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Energy and Power 101 – Basics of conversions and calculations and application to WRRFs

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Outline

- Energy and Power Units
- Electrical energy
- Chemical Energy of COD
- Hydraulic energy and pumping
- Aeration energy
- Energy recovery from digester gas
- Social cost of energy (carbon)

Energy Conversion

$$Work = Force \cdot d$$

$$[N \cdot m] = Joules$$

$$[ft \cdot lb_f]$$

$$[BTU]$$

$$Force = mass \cdot acceleration$$

$$[kg \cdot m/s^2] = Newtons$$

1 BTU = 1054.4 Joules (=~1 kJ)

1 BTU = 778.15 ft-lb_f = 1.355 J

1 kW-hr = 3600 J = 3412 BTU

1 calorie = 4.184 J; 1 Calorie = 1000 calories!

Power Conversion

$$Power = Energy/time$$

S.I. Unit: $[Joules/second] = [kg \cdot m^2/s^3] = Watts$

1 W = 3.414 BTU/hr

1 hp = 550 ft-lb/s

1 hp = 745.7 W (=~ 0.75 kW)

1 hp = 17.9 kWh/day

Electrical Power

Volts = Energy per unit charge = $Joules/Coulomb$

(1 Coulomb = $6.24*10^{18}$ charges)

Current = Flow of charge per unit time = $Coulomb/second$

Power = Energy per unit time = Joules/second = Watts

$$Joules/second = Watts = Joules/Coulomb \cdot Coulombs/second$$

$$P = E \cdot I$$

$$120V \cdot 20Amps = 2400\ W$$

Bad energy unit #1

What is a kW per hr?

$$kW = kJ/second$$

$$kW/hr = kJ/sec/hr = kJ/sec^2 \cdot 1/3600$$

Bad Energy Unit #2:

- Window air conditioner unit rating
- E.g. 12,000 “BTU”

- BTU per What?
- 12,000 BTU/second = 4.2 MegaWatts!
- 12,000 BTU/hour = 3,515 Watts ✓

- Note: A 12,000 BTU/hr A/C actually uses only about 1,170W
- Electric Power Usage =
  Cooling power/Coefficient of Performance
- COP is typically about **3**

GE 12,000 British Thermal Unit WINDOW AIR CONDITIONER WITH REMOTE

- EER = (Cooling Power in BTU/hr) / (Electric Power in W)
- In this example, EER = 12,000/1,170 = **10.2**

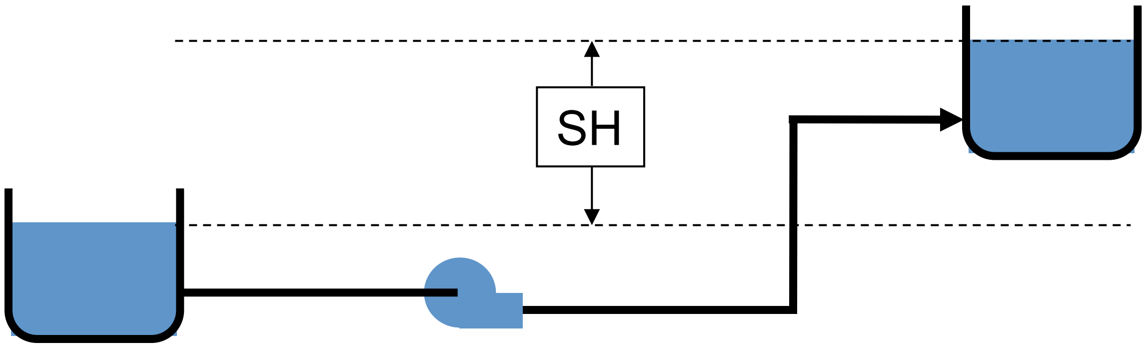
Simple WWRF Energy Balance

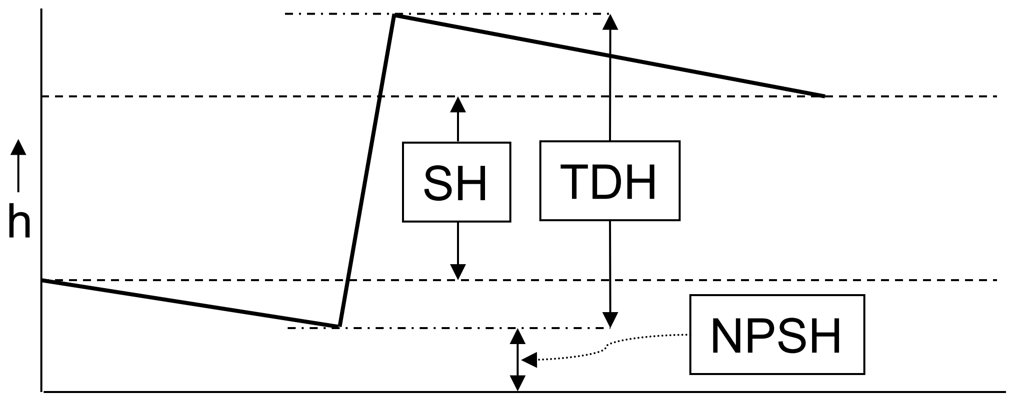
- Chemical energy input (COD)
- Pumping energy
- Aeration energy
- Energy from digester gas

Energy from Influent COD

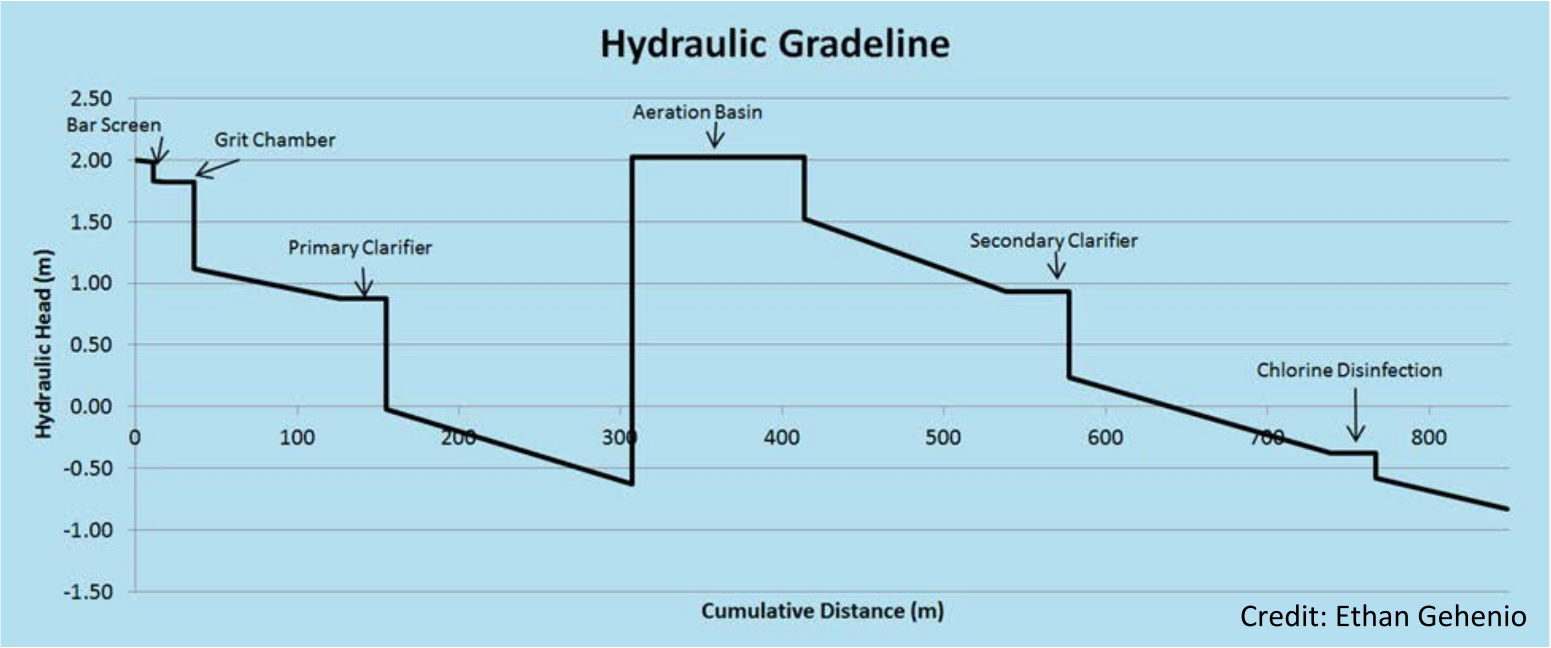
Influent flow rate	100,000	cu m/d
=	26.4	MGD
Influent VSS	96	g/cu m
Energy/COD	4	kWh/kgCOD
Influent COD Conc.	136	g/cu m
Influent COD Flux	13,632	kg/d
Energy input	**54,528**	**kWh/d**

Hydraulic Energy Grade Line





Hydraulic Grade Line



Nominal headloss through plant: 5.5 meters (18 feet)

Water Power

Water Power: $P_W = W \cdot h_L = Q \cdot \rho \cdot h_L$

E.g. Pumping 26.4 MGD against a head change of 18 feet:

$$\dot{W} = 26.4 \times 10^6 \frac{gal}{day} \times 8.34 \frac{lbs}{gal} \times \frac{day}{86{,}400\,\sec} = 2550 \frac{lbs}{s}$$

$$P_W = \dot{M} \cdot h_L = 2550 \frac{lb}{s} \times 18\, ft = 46{,}010 \frac{ft \cdot lb}{s}$$

$$P_W = 46{,}010 \frac{ft \cdot lb}{s} \times \frac{hp \cdot s}{550\, ft \cdot lb} = 83.7\, hp$$

Brake horsepower

$$P_B = \frac{P_W}{\varepsilon_P}$$

E.g. If the previous pump were 80% efficient:

$$P_B = \frac{83.7\,hp}{80\%} = 104.6\,bhp$$

Motor horsepower

$$P_M = \frac{P_B}{\varepsilon_M} = \frac{P_W}{\varepsilon_P \varepsilon_M}$$

E.g. If the motor were 85% efficient:

$$P_M = \frac{104.6\,hp}{85\%} = 123\,hp$$

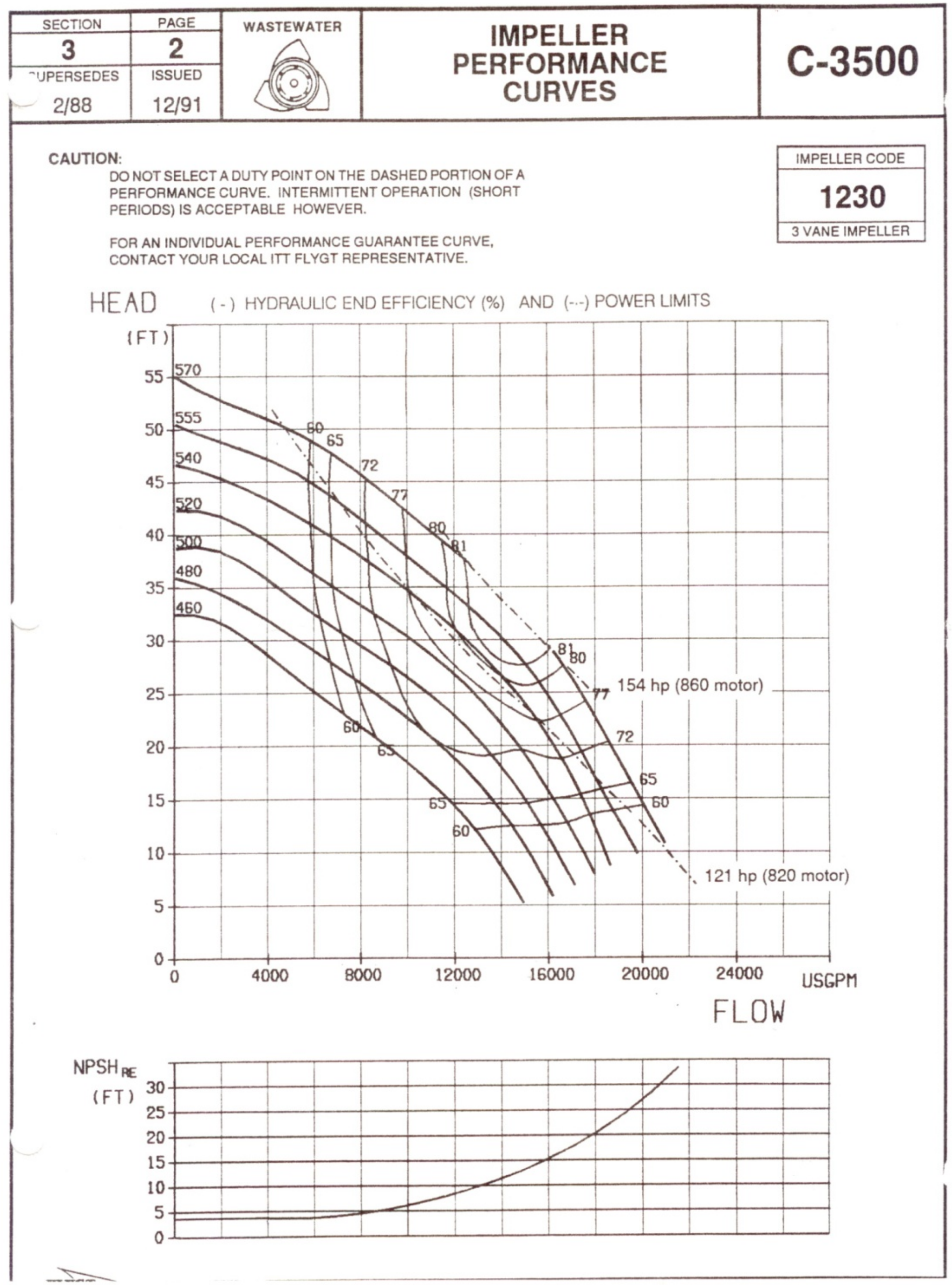
Note: 1 *hp* = 0.746 *kW* = *17.9kWh/d*; so

$$P_M = 123\,hp \cdot \frac{0.746\,kW}{hp} = 91.75\,kW = 2202\ kWh/day$$

$$2202\ kWh/day \cdot \$0.15/kWh = \$330\ per\ day = \$120{,}565 \text{ per year}$$

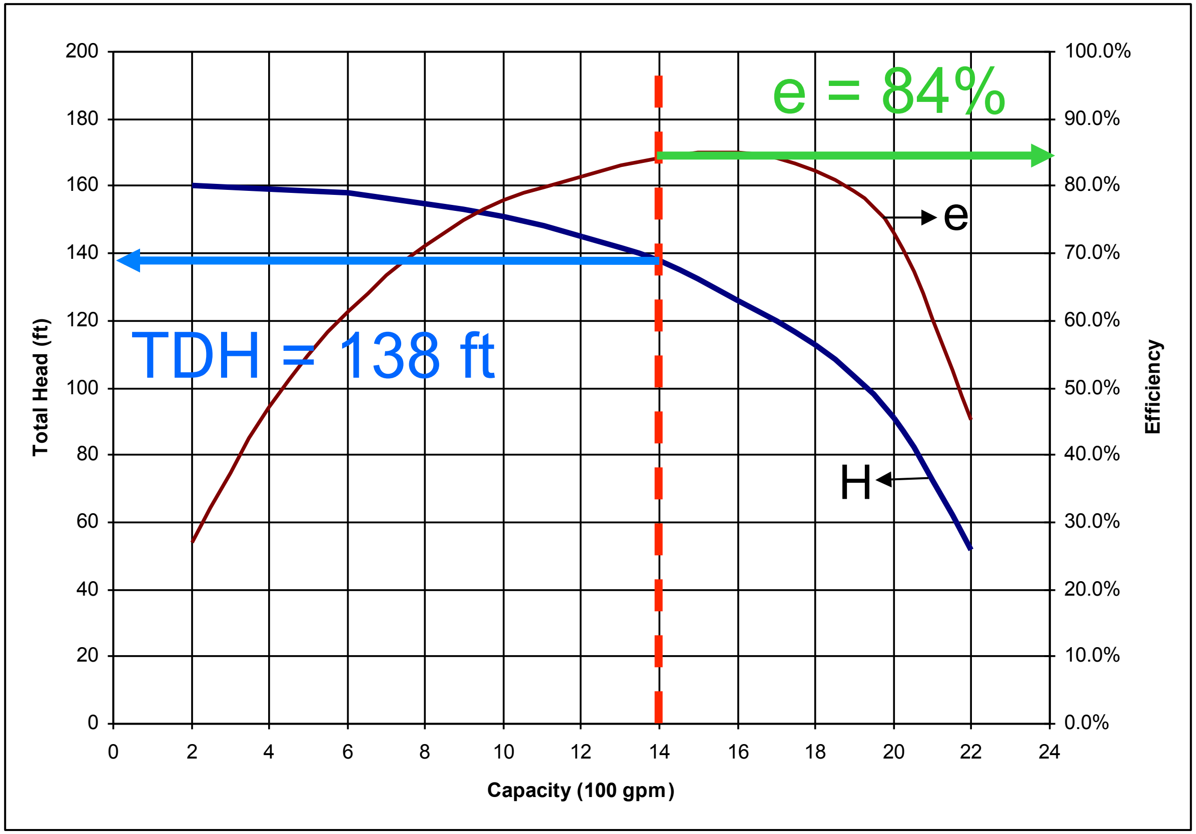
Actual Pump Performance

– The Pump Curve



Simplified Pump Curve

What will be the TDH, efficiency, and power requirement of this pump at **1400 gpm**?



$$P_W = 1400\frac{gal}{d}\times\frac{8.34\,lb}{gal}$$

$$\times\frac{\min}{60\,s}\times 138\,ft\cdot\frac{hp\cdot s}{550\,ft\cdot lb}$$

$$P_W = 48.8\ hp$$

$$P_B = \frac{P_W}{\varepsilon_P} = \frac{48.8\,hp}{0.84}$$

$$P_B = 58.1\ hp$$

S.I. Headloss Calculation

$$P_W = Q \cdot \rho \cdot h_L = M \cdot h_L$$

$$h_L = g \Delta h$$

$$P_W = M \, g \Delta h$$

Influent flow rate	100,000	cu m/d
=	26.4	MGD
Mass flow rate	1,157.41	kg/s
hL	5.5	meters
g	9.8	m/s/s
Pw	62,384	kg-m^2/s^3 [W]
Pw	1,497	kWh/day

Pump efficiency	80%	
Motor efficiency	85%	
Pumping power req'd	2,202	kWh/day

Empirical aeration system design

$$U \equiv \frac{Q \cdot (S_0 - S)}{V \cdot X} = F / M \cdot e$$ *[per day]*

$$SOUR = U - \frac{1.42}{\theta_c}$$ *[per day]*

$$OTR = OUR = SOUR * X$$ *[kg/m³/day]*

Fine bubble diffuser:

$$1.2 < OTE < 2.0$$ *[kgO_2/kW-hr]*

$$OTP = V \cdot OTR / OTE$$ *[kW-hr/day]*

Q	100,000	cu m/d
=	26.4	MGD
S0	120	g/cu m
S	5.4	g/cu m
X (MLVSS)	1,110	g/cu m
V	25,000	cu m
F/M	0.43	per day
MCRT	6.77	days
eB	95.5%	
U	0.413	per day
SOUR	0.203	per day
OTR=OUR	225.5	g/cu m/d
OTE	1600	gO2/kWh
OTP	**3,524**	**kWh/day**

Sludge production mass balance

Primary removal	40%	VSS removal
Underflow VSS flux	3,840	kg/d
Act. Sl. Waste Flow	871	cu m/d
Waste VSS Conc.	3,331	g/cu m
Waste VSS flux	2,901	kg/d
VSS flux to digester	**6,741**	**kg/d**

Digester HRT	20	d
kd	0.03	per d
Kp	0.625	
VSS flux out of dig.	4,212.91	kg/d
VSS destruction rate	2,528	kg/d

Energy recovery from digester gas

Digester HRT	20	d
kd	0.03	per d
Kp	0.625	
VSS flux out of dig.	4,212.91	kg/d
VSS destruction rate	2,528	kg/d

Qgas	2,528	cu m/d
E dig gas	22,000	J/cu m
Power from gas	55,610,410	J/d
	15,447	**Kwh/d**
Engine eff	30%	
New Digester Power	**4,634**	**Kwh/d**

The Social Cost of Carbon

Social Cost of CO_2, 2015-2050 [a] (in 2007 dollars per metric ton CO_2)
https://www.epa.gov/climatechange/social-cost-carbon

	Discount Rate and Statistic			
Year	**5% Average**	**3% Average**	**2.5% Average**	**High Impact (95th pct at 3%)**
2015	\$11	**\$36**	\$56	\$105
2020	\$12	**\$42**	\$62	\$123
2025	\$14	**\$46**	\$68	\$138
2030	\$16	**\$50**	\$73	\$152
2035	\$18	**\$55**	\$78	\$168
2040	\$21	**\$60**	\$84	\$183
2045	\$23	**\$64**	\$89	\$197
2050	\$26	**\$69**	\$95	\$212

Emission Factor
7.03×10^{-4} metric tons CO_2 / kWh
(eGRID, U.S. annual non-baseload CO_2 output emission rate, year 2012 data)

= 703 g CO2e/kWh

Using \$42/tonne CO_2e
Social cost of electricity = \$0.0295/kWh

At \$0.15/kWh → 20% of electric cost

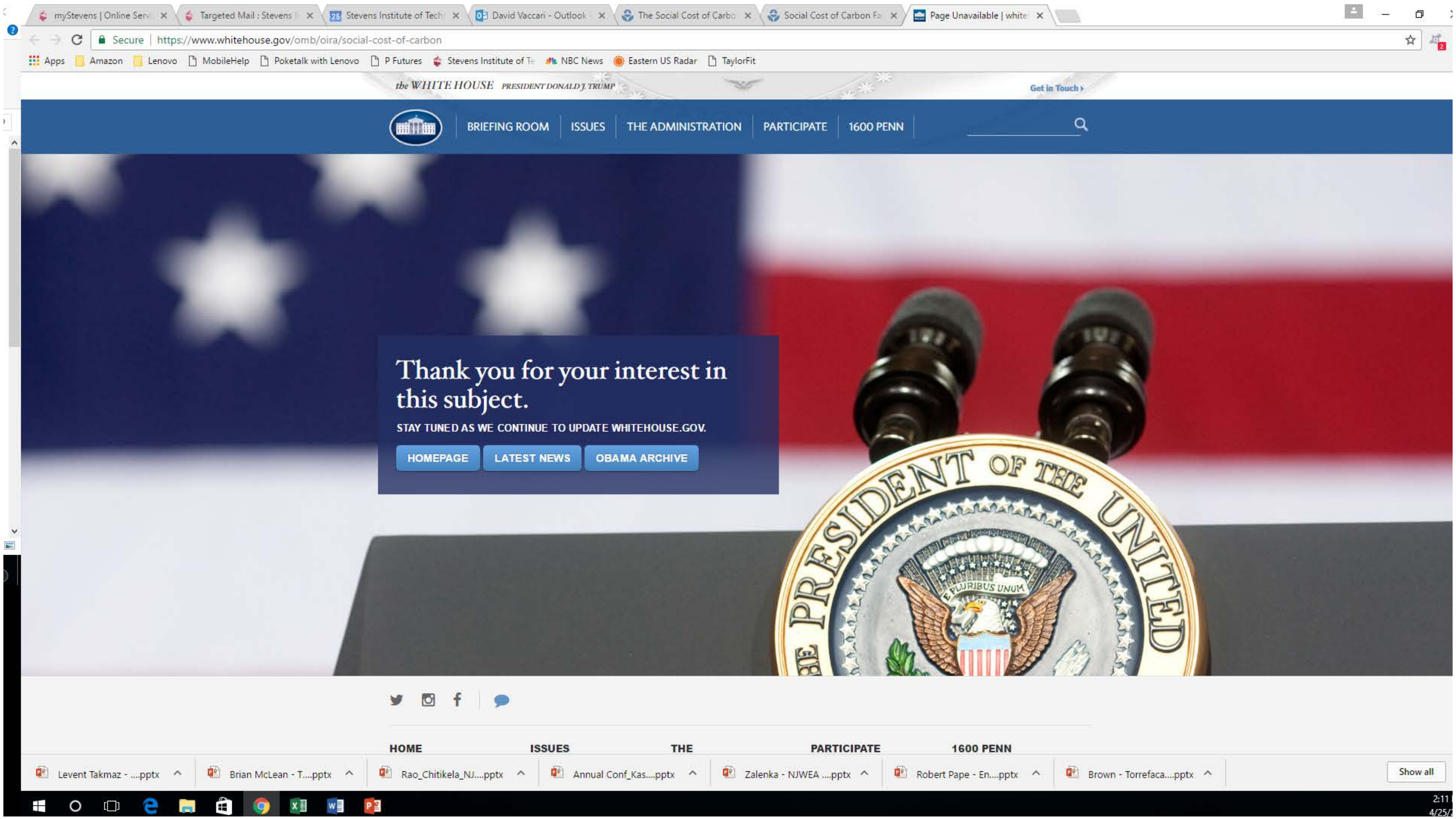
WRRF Net Power

ENERGY BALANCE	kWh/day
COD power	54,528
Hydraulic power	(2,202)
Aeration power	(6,533)
Net digester power	4,634
NET	**50,427**

ELECTRICITY REQUIREMENT:			
Pumping	2,202		
Aeration	6,533		
Digester gas credit	(4,634)		
TOTAL	**4,101**		
COST/day ($.15/kWhr)	**$ 615**	**$ 224,526**	(per year)

SOCIAL COST OF CARBON			
Cost per kWh	$ 0.0295		
TOTAL (per day)	**$ 121**	**$ 44,157**	(per year)

Whitehouse Global Warming Web Site



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Thank you

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