2024 HYDROPOWER COLLEGIATE COMPETITION (HCC)

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Project Description

- **Problem Statement:** Select and convert a US non-powered dam (NPD) into an efficient source of hydropower to address the nation’s clean energy goals

Sponsor: US Department of Energy

Advisor/Client: Dr. Carson Pete

BACKGROUND & BENCHMARKING

Hoover Dam

- Turbines uprated in the 1990s
- Production capacity of 2,080 MW
- History of adapting to regulatory standards

Red Rock Dam

- Recently converted from NPD to hydroelectric
- Incorporates fish ladders and advanced fish guidance systems to mitigate impact on ecosystem
- State of the art Kaplan turbines; high efficiency and adaptable to variable flow conditions

Glen Canyon Dam

- Arch-gravity design significantly reduced amount of concrete required
- Francis turbines and Pelton wheels showcase combination of technologies for different flow conditions
- Recent issues with drop in water levels and not being able to push water through penstocks

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CUSTOMER AND ENGINEERING REQUIREMENTS

Customer Requirements

- Energy Production
- Environmental Impact
- Hydropower Dam Energy Analysis
- Community Engagement
- Scalability
- Cost

Engineering Requirements

- Max/Min Energy Output (MW)
- Environmental Impact (%)
- Efficiency (MWh)
- Social/Community Impact (#)
- Feasibility (years)
- Site Interconnectivity ($)

HOUSE OF QUALITY (QFD)

#	Technical Requirement	1	2	3	4	5
1	Energy Output					
2	Environmental Impact Mitigation	-				
3	Efficiency	++	+			
4	Social/Community Impact	+	-			
5	Feasibility		--		-	
6	Site Interconnectivity		-	+	+	++

Legend	
A	Dam 1
B	Dam 2
C	Dam 3

#	Customer Needs	Customer Weights	Weight %	Energy Output	Environmental Impact Mitigation	Efficiency	Social/Community Impact	Feasibility	Site Interconnectivity	1 Poor	2	3 Acceptable	4	5 Excellent
				Technical Requirements						Customer Opinion Survey				
1	Energy Production	10	21.28	9	3	9	6	6	3					
2	Environmental Impact Mitigation	8	17.02		9		6							
3	Hydropower Dam Energy Analysis	7	14.89	6	9	6		9	9					
4	Community Engagement	6	12.77		3		6							
5	Scalability	9	19.15		6			9	6					
6	Cost	7	14.89	6		6		9	6					
	Technical Requirement Units			mW	%	mWh, %	#	Years	$					
	Technical Requirement Targets			1-10 MW		>= 90%								
	Absolute Technical Importance			370.2	504.3	370.2	306.4	568.1	402.1					
	Relative Technical Importance			5	2	4	6	1	3					

- Feasibility
- Environmental Mitigation
- Turbine Efficiency
- Customer Opinion Survey TBD

Literature Review

- **Books**
  - The Guide to Hydropower Mechanical Design [2]
    - Serves as comprehensive reference for mechanical design aspects, components, and design considerations in hydropower
  - Design of Hydroelectric Power Plants – Step by Step [15]
    - Useful textbook that helps understand planning and design phases of project (types of studies, layouts, conveyance, equipment, etc.)
- **Papers**
  - Design models for small run-of-river hydropower plants: a review [16]
    - Provided design models and considerations to components like penstock design, turbine selection, and cavitation models/calculations
  - A high-resolution hydro power time-series model for energy systems analysis: Validated with Chinese hydro reservoirs [17]
    - Introduced different models and graphs to help apply to our future energy systems analysis, such as modeling power production and daily inflow data, and using this to find cost-effective ways to operate the systems while considering the presence of wind, solar, and carbon reduction
  - Hydropower development potential at non-powered dams: Data needs and research gaps [5]
    - A great resource discussing the new technologies, socio-economic factors, insights on successful and unsuccessful NPD retrofit projects, and even a perfect list of stakeholders involved in these projects (electric utilities, regulatory agencies, project developers, etc.)
- **Other**
  - ASME PTC 18-2011 [6]
    - Covers most of (if not all) performance testing and measurement guidelines for ensuring efficiency and performance of a hydropower system
  - Hydropower dams make a fish-friendly splash (article) [18]
    - Highlights the prevalence of hydropower plants in Europe and the threat that dams pose to fish species during their migration upstream
  - How a hydro generator works (YouTube video animation) [19]
    - One of the many visual aids found to help understand the fundamental components and operations of hydropower system

Literature Review

- **Books**
  - Small Hydropower Design and Analysis [7]
    - Classifications of components, approaches to the dam design based on head, discharge, capacity, etc.
  - Renewable Energy Volume 131 [8]
  - Looking into the head **losses** and the volumetric flow rates to analyze the arrangements of the system components. This book with help with calculations related to flow rates and fluid dynamics.
- **Papers**
  - Combined-cycle hydropower systems – The potential of applying hydrokinetic turbines in the tailwaters of existing conventional hydropower stations [9]
    - An in-depth look at the feasibility of the addition of hydropower generators and the math to validate these selections.
  - Non-stationary hydropower generation projections constrained by environmental and electricity grid operations over the western United States [10]
    - Research on the electricity grid and how current proposed additions to hydropower generation would impact the current electricity grid.
  - Dams and tribal loss in the United States [11]
    - Looks into the ownership of dams and how the United States has acquired the land which current dams have been built on.
- **Other**
  - Oak Ridge National Laboratory Website – NPDamCAT Tool [12]
    - Online tool used to assist in siting locations for potential dam sites
  - Welcome to REDi island – NREL video and interactive site [13]
  - Ownership Responsibility and Liability [14]
    - Site on who is responsible for dam safety, the dam ownership and dam failure and loses research.

Literature Review

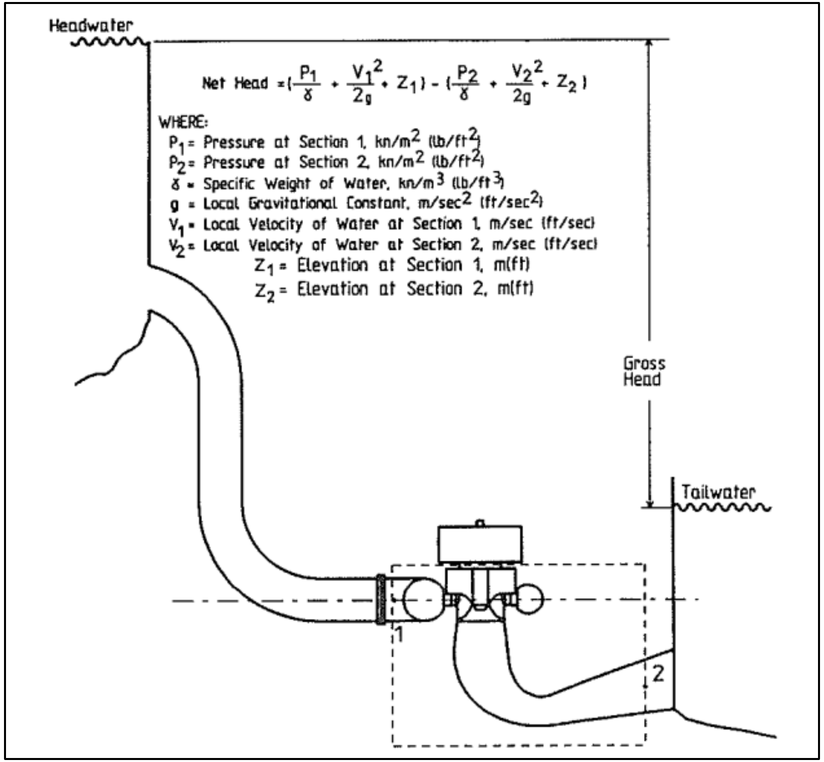
- **Books**
  - Hydroelectric Energy: Renewable Energy and the Environment – Chapter 3: Site Selection and Feasibility Study for Hydropower Projects
    - **Experimental procedures and equations for determining hydropower project site feasibility**

- **Papers**
  - An Assessment of Energy Potential at Non-Powered Dams in the United States
    - **Quantifies a potential capacity and generation for NPDs across the US, locating top NPDs according to defined criteria**
  - Renewable Energy Technologies: Cost Analysis Series – Hydropower
    - **Provides cost and performance data of hydropower energy production**
  - Environmental Impact Post-Assessment of Dam and Reservoir Projects: A Review
    - **Identifies areas for environmental awareness and assessment, focusing on water temperature, aquatic livings, environmental geology, and the resettlement of migrants.**

- **Other**
  - 2020 Cost Analysis of Hydropower Options at Non-Powered Dams
    - Characterizes the cost profile of potential hydropower sites based on existing technologies and evaluates potential cost reductions. Identifies economic and technological challeneges.

MATHEMATICAL MODELING – NET HEAD LOSS

- **Net Head:** Represents usable energy available in flow as it passes through turbine (see equation to right)
  - ASME Test Code PTC-18 and IEC test codes say to neglect draft tube exit loss from net head
- **Results From Excel:** Using Hoover Dam dimensions as model example
  - Assuming distance of 500 ft between the headwater and tailwater
  - **Net Head = 170 ft. (real value reported to be**
- Note: NPDamCat (discussed in next slides) may provide flow characteristics and generation potential



MATHEMATICAL MODELING – LCOE

LCOE = the average lifetime levelized cost of electricity generation

I_t = investment expenditures in the year **t**

M_t = operations and maintenance expenditures in the year **t**

F_t = fuel expenditures in the year t

E_t = electricity generation in the year t

r = discount rate

n = economic life of the system

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

- **Results From Excel:**
  - Assuming $600,000,000 in total costs and 13,220,000 MWh
  - **LCOE = $0.04538/kWh**
    - Hoover Dam reports $0.02018/kWh [XX]

Mathematical Modeling

Practically Available Power: P_a (W)

$$P_a = u * p * q * g * h$$

MATLAB code example calculation:

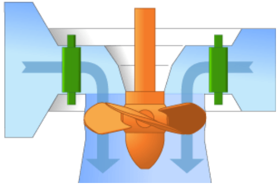
```
% Practically Available Power Calculations
clc;
u = input('Enter efficiency in decimal form: '); %efficiency
p = 1000; % kg/m^3
q = input('Enter water flow in m^3/s: '); %flow rate
g = 9.81; % gravity in m/s^2
h = input('Enter the head height (m): '); %head hight

Pa = u*p*q*g*h; %formula for power

%prints the result
fprintf('The practically available power (Pa) in Watts is: %d \n',Pa)
```

Command Window

```
Enter efficiency in decimal form: 0.76
Enter water flow in m^3/s: 5
Enter the head height (m): 10
The practically available power (Pa) in Watts is: 372780
fx >>
```

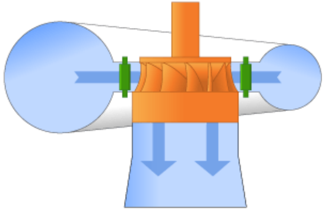
Using Engineering Toolbox

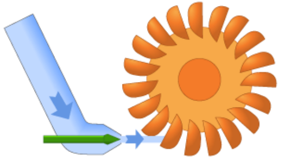
- Efficiency (u) general range 0.75 to 0.95
- Water flow (q) (m^3/s)



Kaplan Turbine ~ 90-90% efficiency

Francis Turbine ~ 80-95%





Pelton Turbine ~ 85%

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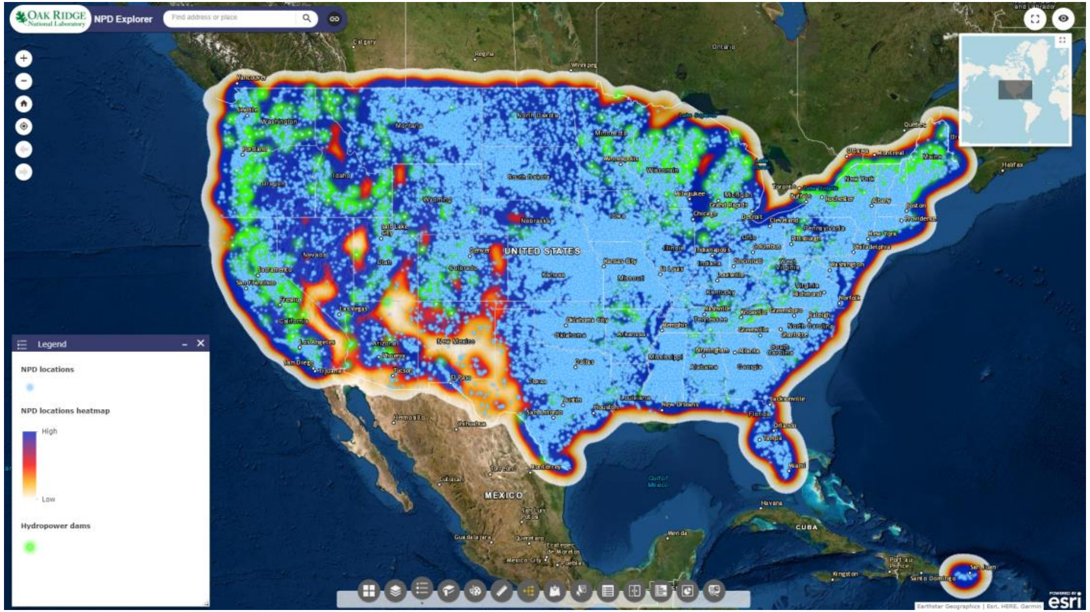
Mathematical Modeling

Using **NPDamCAT** web app developed by the Oak Ridge National Laboratory to gather data characteristics of non-powered dams in the U.S.

Attributes for the dam selection in the site can include:

- Age of the dam
- Size/dimensions
- Water conveyance
- Hydropower opportunity
- Environmental factors



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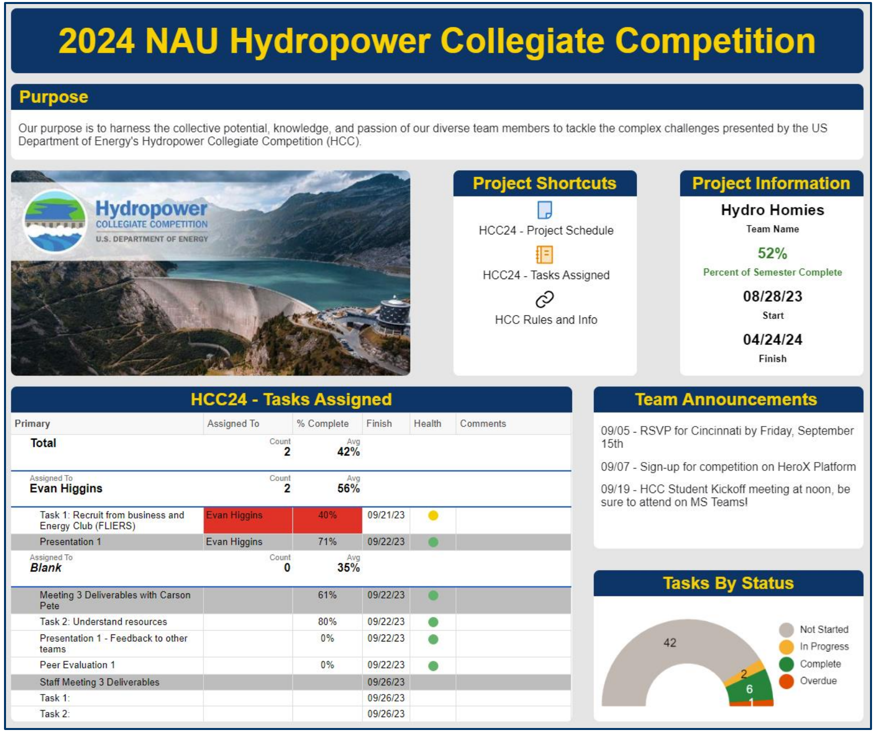
SCHEDULE AND BUDGET

- Key Dates:
  - Clean Currents Conference: **October 10th-13th**
  - Midyear Submission: **January 28, 2024, at 11:59 p.m. MT**
  - Siting and Design Report: 2 weeks prior to final event
- Budget: $15,000
  - Additional $5,000 if team commits to optional Build and Test Challenge
- Reaching out to the energy club for additional funding



CONCLUSION

- Overall: Project requirements identified, and team is familiar with technology
- Next Steps: Meet with Energy Club on Thursday & begin recruitment/onboarding
- Prepare for conference with questions and background knowledge
- Obtain more resources and project personnel to begin site selection

THANK YOU!

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