Lecture 7: Renewable Power

Energy Law and Policy

Fall 2013

Types of Renewables

- Wind
- Solar
- Biomass
- Geothermal
- Hydroelectric/tidal

Common Themes

- Generally more successful in DG settings
  - Hydro is exception, sometimes wind
- More successful with smart grid or storage support strategies
- Valuation of externalities crucial to economics
- High installation costs
- Low O&M, fuel costs

California Accounting for Externalities (stationary fuel cells)

• Job Creation	0.22-0.26
• Health Benefits	2.34-2.54
• Avoided CO2 Emission	0.11-2.21
• Avoided Other Emissions	0.11-1.90
• Increased Reliability	0.01-0.22
• Grid Support	0.03-0.40
• T&D Loss Avoidance	0.26-0.64
• Avoided Distribution Costs	0.06-0.97
• Avoided Transmission Cost	0.01-0.24
• Avoided Water Use	0.00-0.26
• Value of Fossil Fuel as Price Hedge	0.36-0.96
• Avoided Generation Cost	1.28-7.03
• Avoided Generation O&M Cost	0.22-0.54
• Avoided Generation Capital Cost	1.71-2.31
• Total	6.6-20.5 cents/kWh

Going Renewable

- Most experts think we can replace significant fraction of electricity load with renewable energy
- Minority believe we can replace entire load
  - Al Gore US model: 100% carbon free power by 2020
  - Hermann Scheer – German Parliamentarian
    - Incumbent industries have made efforts to propagate the notion that we cannot replace load.
    - Unsuspecting public seldom differentiates between a vested interest and an independent expert.
    - Scientists and industrialists, dependent on nuclear and fossil fuel industries for their livelihoods, shun evidence that suggests a total shift to renewable energy is possible

Plan for 100% Renewable by 2030

- Jacobson & Delucchi – Scientific American November 2009
  - Accessible wind and solar energy dwarf energy consumed around the world
  - Can achieve 100% renewable power with:
    - 90,000 large 300 MW solar plants (40% of demand)
    - 3.8 mm large wind turbines (51% of demand)
    - Distributed rooftop solar pv, geothermal, tidal power
  - Cost of generating and transmitting power less than fossil fuel or nuclear on kw-hr basis
  - Obstacles:
    - Need more materials
    - Political will

Problems

- Solar plants would occupy 0.33% of the world's land space
  - But current and projected coal plants have same foot print (excluding mining)
- Materials/Life Cycle costs
- Energy Storage
  - Mitigate intermittency problem with smart grid. But will this work?

Political Will

- Near term costs will be high
  - Requires subsidies, portfolio standards or feed in tariffs
  - Carbon taxes/cap and trade
  - Favorable regulatory treatment
- Disruptive effects of change
  - Resistance to lobbying of entrenched interests
  - Plans for social changes must be in place

Costs of Renewable Power Capital Costs 2007$/Installed kW

Technology	Average Cost
Gas Turbine	$ 500
Combined Cycle turbine	878
Scrubbed Coal	1534
Wind	1710
Hydroelectric	1900
Biomass combustion	2300
Geothermal	2400
Solar Thermal	3744
Fuel Cell	5374
Nuclear	5800
Solar PV	5850

Source: Sovacool, Electricity Journal, May 2009

Costs of Renewable Power Levelized Cost 2007 cents/kWh

Technology	Average Cost
Offshore Wind	2.6 cents
HydroElectric	2.8
Onshore wind	4.1
Geothermal	6.4
Biomass combustion	6.9
Scrubbed Coal	7.2
Combined Cycle natural gas	8.5
Solar Thermal	10.5
Nuclear	24.0
Solar PV	39.0

Source: Sovacool, Electricity Journal, May 2009

Carbon Emission Lifecycles for Selected Generation (g/kWh)

Technology	Average Emission
Wind	5.1 g/kWh
Geothermal	38.6
Solar PV	39.0
HydroElectric	59.5
Nuclear	124.0
Clean Coal w CCS	439.0

Sovacool, Electricity Journal, May 2009

Advantages to Renewable Energy

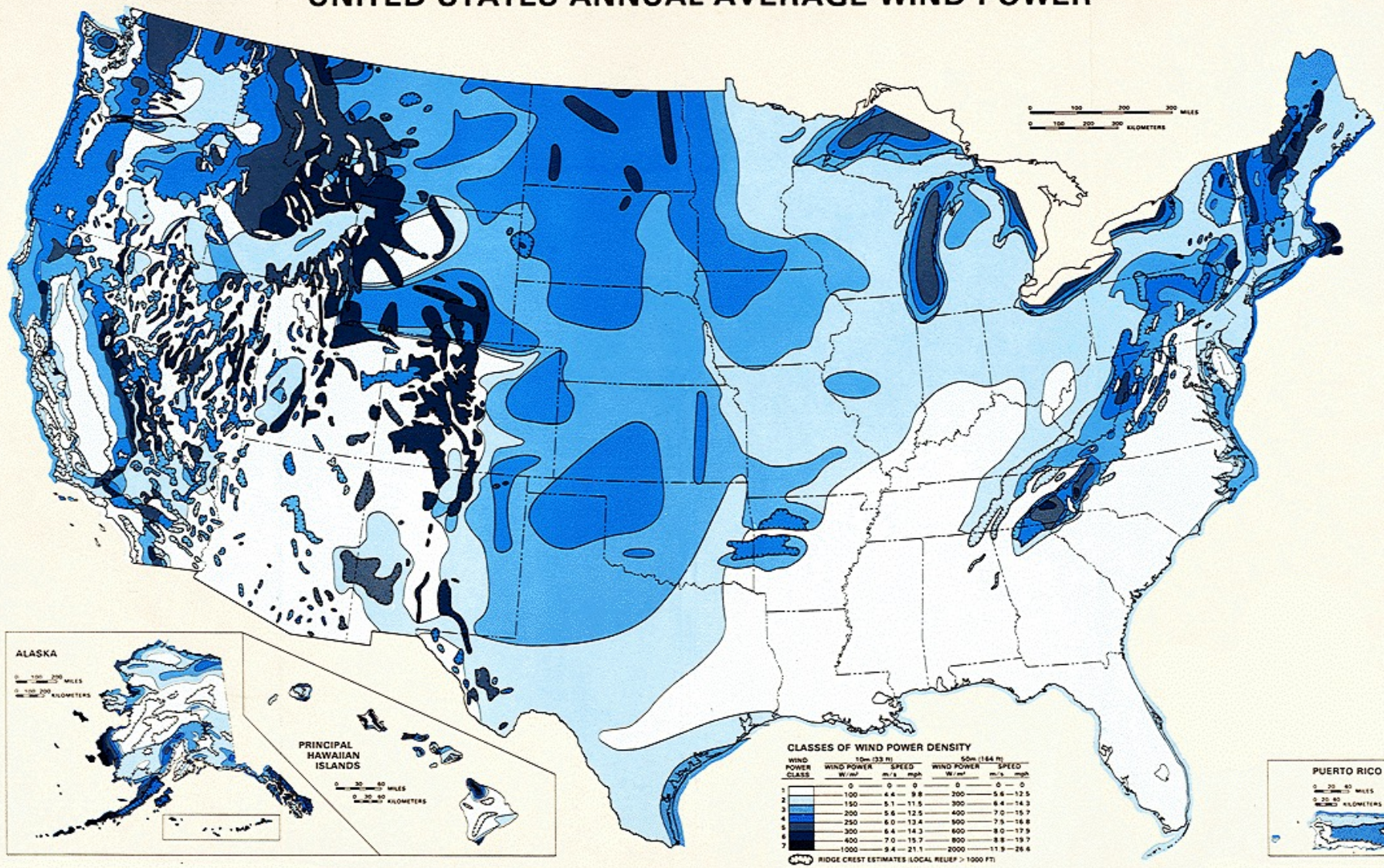
- Lower negative externalities
- Stable or Free Fuel Supply
- Fewer Greenhouse gases
- Reduced water usage
- Local employment and revenue
  - Estimates of $1.40 local return for every $1.00 spent
  - Current system: 50-95% of every dollar spent on conventional electricity leaves the local economy

Utilization of Wind Energy

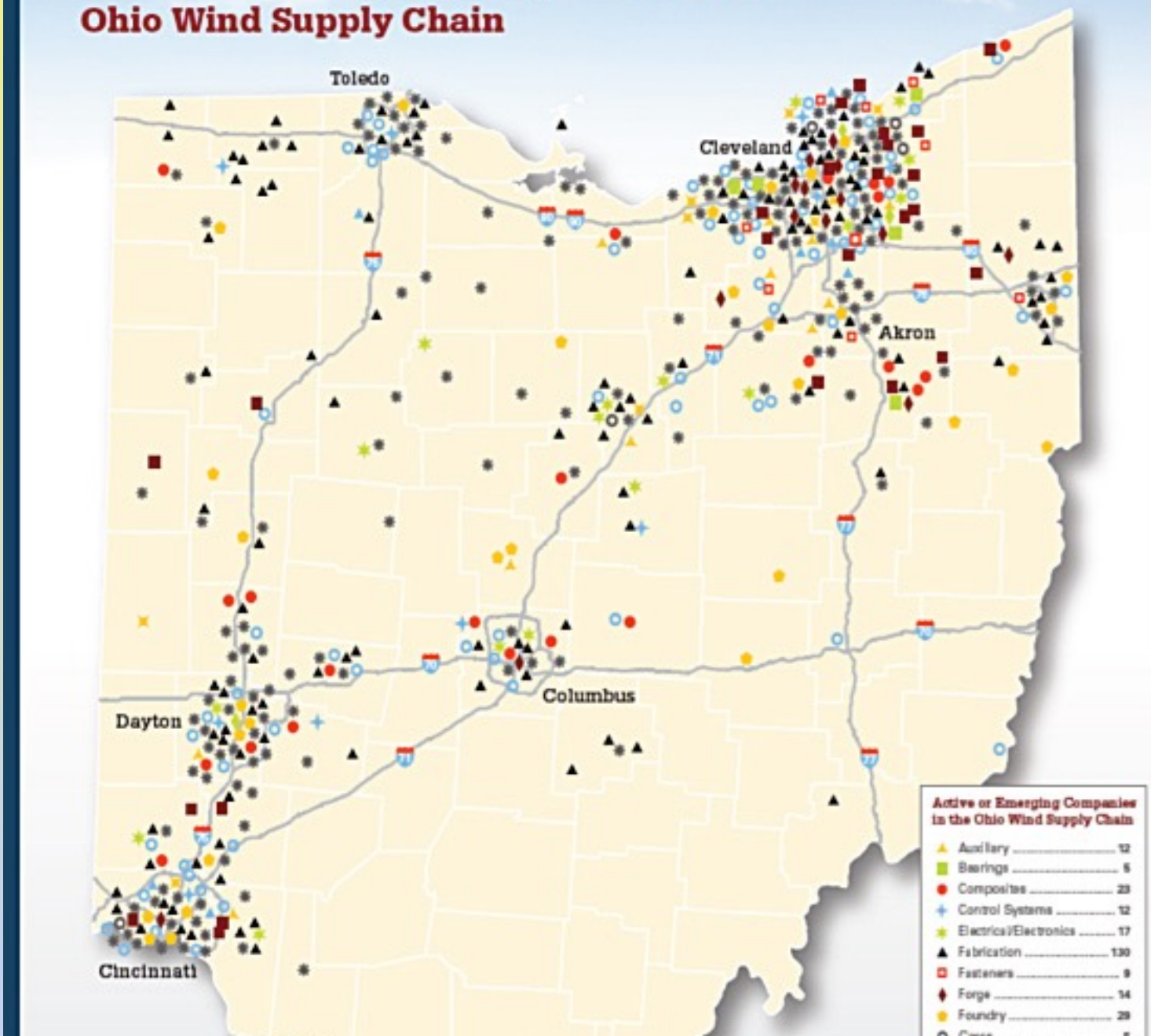
- Off-Grid
  - Small turbines (50 W to 10 kW)
  - Battery charging
  - Water pumping
- Isolated-Grid
  - Turbines typically 10 to 200 kW
  - Reduce generation costs in remote areas: wind-diesel hybrid system
- Central-Grid
  - Turbines typically 200 kW to 2 MW
  - Wind farms of multiple turbines

Photo Credit: Charles Newcomber/ NREL Pix

UNITED STATES ANNUAL AVERAGE WIND POWER

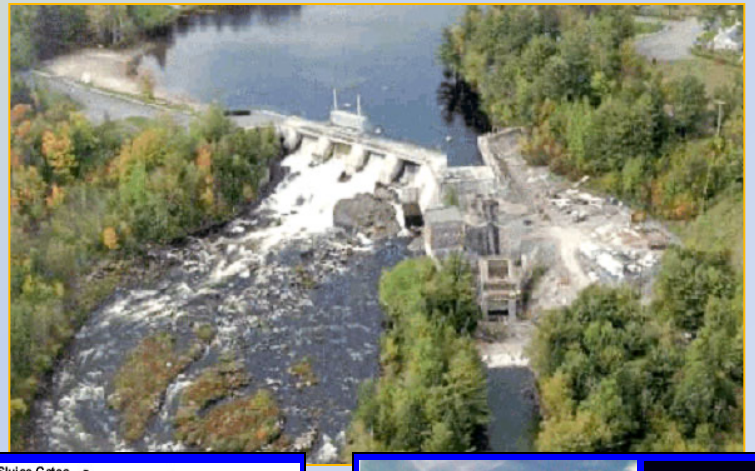


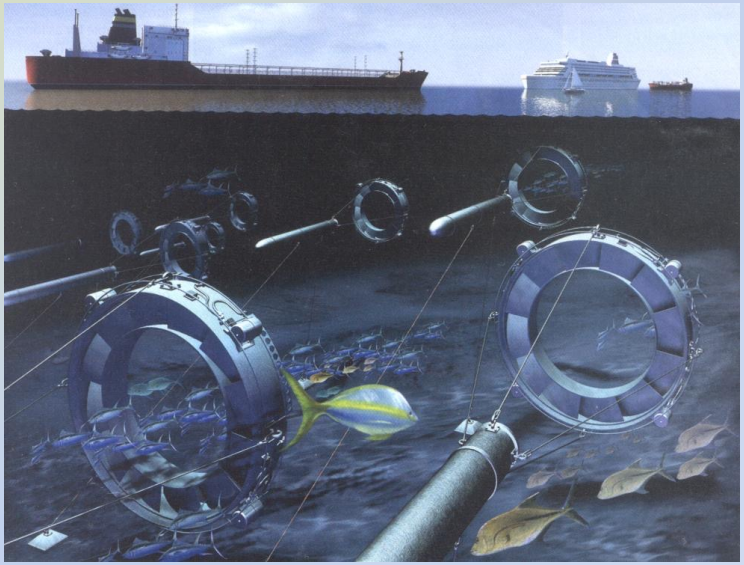
Active and Emerging Companies in the Ohio Wind Supply Chain

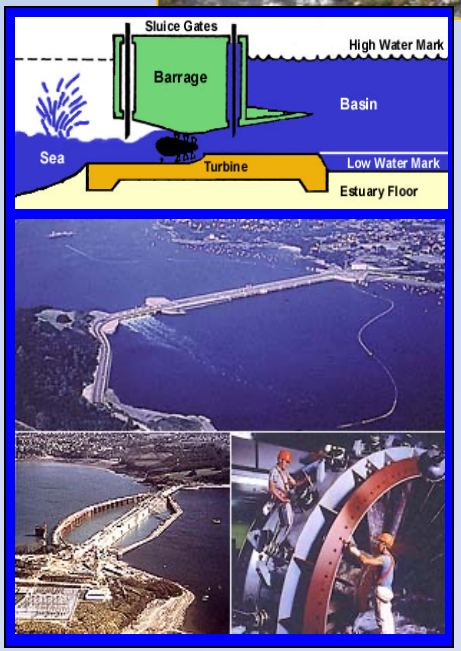


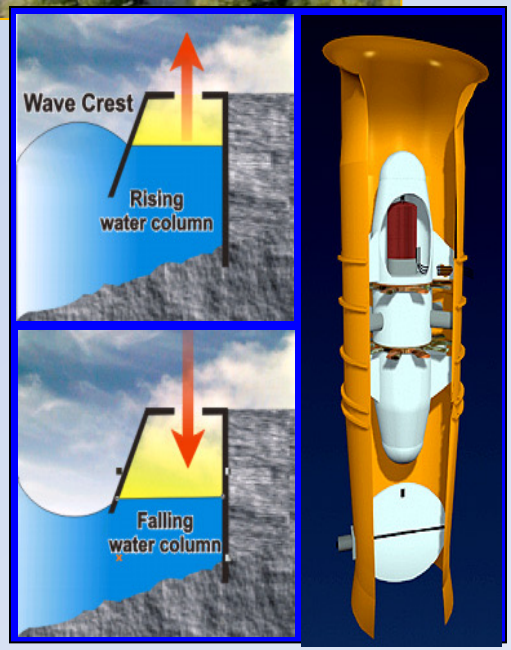
Moving Water

- Dams (Hydro and micro-hydro)
- Current
- Tidal
- Wave









What do Small Hydro systems provide?

- Electricity for
  - Central-grids
  - Isolated-grids
  - Remote power supplies

…but also…

  - Reliability, possible storage
  - Very low operating costs
  - Reduced exposure to energy price volatility

Photo Credit: Robin Hughes/ PNS

Site Selection for Micro-Hydro

- Very site specific: an exploitable river is needed!
  - Significant change in elevation over a relatively short distance
  - Acceptable variation in flow rate over time

Small Hydro System Costs

- 75% of costs are site specific
- High initial costs
  - But civil works and equipment can last >50 years
- Very low operating and maintenance costs
  - One part-time operator is usually sufficient
  - Periodic maintenance of major equipment requires outside contractor
- High head developments tend to be less costly
- Typical range: $1,200 to $6,000 per installed kW

Photo Credit: Ottawa Engineering

Example: USA and China

Isolated-Grid Small Hydro Systems

- Remote communities
- Remote residences & industry

Small Hydro Generators, China

Photo Credit: International Network on Small Hydro Power

King Cove 800 kW Small Hydro System, Town of 700 People

Photo Credit: Duane Hippe/ NREL Pix

- Higher price paid for electricity
- Run-of-river projects typically need supplemental capacity and may have flow in excess of demand

Biogas-Fueled DG

- Biogas Exists Naturally on Earth
  - Natural gas – CH_4
    - Decomposition of animal/vegetable matter
  - Heating Value: 950 – 1200 BTU/cu ft
- Artificially Produced Biogas
  - Process hot air exhaust
  - Biodegradation of volatile organic compounds
  - Biogas consists of CO_2 and CH_4
  - Typical concentrations of CH_4 = 45 – 70%
  - Biogas heating values = 450 – 700 BTU/cu ft

Biogas Plant Applications

- Biogas plant projects are generally found in two primary applications
  - Municipal solid waste landfills where the decomposition of VOC's is naturally occurring under the clay cap of the closed landfill
  - Anaerobic digesters used at waste water treatment plants, agricultural enterprises (large CAFO) and regional settings using mixed waste materials as feedstock (substrates) to "fuel" the digester

How Biogas Is Produced

- Biodegradable Materials – best to least
  - Fats, oils, greases (FOG)
  - Whey (from cheese production)
  - Candies and other sugar-containing foods
  - Grains and vegetable matter
  - Dairy, hog, poultry manure

Anaerobic Digestion

- Biodegradable action in the absence of oxygen
- Creates “digester” gas with 45 – 65 % CH_4
- Reduces material volume slightly
- Eliminates odors
- Eliminates pathogens (pasteurization)
- Retains nutrient value of residue for use as fertilizer

Digester Vessel

Cost In vs. Energy Out Comparison – 2800 kW
Hull & Associates

Renewable Energy Resource Type	Installed Cost per KW	Annual Energy Output (kWhrs)
Solar	$5000	3.700,000
Wind	$4000	4,900,000
Biogas	**$3600**	**22,600,000**

CSU Energy Policy Center

Thank you!