Power Generation through Recycled Materials

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Sponsor: Cummins

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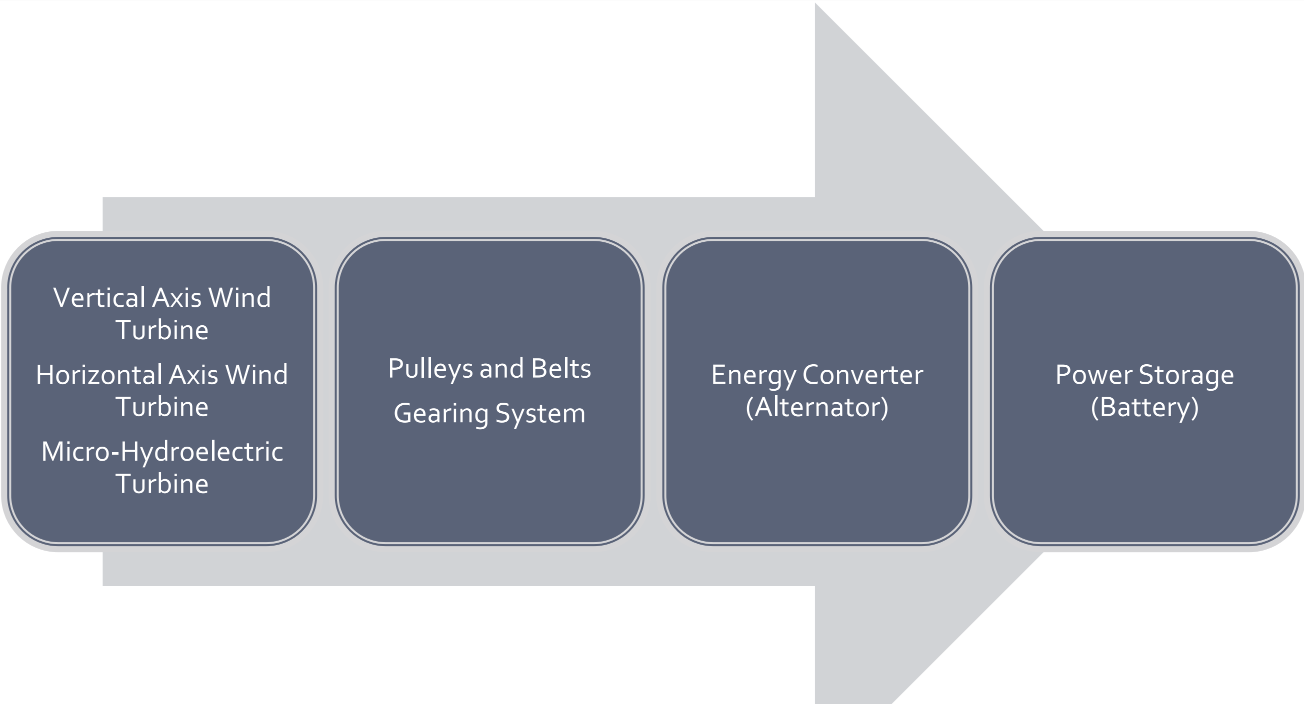
Background Overview

- **Problem Statement:**
  - Design and construct a power generation device that implements the use of a renewable energy source and is composed entirely of recycled materials
- **Objectives:**
  - Must generate 100 W•h/day
  - Must store 300 W•h
  - Output must be 12 V DC
- **Constraints:**
  - Must choose three different geographic locations
    - 100 km away from the ocean, 500 km away from each other
  - Final product must cost under $50

Design Layout

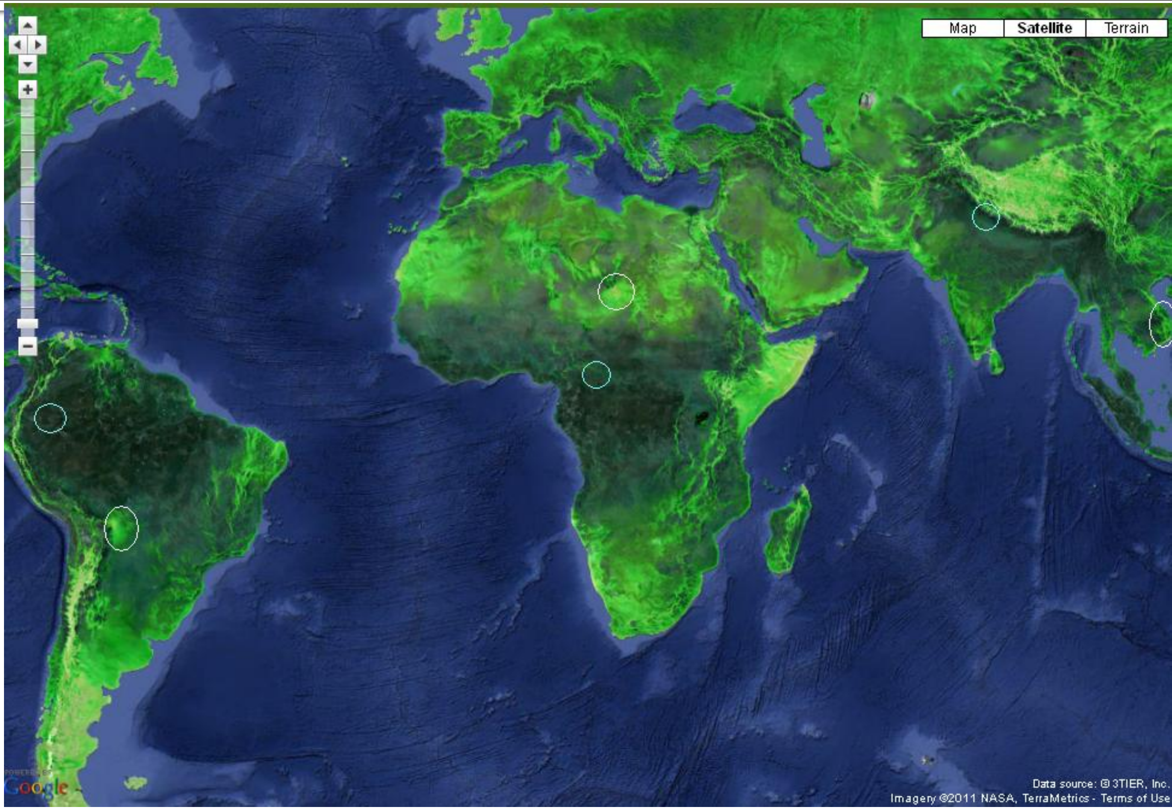


- **Design Concept Box Layout**
  - Energy Capture→ Speed Change→ Energy Conversion→ Battery Storage
  - Simplicity with 4 component layout

Geographical Locations

- **Wind Energy Locations**
  - Faya-Largeau, Chad
    - Average wind speed = 4.6 m/s ~ 10 m height
  - Santa Cruz, Bolivia
    - Average Wind = 3.9 m/s ~ 10 m height
  - Sen Monorom, Cambodia
    - Average Wind = 4.3 m/s ~ 10 m height

- **Water Energy Locations**
  - Atrato River, Colombia
    - Average Flow = $2.0 \bullet 10^6$ L/s
  - Indus River, Pakistan
    - Average Flow = $6.5 \bullet 10^6$ L/s
  - Benue River, Cameroon
    - Average Flow = $1.75 \bullet 10^5$ L/s



Boundary Layer Effects

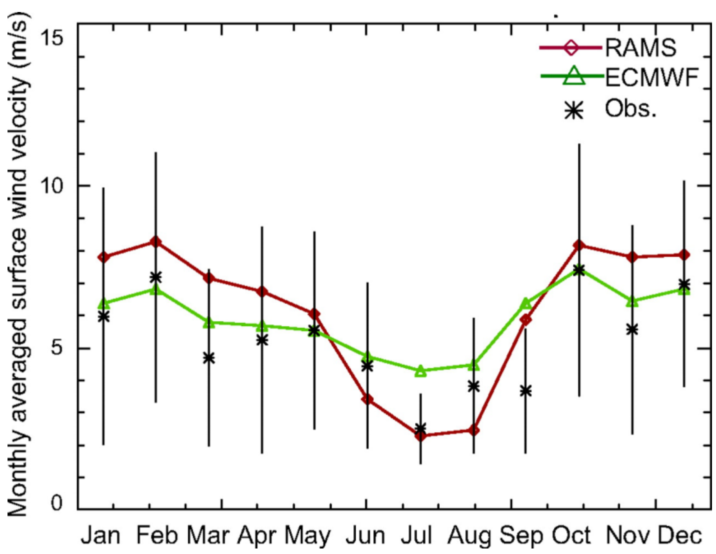
- Average wind speed at 10m

Lat 17.917 Lon 19.117	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	AnnualAverage
10-year Average (m/s)	5.56	5.44	5.15	4.68	4.12	4.04	4.16	3.99	3.88	4.87	5	5.14	4.66

- Average wind speed at 50m

Lat 17.917 Lon 19.117	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	AnnualAverage
10-year Average (m/s)	7.04	6.88	6.52	5.93	5.21	5.11	5.26	5.05	4.91	6.17	6.3	6.51	5.9

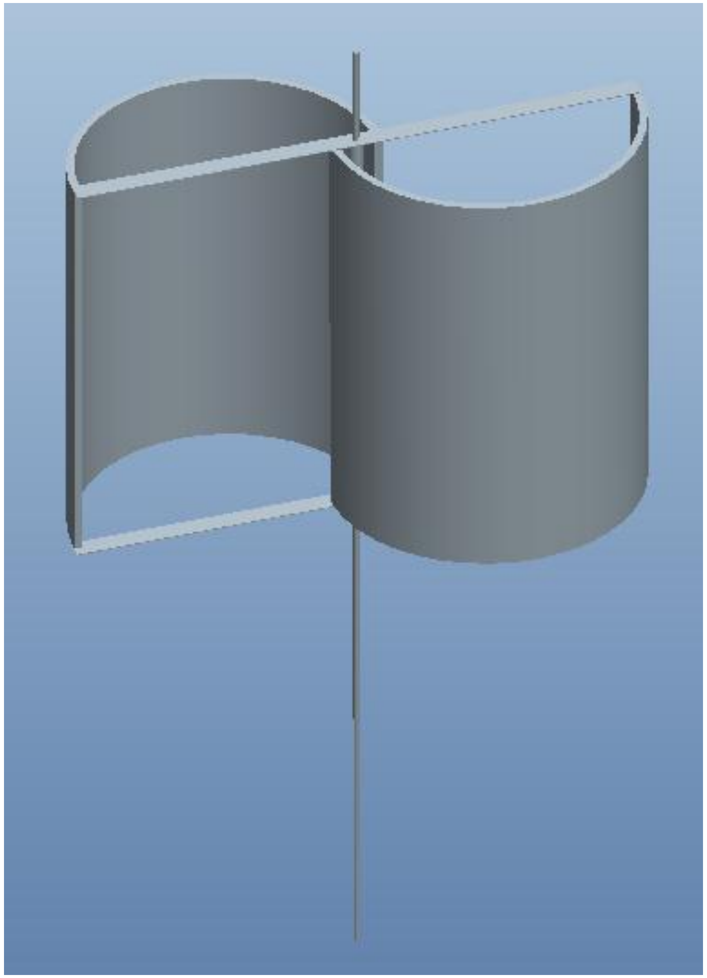
- Annual approximate wind speed at 5 m = 4.0 m/s



"Dust as a Tipping Element: The Bodélé Depression, Chad." *Proceedings of the National Academy of Sciences*. Web. 17 Nov. 2011. <http://www.pnas.org/content/106/49/20564.full>.

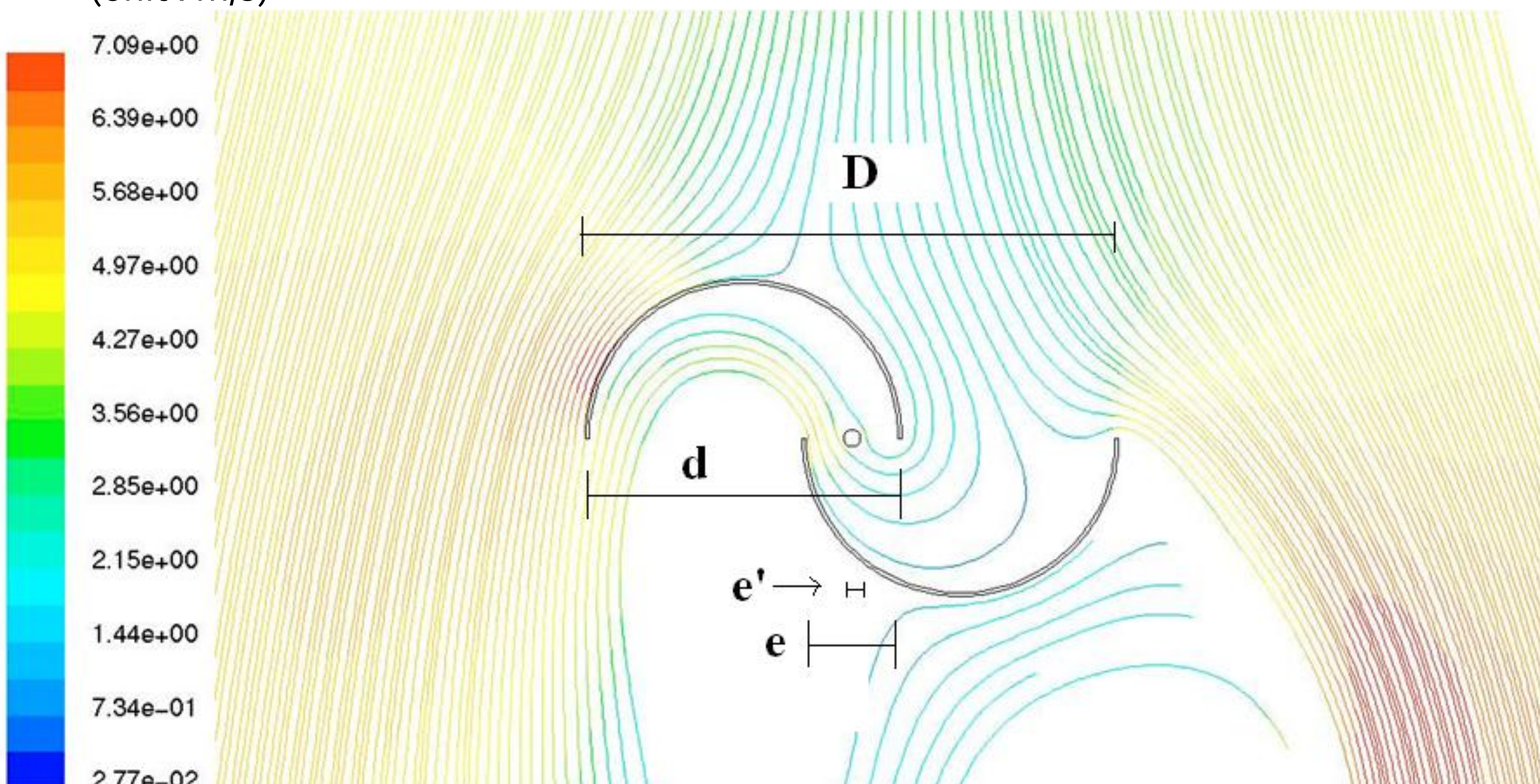
Design Concept #1: Vertical Axis Wind Turbine (VAWT)

- **Design Specifications**
  - Savonius design
  - Drag based system
- **Available Wind Energy**
  - Average annual wind speed is ~4m/s (Faya-Largeau, Chad)
- **Calculation Analysis**
  - Power coefficient of turbine
  - Minimum area of turbine
  - Power generation



Design Concept #1: Vertical Axis Wind Turbine (VAWT)

- Example Velocity Flow Field – Ideal Savonius Design
  - *(e-e')/d=0.242 and ReD=1.56x105, i.e. U=5m/s*
    (unit : m/s)



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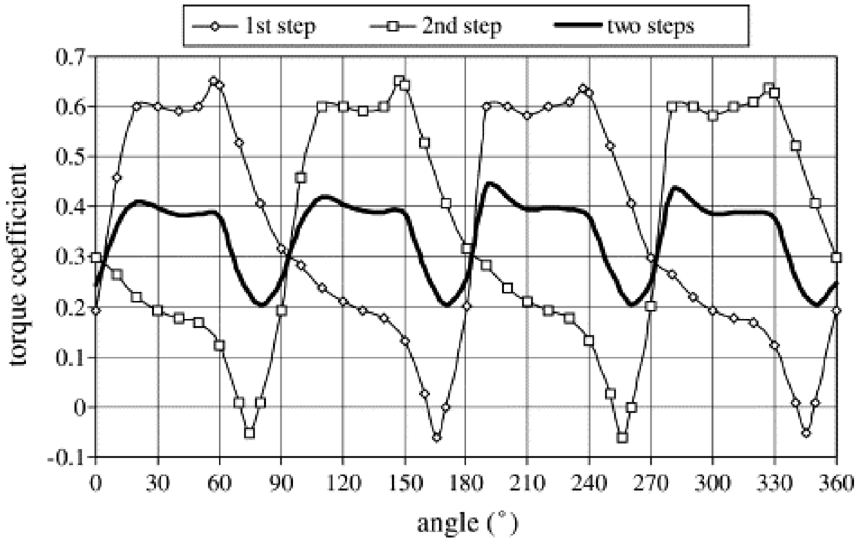
Design Concept #1: Vertical Axis Wind Turbine (VAWT)

- **Savonius Optimization**
  - Two blades & offset of e
  - Wind vane apparatus to block and channel wind
  - Optimized alternator/gearing
  - Second turbine set at 90°
    - Provides self-starting
  - $e_{opt}=d/6$



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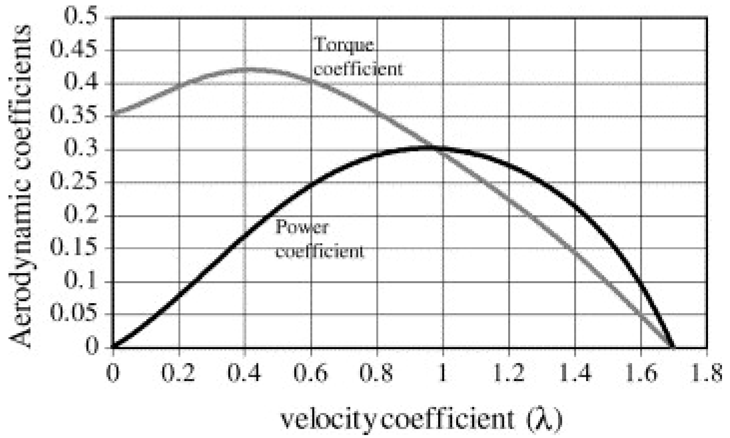
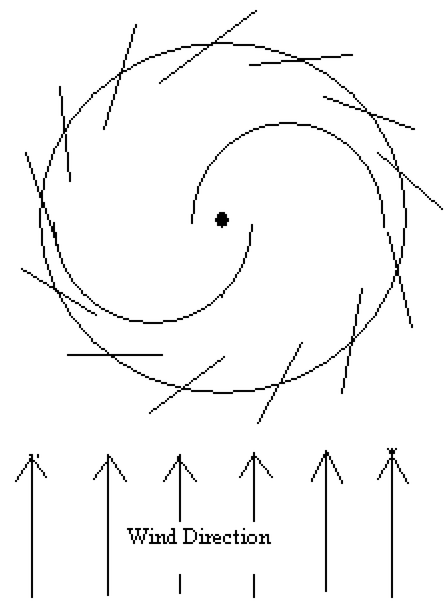
Design Concept #1: Vertical Axis Wind Turbine (VAWT)

- With wind channeled, ratio of turbine tip speed to undisturbed wind speed, (λ) is approximately 1
  - Blocks wind incoming to convex portion
  - Channels wind into concave portion
  - Omnidirectional
- $Cp_{opt} = 0.3$





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Design Concept #1: Vertical Axis Wind Turbine (VAWT)

IDEAL SAVONIUS SYSTEM

- **Power coefficient of Turbine**
  - 0.3
- **Area Specifications**
  - $e_{opt} = d/6$
  - $\alpha_{opt} = H/D = 4$
  - $e'_{opt} = e_{opt} - 0.242d$
- **Power Generated**
  - Gearing/pulley efficiency ~ 96%
  - Alternator efficiency ~90%

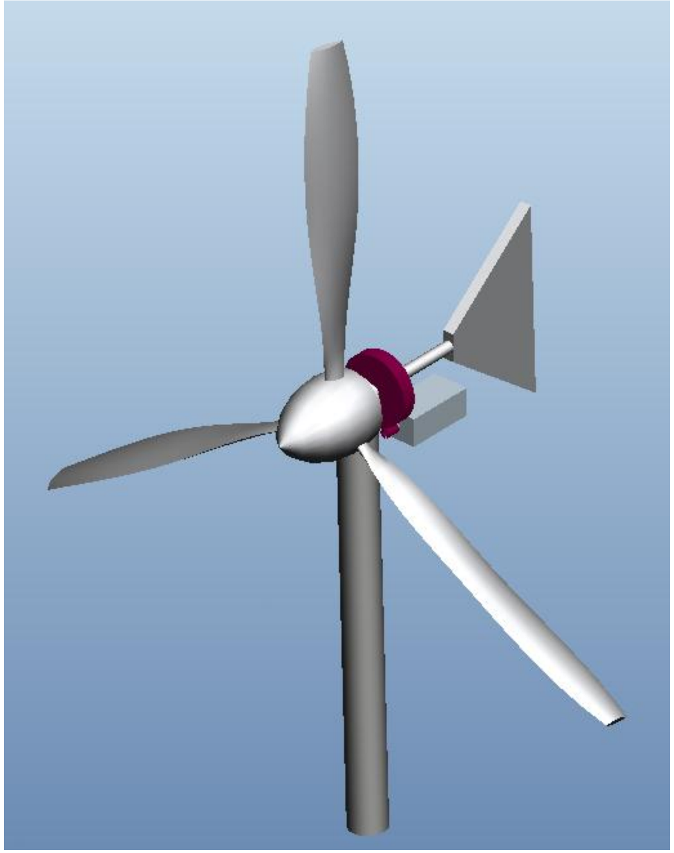
VAWT DESIGN CONCEPT#1

- **Power Coefficient of Turbine (90% of ideal design):**
  - 0.27
- **Minimum Rotor Area (4.2 W)**
  - Area = 0.579 m^2 = 2[d-(d/6)]H
- **Design Specifications**
  - 2- rotor design
  - 90° offset
  - Area = 1.39 m^2
- **Power Generated**
  - Gearing/pulley efficiency ~ 85%
  - Refurbished alternator efficiency ~ 80%
  - ~ 10 W

$$P_{actual} = \left(\frac{\rho H D V^3}{2}\right)(turbine\ efficiency)(belt\ efficiency)(alternator\ efficiency)$$

Design Concept #2: Horizontal Axis Wind Turbine (HAWT)

- **Design Specifications**
  - Three-blade turbine design
  - Airfoil shape in blades will be approximated
- **Available Wind Energy**
  - Average annual wind speed is ~4m/s (Faya-Largeau, Chad)
- **Calculation Analysis**
  - Power coefficient of turbine
  - Minimum area of rotor required
  - Power generation
  - Gearing/pulley ratio



Design Concept #2: Horizontal Axis Wind Turbine (HAWT)

ARE442 WIND TURBINE (NREL)

- **Power coefficient of Turbine**
  - 0.190
- **Minimum Rotor Area (4.2 W every hour)**
  - Area = 0.625 m^2
  - Diameter = 0.912 m
- **Design Specifications**
  - 3-blade Design
  - 7.2 m rotor diameter
- **Power Generated**
  - Gearing/pulley efficiency ~ 96%
  - New alternator efficiency ~90%
  - ~ 525 W

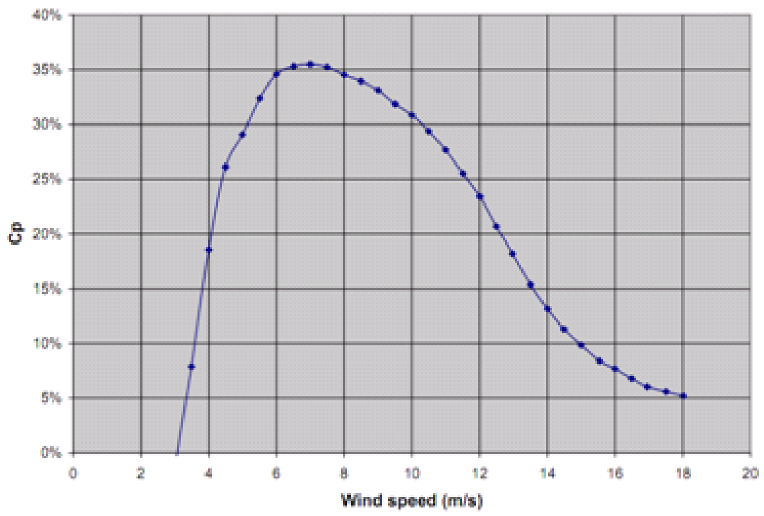
$$P_{gen} = \frac{1}{2}\rho U_1^{\,3} A C_p (\eta_{Belt}\eta_{Alternator})$$

HAWT DESIGN CONCEPT #2

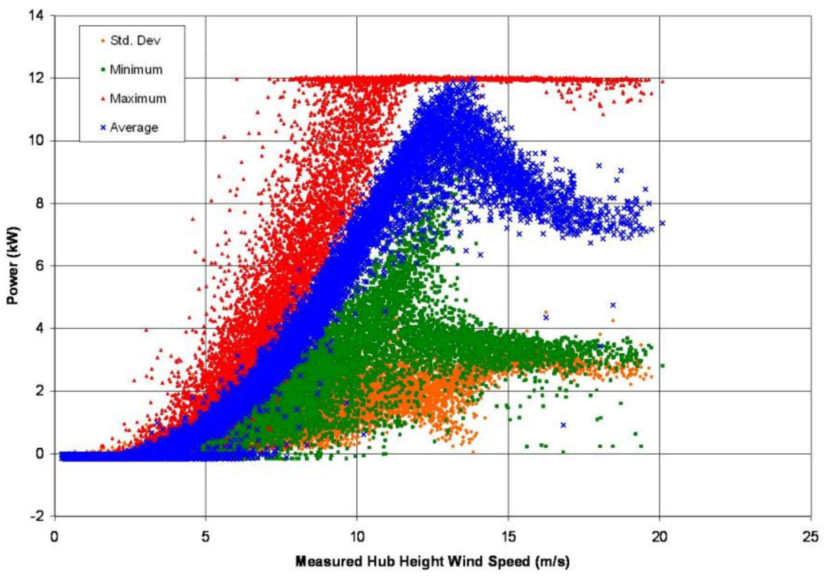
- **Power Coefficient of Turbine (60% of ARE 442):**
  - 0.114
- **Minimum Rotor Area (4.2 W)**
  - Area = 1.39 m^2
  - Diameter = 1.33 m
- **Design Specifications**
  - 3-blade design
  - 2.05 m rotor diameter
  - Area = 3.29 m^2
- **Power Generated**
  - Gearing/pulley efficiency ~ 85%
  - Refurbished alternator efficiency ~ 80%
  - ~ 10 W

Design Concept #2: Horizontal Axis Wind Turbine (HAWT)

ARE442 WIND TURBINE (NREL) – POWER COEFFICIENT VS. WIND SPEED

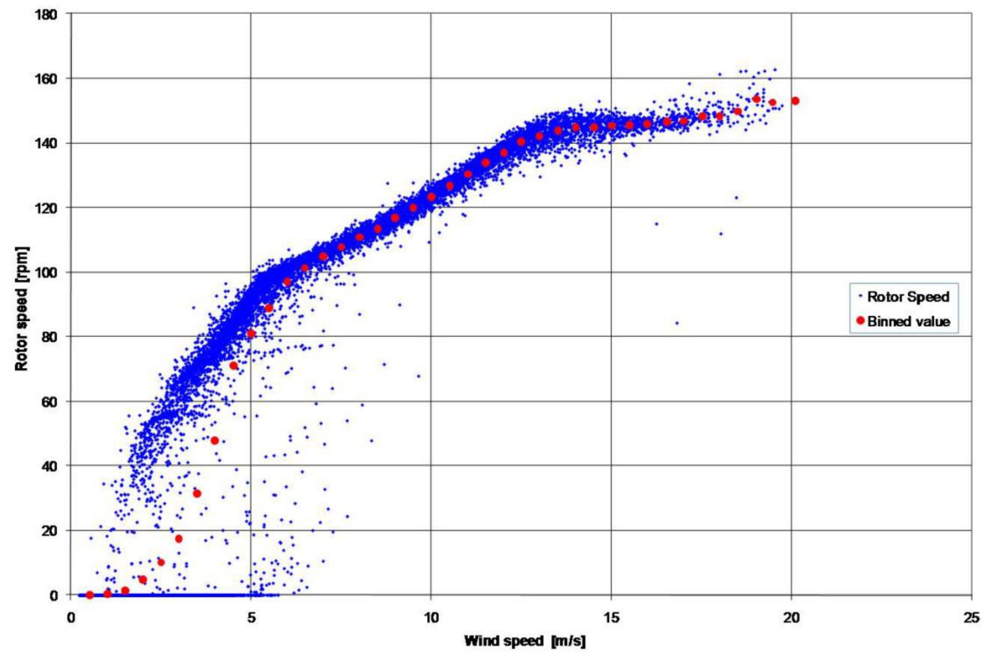


ARE442 WIND TURBINE (NREL) – POWER GENERATED VS. WIND SPEED



Design Concept #2: Horizontal Axis Wind Turbine (HAWT)

- **Gearing/Pulley System**
  - Angular rotor velocity (ARE442)
    - 48 rpm
  - Alternator angular velocity
    - ~700 rpm
  - 15:1 - Gear ratio



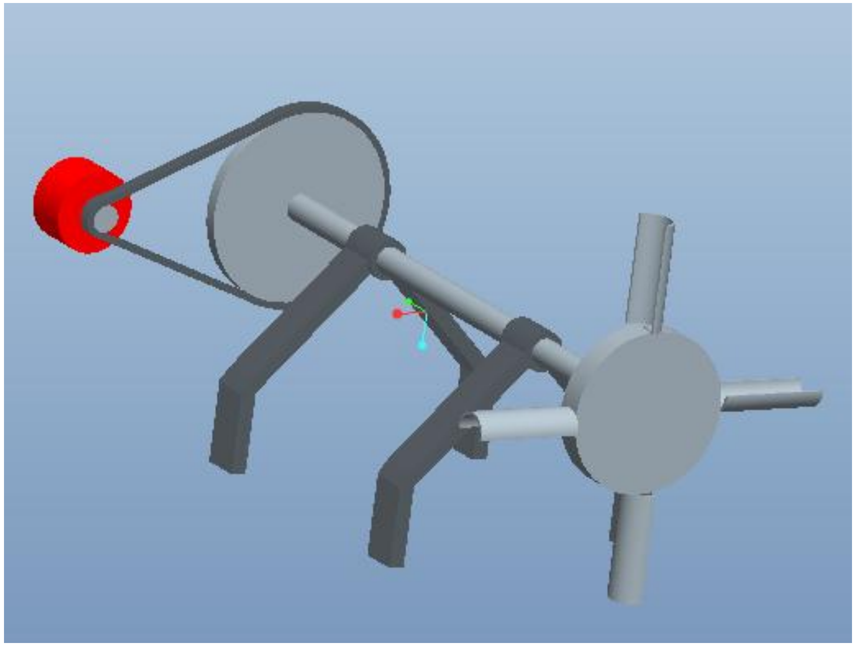
Wind speed	[m/s]	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0
Rotor speed	[rpm]	0	0	1	5	10	17	31	48	71	81	89	97	101	105	108	111	114	117	120	123

Wind speed	[m/s]	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5	16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.1
Rotor speed	[rpm]	127	130	134	137	140	142	144	145	145	145	145	146	147	147	148	148	150	154	152	153

Van Dam, Jeroen. "Wind Turbine Generator System Power Performance Test Report for the ARE442 Wind Turbine." National Renewable Energy Laboratory, Feb. 2010. Web. 17 Nov. 2011. <http://www.nrel.gov/wind/smallwind/pdfs/are_power_performance_test_report.pdf>.

Design Concept #3: Micro-Hydroelectric Generator

- **Design Specifications:**
  - Paddle- Wheel Design
  - Flexible Setup
    - Undershot
    - Breastshot
    - Overshot
- **Available Water Energy:**
  - Atrato River, Columbia
  - Indus River, India
  - Benue River, Cameroon
- **Calculation Analysis**
  - Head calculation (potential energy)
  - Flow rate
  - Power generation

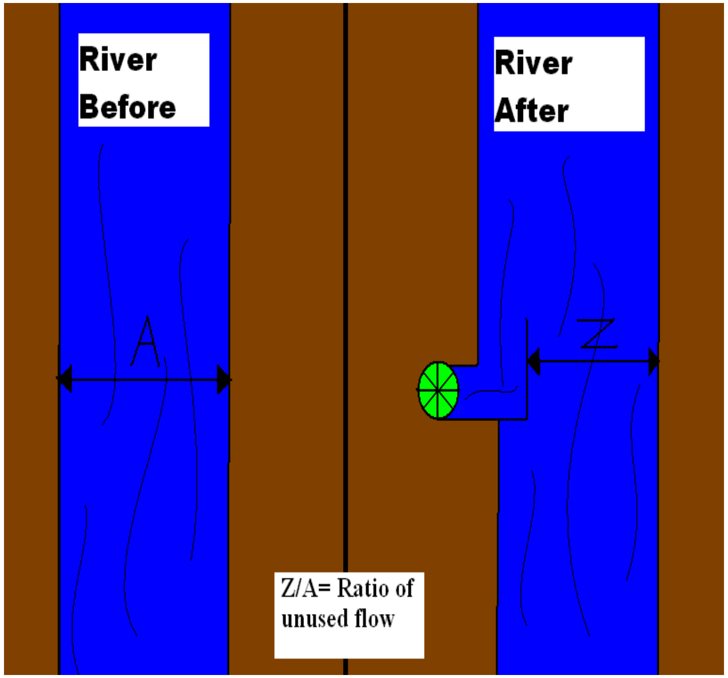


Design Concept #3: Micro-Hydroelectric Generator

- **Flow Diversion**
  - The amount of flow that will be diverted, will depend on head built into the system

Turbine Mechanical Power Output (Watts)						
Flow Rate	**Net Head** (meters)					
Liters/s	**1**	**2**	**3**	**5**	**7**	**10**
1	6.867	13.734	20.601	34.335	48.069	68.67
2	13.734	27.468	41.202	68.67	96.138	137.34
5	34.335	68.67	103.005	171.675	240.345	343.35
8	54.936	109.872	164.808	274.68	384.552	549.36
11	75.537	151.074	226.611	377.685	528.759	755.37
14	96.138	192.276	288.414	480.69	672.966	961.38
18	123.606	247.212	370.818	618.03	865.242	1236.06

$$P_{gen} = H_{Head} * \dot{V} * Gravity * \eta_{system}$$



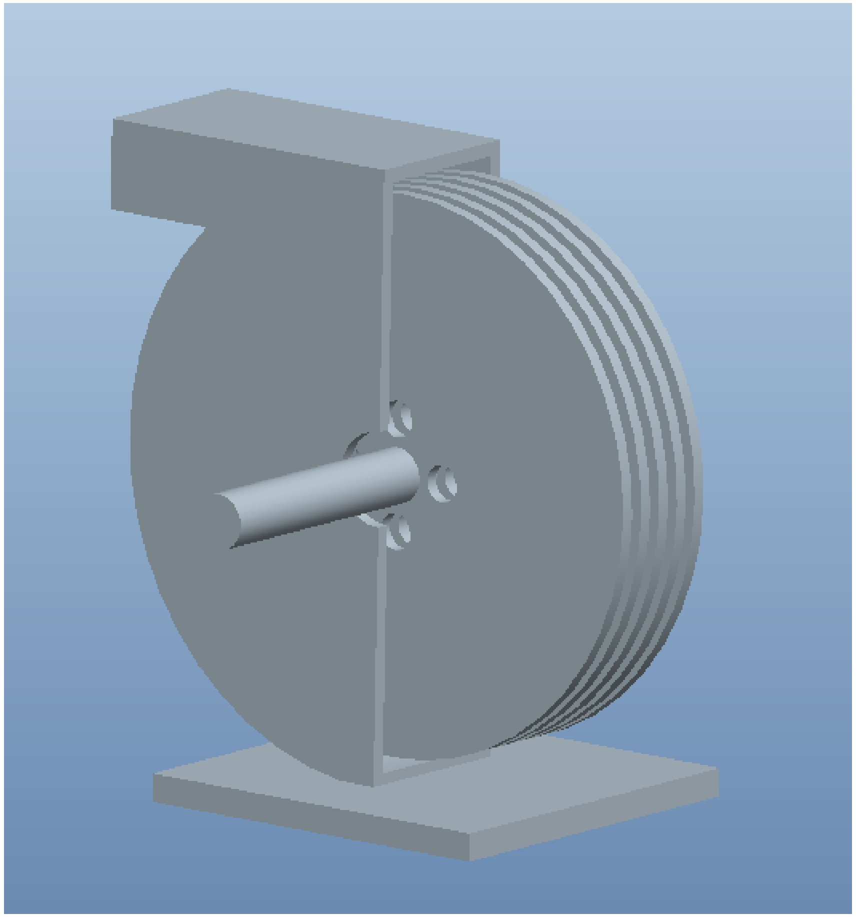
Design Concept #3: Micro-Hydroelectric Generator

- **Paddle-Wheel Optimization**
  - Approximate turbine shape
  - High number of PVC blades
  - Turbo-charger turbine and gear pump concepts eliminated
    - High cost and high flow requirements
    - Turbo/gear pump ~ $70-$100

- **Onsite Work Requirements**
  - Infrastructure must be implemented to divert flow
  - Basic water channeling via PVC piping will be required

Additional Concept: Tesla Turbine

- **Complexity**
  - Necessary scale will make design impractical
  - Requires precise installation
  - High maintenance required
  - Water flow can consistently damage discs
- **Large Size**
- **Water Filtration System**



Alternator

- Efficiency ranges from 90-95%
  - Used alternator approximated as 80% efficient
- Wide variety and easily obtainable/replaceable
- Design rpm much lower, gearing required
  - Minimum rpm = 700
  - Maximum rpm = 6,000
- Research alternative DC motors or stepper motors
  - Do not include voltage regulator

Cost Analysis

Part	Turbine	Supporting Stucture	Alternator	Pulley System	Bearings	Battery	Battery Cables	Total
VAWT	~$.90	~$4.90	$18.89	~$0.30	~$0.30	$19.79	$3.59	$48.67
Hydro	~$1.00	~$6.00	$18.89	~$0.30	~$0.30	$19.79	$3.59	$49.87
HAWT	~$1.00	~$2.00	$18.89	~$0.30	~$0.30	$19.79	$3.59	$45.87
Tesla	~$1.00	~~~	$18.89	~$0.30	~$0.30	$19.79	$3.59	~~~

Decision Matrix

		Concepts							
		VAWT		**HAWT**		**Hydro-electric**		**Tesla**	
Specifications	Importance Weight	Rating	Weighted Scores	Rating	Weighted Scores	Rating	Weighted Scores	Rating	Weighted Scores
Durability	15%	5	0.75	3	0.45	3	0.45	1	0.15
Ease of Assembly	20%	3	0.60	5	1.00	3	0.60	1	0.20
Cost	40%	5	2.00	3	1.20	1	0.40	3	1.20
Maintenance	20%	3	0.60	3	0.60	3	0.60	1	0.20
Innovative	5%	3	0.15	3	0.15	3	0.15	5	0.25
	Score	**19**	**4.1**	**17**	**3.40**	**15**	**2.20**	**11**	**2.0**

Durability	10%	5	0.50	3	0.30	3	0.30	1	0.10
Ease of Assembly	15%	3	0.45	5	0.45	3	0.45	1	0.15
Cost	30%	3	0.90	3	0.90	5	1.50	3	0.90
Maintenance	15%	3	0.45	3	0.45	3	0.45	1	0.15
Efficiency	30%	1	0.30	1	0.30	5	1.50	1	0.30
	Score	**15**	**2.6**	**15**	**2.4**	**19**	**4.20**	**7**	**1.60**

Future Plans

- Teleconference with Cummins
  - Bi-weekly teleconferences with the Cummins rep. Terry Shaw
- Further Material Research and Collection
  - Return to junkyards and recycle facilities
  - Alternative choices for energy conversion and power storage
- Finalize Concept Selection
- Construct, Test, and Refine Prototype

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Questions?