output (Daily): 6.01 kW

Energy(Panel Area)= 1962 kW

Energy(Rated Power) = 1997 kW

Expected Power Output (Yearly): 2192 kW

Figure 17. Current Solar Panels

Engineering Analysis Tools

PVWatts Calculator

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)
January	4.61	151
February	5.67	166
March	6.26	194
April	7.20	214
May	7.56	224
June	7.95	221
July	6.18	178
August	5.82	168
September	6.67	191
October	6.01	183
November	5.22	161
December	4.28	141
Annual	6.12	2,192

Figure 18. PVWatts Calculations

Greenhouse Eng. Calculations: Turtle Environment

Equations Used

First Law of Thermodynamics

$$\dot{Q}_{net} - \dot{W}_{net} = \frac{dE_{cv}}{dt}$$

Steady State

$$\dot{Q}_{loss} = \dot{Q}_{heater} = UA(T_{in} - T_g) + \dot{Q}_{evap} + \dot{Q}_{vent}$$

Power

$$\dot{Q} = UA\Delta T$$

kWh Conversion

$$E = \frac{\dot{Q}(W) \cdot t(hr)}{1000}$$

E basking

$$E_{bask} = lamp(kW) \cdot time(^{hr}/_{day}) \times 365\, ^{day}/_{year}$$

Assumptions

T_{in}= 80°F [8]

A=4.961926 m^2

Tank size= 59568 in^3

U= .6 $^{W}/_{m^2 * K}$ [9]

E=475.595 kWh/yr for a 24,725 in^3 enclosure [10]

Expected: 951.19 kWh/yr

Temperature	Winter	Spring/Fall	Summer
Average	273.17 K	281.4 K	292.19K
High	292.04K	299.63K	272.22K
Low	252.59K	264.076K	307.409K

Table 6. Temperature over 5 years

Greenhouse Eng. Calculations: Results

Power (W)	Winter	Spring/Fall	Summer
Average	79.341	54.839	22.716
High	23.162	.566	-22.594=0
Low	140.611	106.415	82.169

Table 7. Power Consumption

Energy (kWh)	Winter	Spring/Fall	Summer	Total (kWh/yr)
Average	174.534	240.36	49.781	464.645
High	50.7602	2.479	-49.514=0	53.2392
Low	308.149	466.419	180.074	954.642

Table 8. Yearly Energy Consumption

Power (kWh)	Yearly Total
Average	$739.675 + \sum_{i=1}^{12} \frac{\dot{Q}_{evap,i} \cdot t_i}{1000}$
High	$328.24 + \sum_{i=1}^{12} \frac{\dot{Q}_{evap,i} \cdot t_i}{1000}$
Low	$1229.6 + \sum_{i=1}^{12} \frac{\dot{Q}_{evap,i} \cdot t_i}{1000}$

Table 9. Yearly Power Consumption

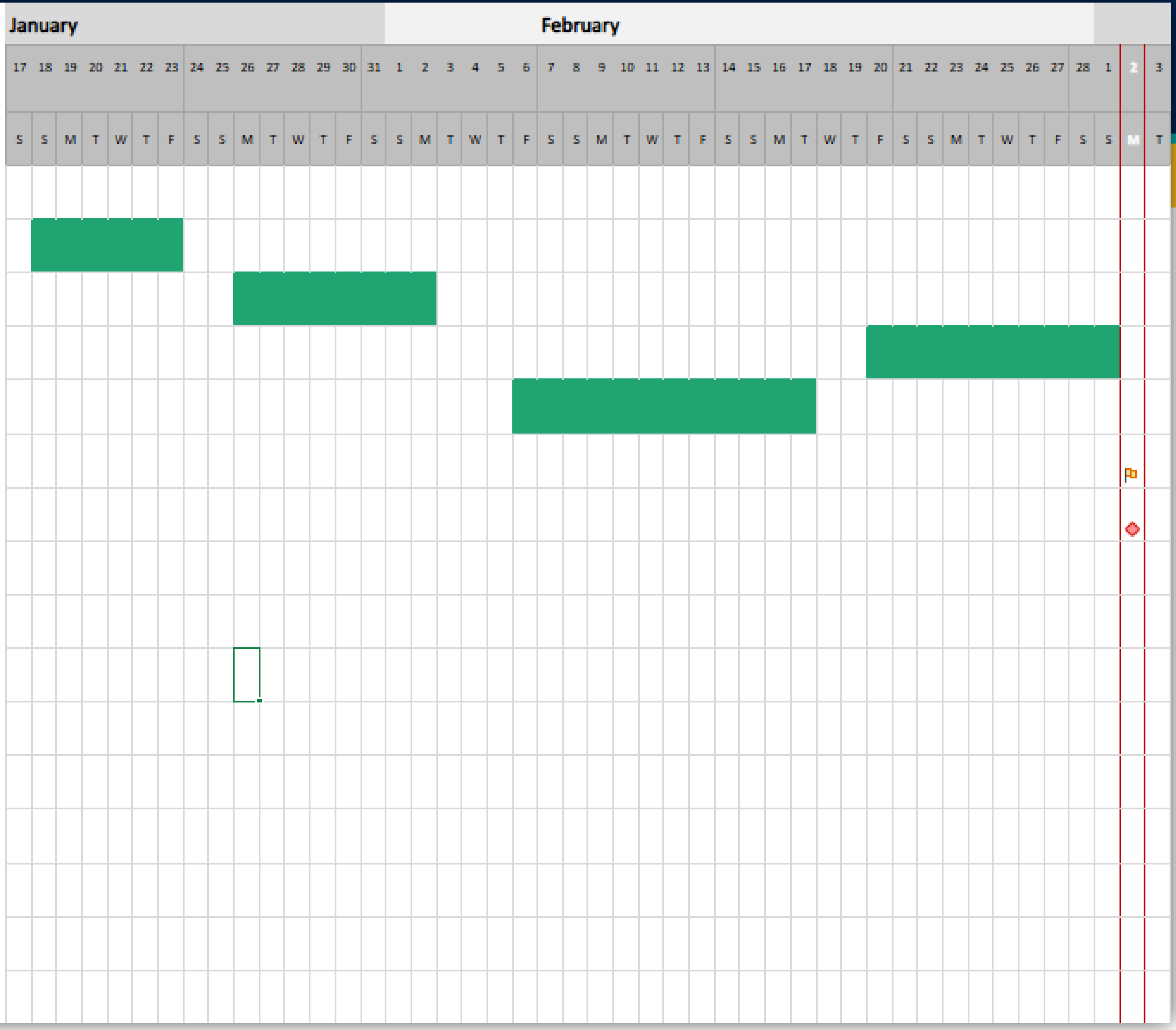
Schedule: Course Deliverables

Fig 19. Gantt Chart Course Deliverables

Project start date: 1/17/2026

Scrolling increment: 0

Milestone description	Category	Assigned to	Progress	Start	End	Days
Course Deliverables						
Team Charter	On Track	Team	100%	1/18/2026	1/23/2026	6
Presentation 1	On Track	Team	100%	1/26/2026	2/2/2026	8
Presentation 2	On Track	Team	100%	2/20/2026	3/2/2026	10
Self Learning (HW3)	On Track	Individual	100%	2/6/2026	2/27/2026	12
Report #1	Milestone	Team		3/2/2026	3/8/2026	1
Website Check #1	Goal	Alex		3/2/2026	3/16/2026	1
Analytical Analysis Memo	On Track	Team		3/16/2026	3/23/2026	
Presentation 3		Team		3/16/2026	3/30/2026	
1st Proto Demo				3/30/2026	3/30/2026	
Report #2	Milestone	Team		4/13/2026	4/13/2026	
Mathematical Analysis (HW4)		Individual		4/20/2026	4/20/2026	
Final CAD/BOM		Carson and Kaitlyn		4/20/2026	4/20/2026	
Project Management				4/27/2026	4/27/2026	
2nd Proto Demo				4/27/2026	4/27/2026	
Website Check #2	Med Risk			5/4/2026	5/4/2026	



Ahead: bike design, CAD - **On Track:** lesson plan, report 1, energy audit - **Behind:** system analysis, website building

Schedule: Client Deliverables

Project start date: 1/17/2026

Scrolling increment: 0

Milestone description	Category	Assigned to	Progress	Start	End	Days
Client Deliverables						
Energy Audit Report	Goal	Team	30%	2/20/2026	3/16/2026	11
System Capacity and Performance Analysis	Goal	Team	10%	3/16/2026	3/27/2026	
Improvement/Expansion Reccommendations	Milestone	Kaitlyn and Alex	0%	3/16/2026	3/30/2026	
Human-Powered Bicycle Generator	On Track	Ethan	50%	2/3/2026	5/10/2026	28
Education Curriculum Materials	On Track	Jenna	12%	2/15/2026	11/30/2026	16
Final Written Report and Presentation	Milestone	Team		5/4/2026	12/10/2026	

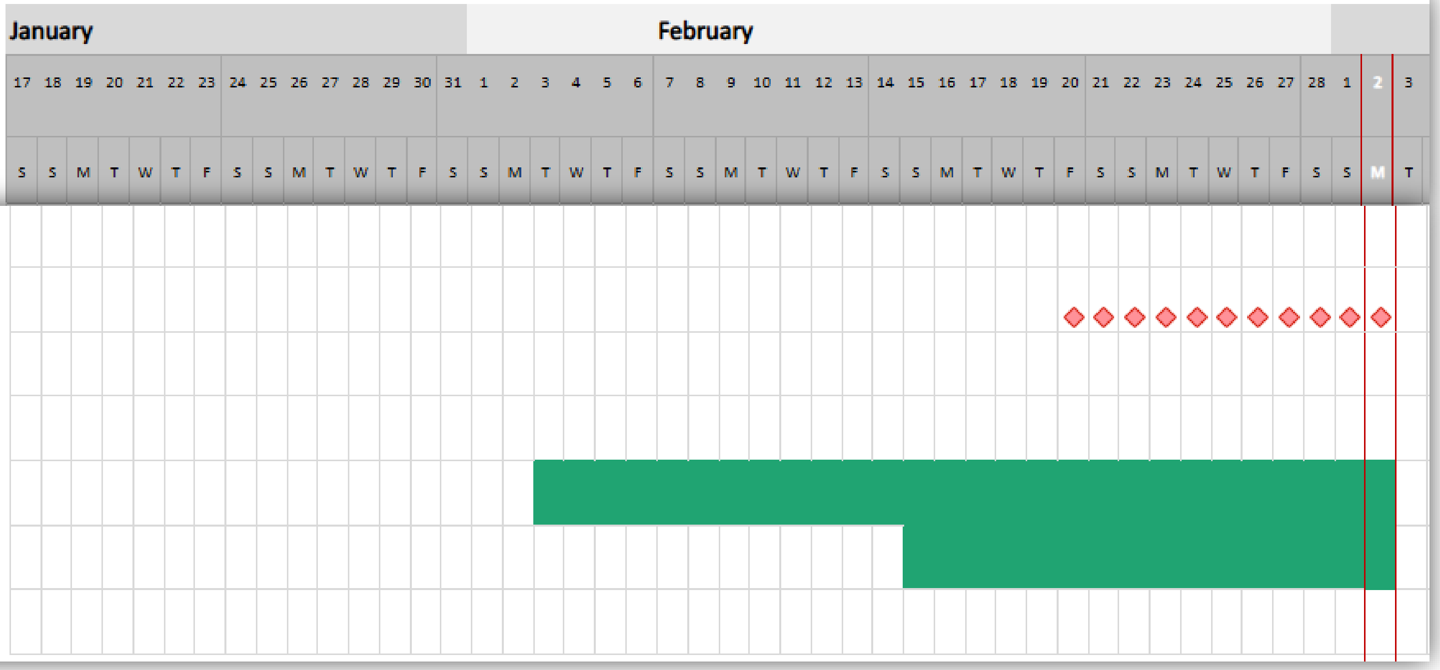


Fig 20. Gantt chart client deliverables

Ahead: bike design, CAD - **On Track:** lesson plan, report 1, energy audit - **Behind:** system analysis, website building

Budget

PHS Sustainability Budget

Revenue		Estimated	Actual
NAU		$1,000.00	$1,000.00
Fundraising		$750.00	$750.00
Ponderosa High School		$4,000.00	$0.00
		$5,750.00	**$1,750.00**

Expense Type		Budget	Expense	Remaining
Tools		$250.00	$60.14	$189.86
Batteries		$4,000.00	$0.00	$4,000.00
Solar Panel		$505.00	$0.00	$505.00
LED Lights		$75.00	$0.00	$75.00
Human Powered Energy Bike		$500.00	$0.00	$500.00
Wind Turbine		$100.00	$0.00	$100.00
Animal Insulation		$400.00	$0.00	$400.00
Curriculum		$300.00	$13.00	$287.00
Total Expenses:		**$6,130.00**	**$73.14**	**$6,056.86**
			Total Revenue:	$1,750.00
			Total Balance:	**$1,676.86**

Table 10. PHS Sustainability Budget

Donations

- Bicycles
  - Value: $150.00
- Solar Panels
  - Value: $36,000
- Alternator
  - Value: $500.00

Fundraising

- Chipotle: April 8th 4:00PM
- Plant Sale: April TBD

Bill of Materials

PART NAME	DESCRIPTION	VENDOR	UNITS	UNIT COST	AMOUNT
Bicycles	2 mountain bike with gear shifts and 1 non shifting bike donated to use to create the human powered energy generation stationary bike	Donated	3	$-	$-
Alternator	Converts mechanical energy into electrical energy	Donated	2	$-	$-
Wood 2 X 4	To build a wooden frame to fix the back tire of the bicycles and hold them in place	Home Depot	6	$3.85	$23.10
Plywood Sheet	Flat plywood surface to be place under the frame and secured	Home Depot	2	$21.48	$42.96
Prime-Line carriage nuts and bolts	1/4 inch-20 teeth per inch (TPI) measuring 1/4 inch diameter x 1-7/8 inch length.	Home Depot	10	$3.30	$33.00
Metal Rod	Zinc plated steel rod	Home Depot	2	$10.53	$21.06
LED Display	Display screen that provides a visual that supports student engagement	Amazon	2	$80.00	$160.00
		TOTAL PARTS:	27	TOTAL COST:	$280.12

Table 11. Human Powered Bicycle Bill of Materials

Other supplies that support this final design and other components of the capstone project:

Kill A Watt Electric Monitor	Device that monitors and records electrical expenses by the hour, day, week, month, and year.	$ 29.99
Digital Multimeter	Measures AC/DC voltage to 600 volts, DC current, resistance, diode, capacitance, audible continuity, and battery test.	$ 24.99

Fig 21. Additional components

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Thank You

Questions?