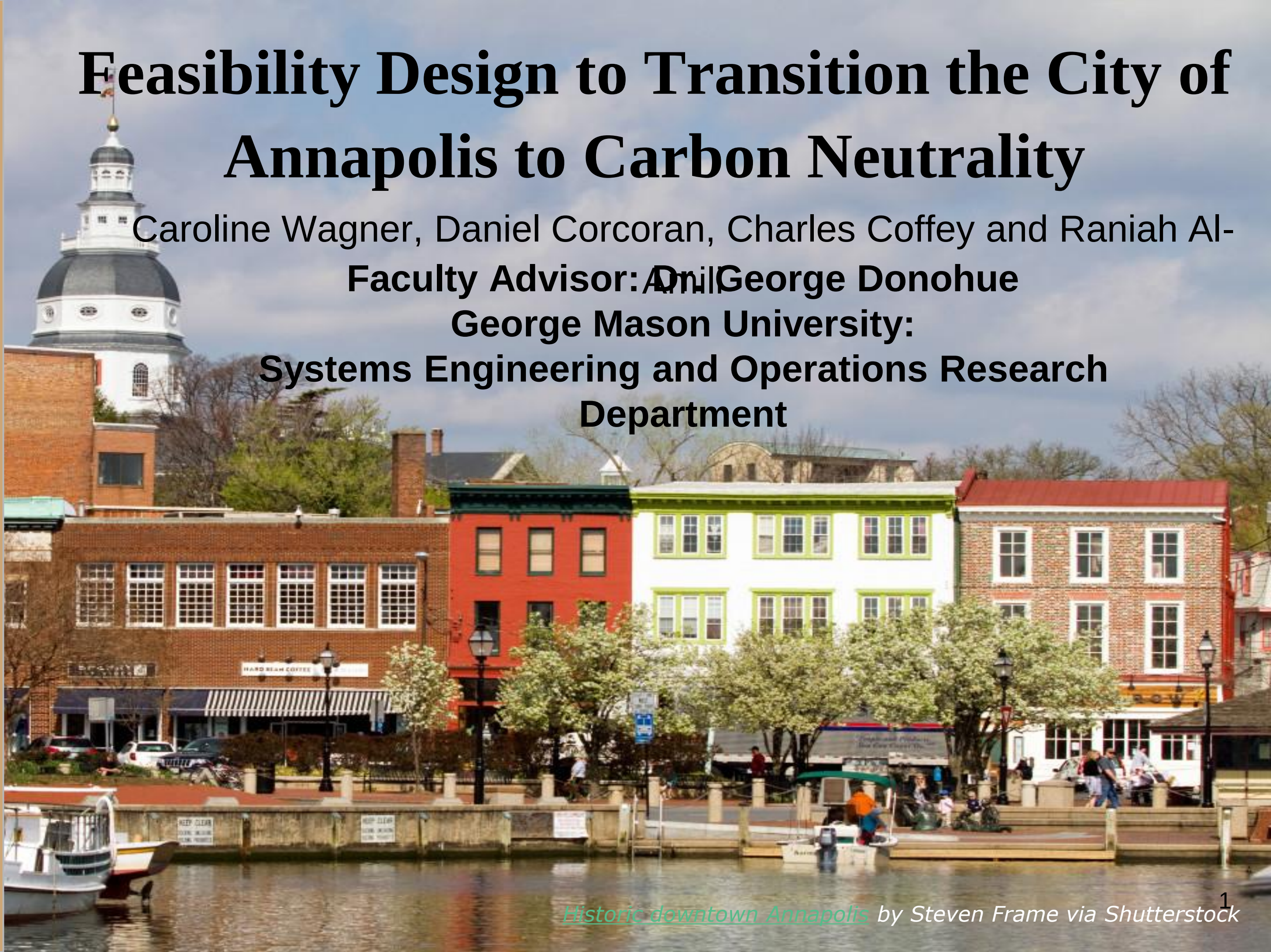
Feasibility Design to Transition the City of Annapolis to Carbon Neutrality

Caroline Wagner, Daniel Corcoran, Charles Coffey and Raniah Al-Amili

Faculty Advisor: Dr. George Donohue

George Mason University:

Systems Engineering and Operations Research Department



Historic downtown Annapolis by Steven Frame via Shutterstock

Agenda

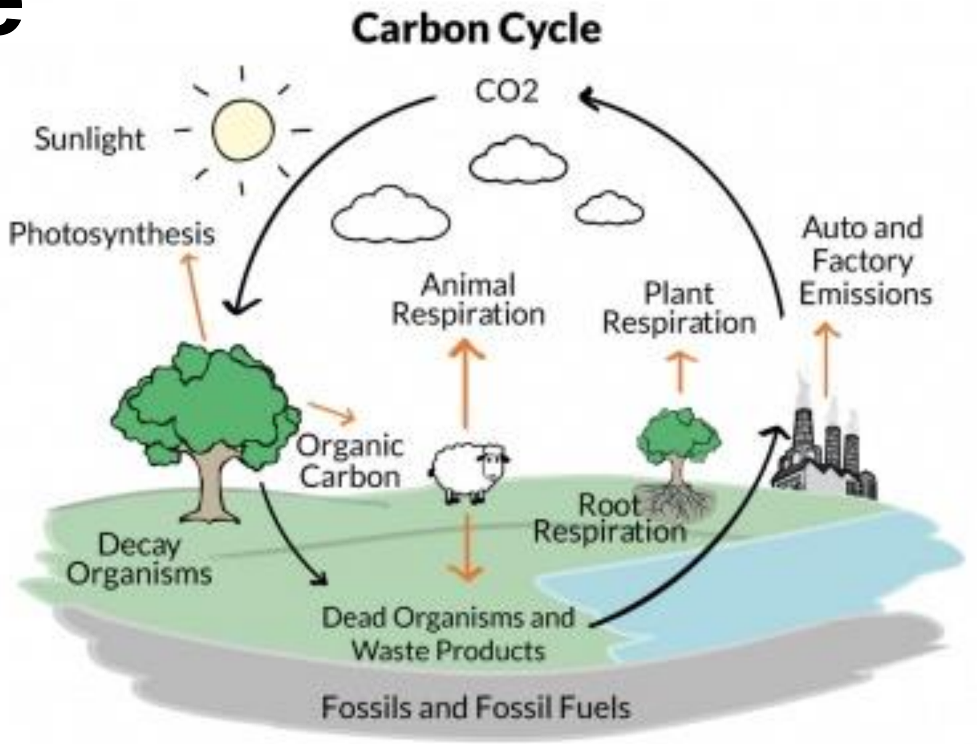
- Context
- Problem, Need, Scope
- Stakeholders
- Requirements
- Utility Function
- Design Alternatives
- Architecture
- Models & Simulation
- Utility vs. Cost
- Preliminary Observations

The Energy Grid is like a Bank...

- Energy flow is like a cash flow
- You want to have more stored than you are using
- When you don't have enough, you take out a "loan"
- When you have more than enough, you can "bank" the excess
- A consistent energy supply can be thought of as a financial problem instead of an electrical one
- How much carbon neutral (CN) energy am I producing? How much energy do I need to "spend"? Do I have any in my "bank"? Do I need to acquire some extra from another party?

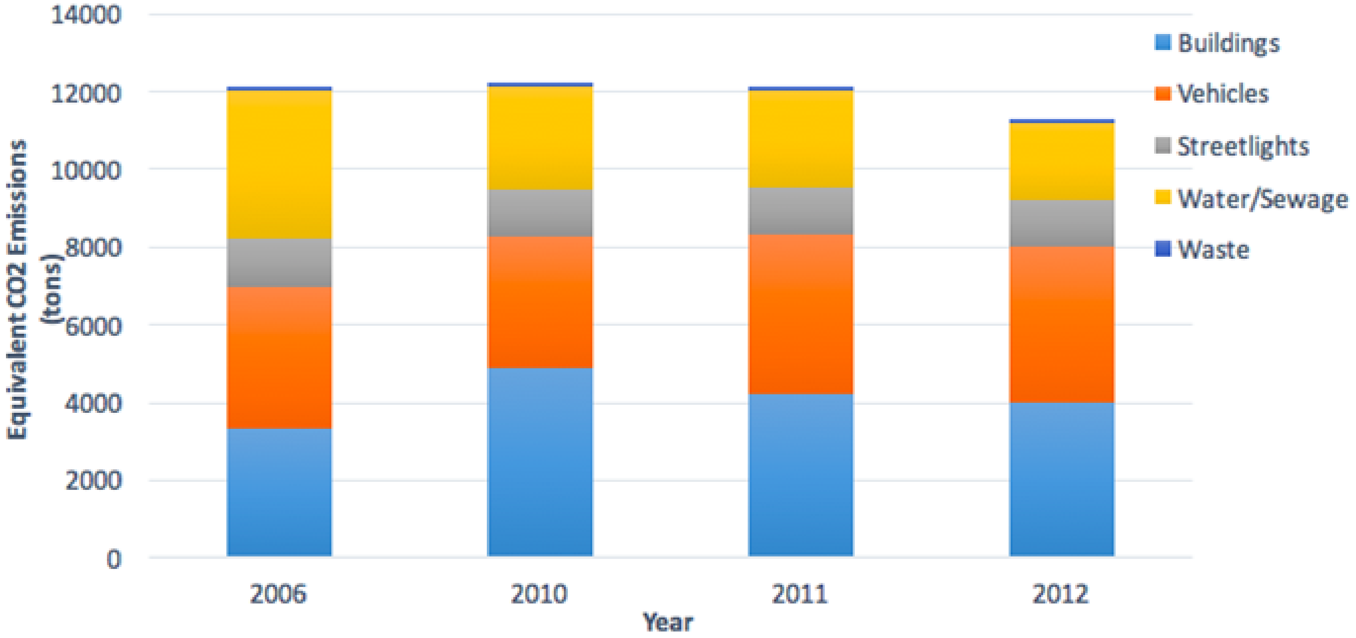
Carbon Dioxide

- CO_2 is emitted into to the atmosphere by burning fossil fuels, solid waste, trees and wood products, and by certain chemical reactions
- CO_2 emissions account for **81% of Greenhouse gasses** emitted in 2016
- "CO_2 emissions cause increases in atmospheric concentrations of CO_2 that will last thousands of years" - EPA



Environmental Protection Agency

Annapolis Government's CO_2 Emissions '06-'12

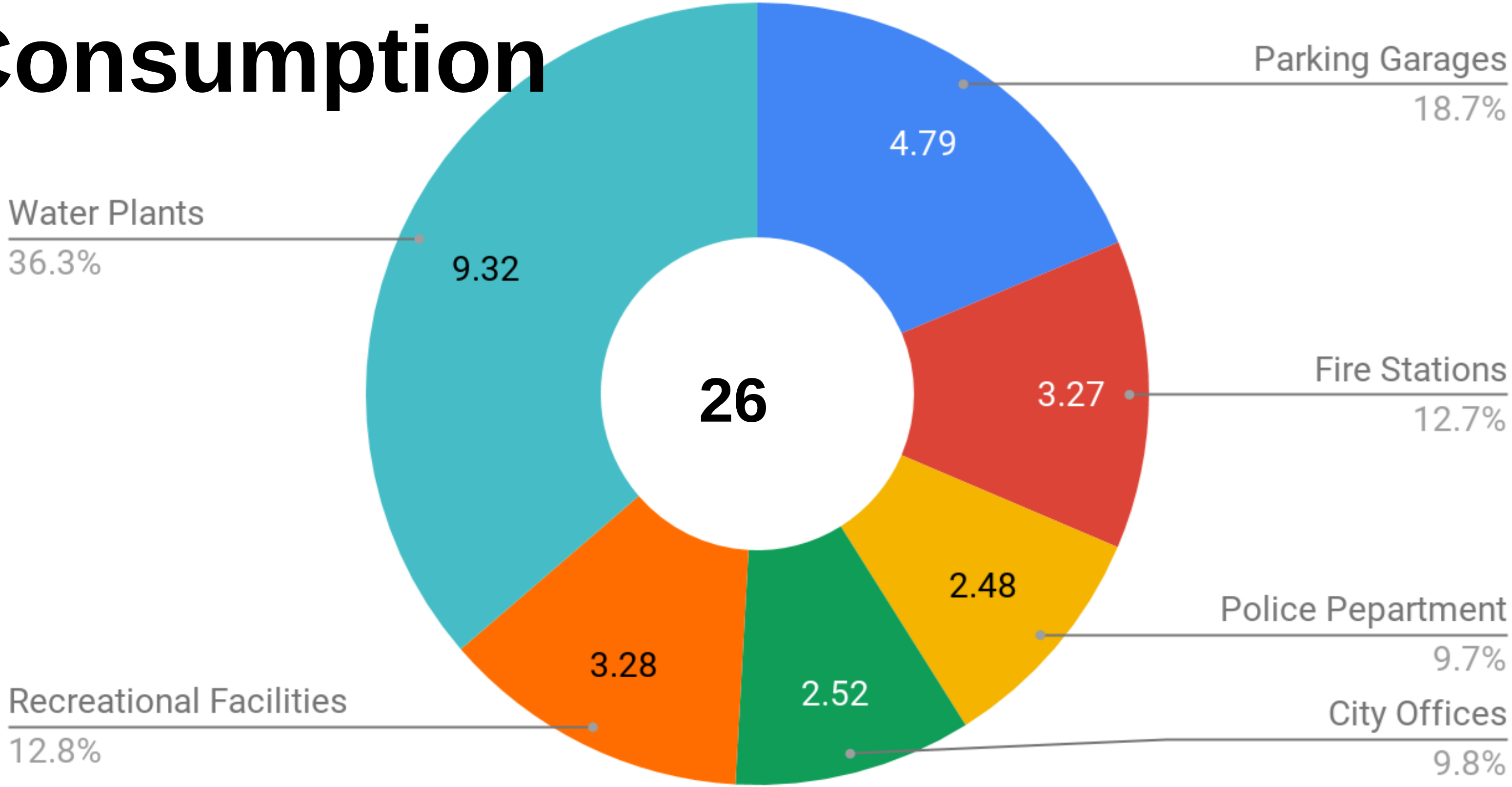


Data from *2012 Sustainable Annapolis Annual Report*

2012 Annapolis Sustainability Initiative

- **Goal:** Coordinate efforts to become a sustainable, and carbon neutral city.
    - Reduce government CO_2 emissions by **75% by the year 2025**
    - **Become 100% carbon neutral by 2050**
- Building emissions **increased by 22%** from 2006-2012 because of new infrastructure
- Vehicle Fleet emissions **increased by 9%**
- Water/ Sewage emissions **decreased by 43%**
- Streetlights and Waste emissions remained constant

2017 Annapolis Buildings Daily Consumption (MWh)

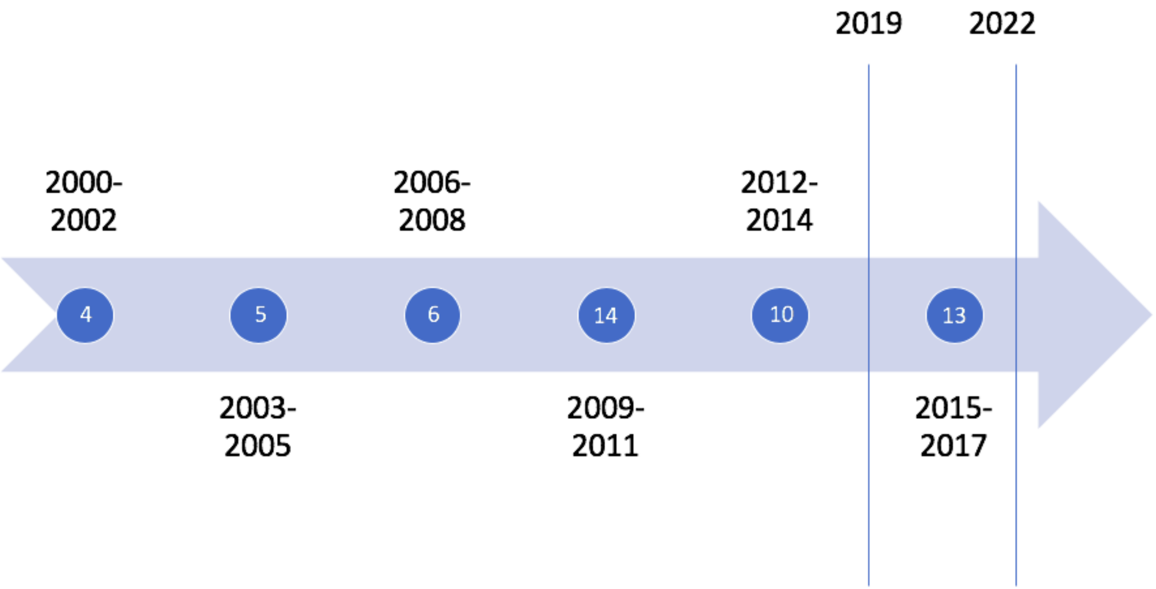


Data from the Annapolis Government

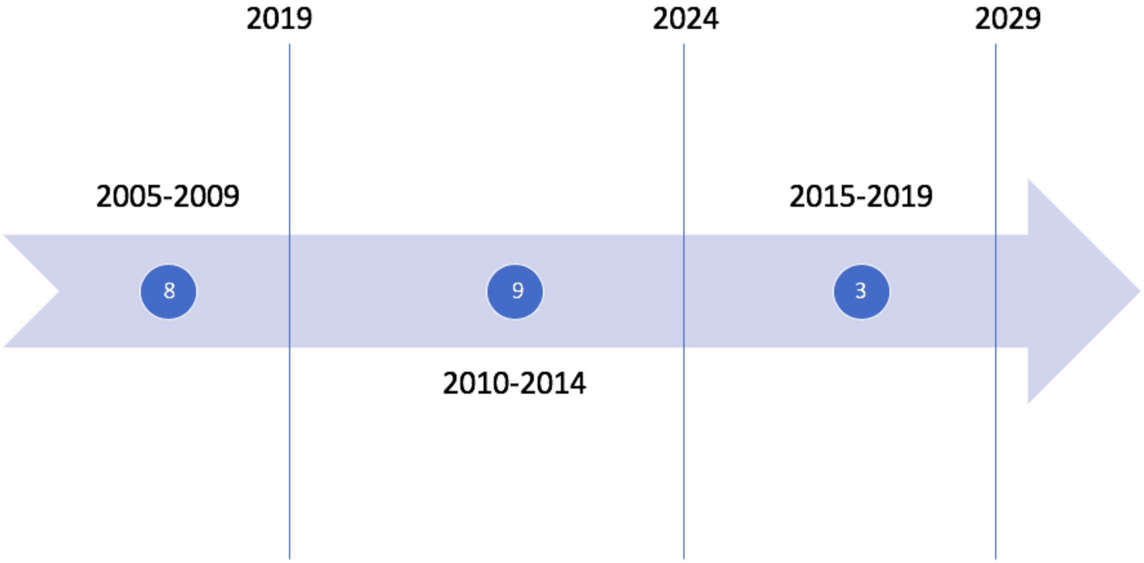
Annapolis Government Vehicle Fleet

- **83 Police Vehicles**
  - **2 Motorcycles**
  - **6 Vans**
  - **23 SUVs/Pickups**
  - **50 Sedans**
  - **1 Utility Body Truck**
- **60 Fire Vehicles - No Electric Alternative Currently**
- **20 Transit Busses**
- **147 Other Vehicles (Public Works)**
  - **Primarily utility trucks - Some Electric Alternatives Available**
- **Will require an additional 5-8 MW to charge electric vehicles**

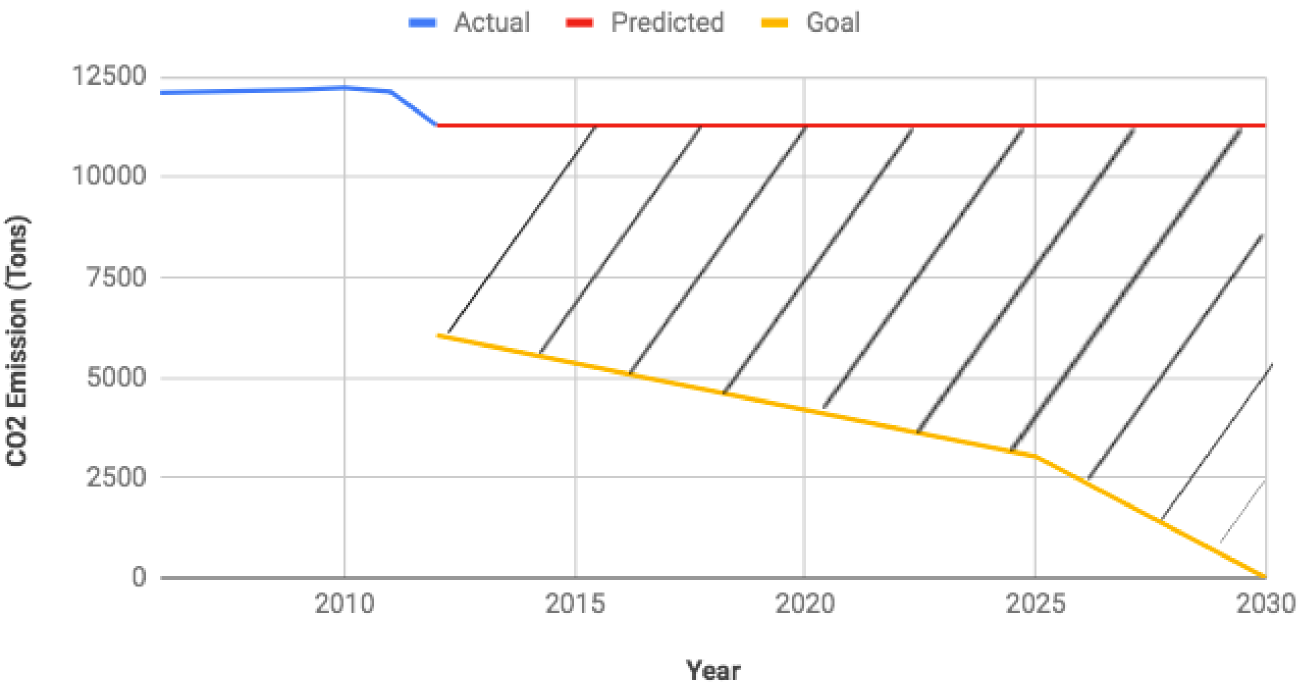
Vehicles and Motorcycles Retirement Timeline



Busses Retirement Timeline



Annapolis Government Gap Analysis



Problem Statement

The city of Annapolis produces approximately 500,000 tons of CO_2 emissions annually. The Annapolis Government produces approximately **11,000 tons of CO_2 emissions annually.** The goal is to transition **all city facilities and certain vehicles** to run on carbon neutral energy in an effort to reduce the city's impact on climate change within 12 years (IPCC Goal).

Image by *Consultancy.UK news*

Statement of Need

As CO_2 emissions are rising and the climate changes worldwide, citizens and governments are starting to make changes to reduce pollutants. Annapolis, MD has taken an interest in making their city facilities and certain vehicles carbon neutral. George Mason University must design a system that would make the Annapolis city facilities operate on carbon neutral energy supply that produces 75% reduction of CO_2 emissions by 2025, and at least 85% reduction by 2030.

Statement of Work

The project team Shall Answer the Following Questions:

1. Is it feasible to achieve carbon neutrality by 2030?

2. Can we purchase the energy and from whom and at what price?

3. What elements of city owned energy consumers can we transition to renewable?

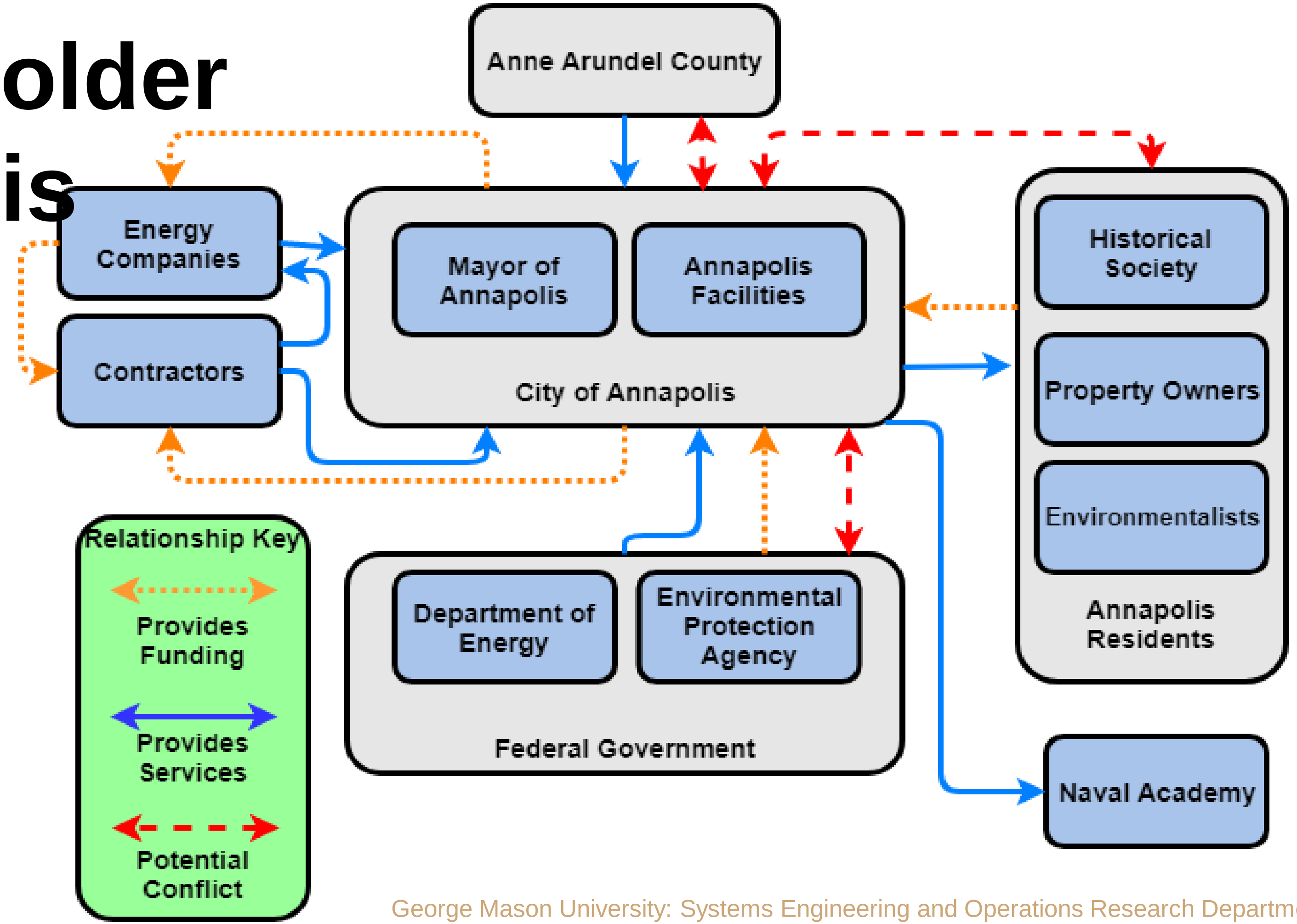
4. What order should the phased in transition take and what will be the cash flow requirements? Will we save money over time or will it cost us more?

5. How much does the existing solar farm supply of our total electric needs?

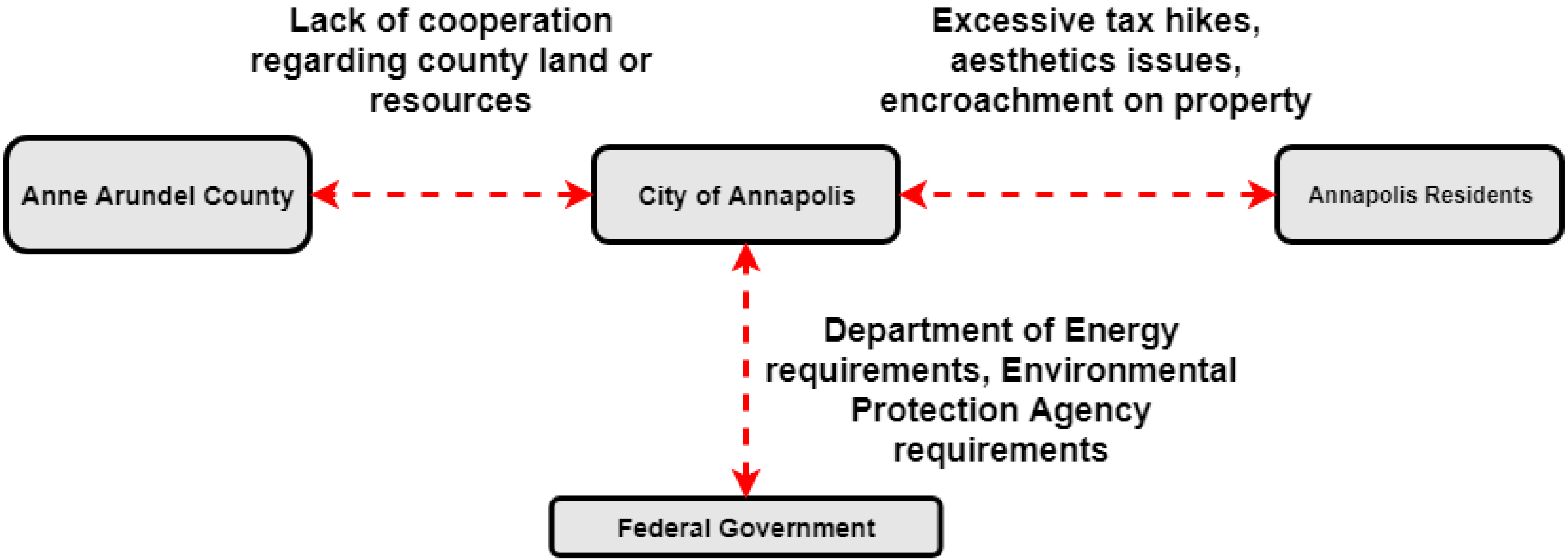
Scope Statement

The project team will develop a feasibility design for the Annapolis City facilities and select vehicles to be powered by carbon neutral energy. The design will discuss the costs and benefits of carbon neutral power supply types and CO_2 reduction strategies to ensure the city government will reach carbon neutrality.

Stakeholder Analysis



Potential Stakeholder Tensions



Mission Requirements

MR.1 The system shall **generate** and transmit enough power to run the Annapolis city facilities (approx. 30 MW/h or 35 MW/h if vehicles included).

MR.2 The system shall **reduce** the carbon footprint generated by the city of Annapolis facilities.

MR.3 The system shall be completed within the **schedule set** by the government of Annapolis but also by the IPCC goal of 2030.

MR.4 The system shall **offset environmental damage** due to construction with materials that are suitable for developing local ecology.

Functional Requirements

FR.1 The system shall consist of **100%** carbon neutral energy options.

FR.2 The system shall maintain the same or higher **level of reliability** as the current power generation methods.

FR.3 The system shall **interface** with the current electric infrastructure in Annapolis.

FR.4 The system shall be able to **operate indefinitely** by utilizing replaceable components.

Design Requirements

DR.1 The system shall **not interfere** with shipping, naval, or other critical marine operations around the city of Annapolis or in the Chesapeake Bay

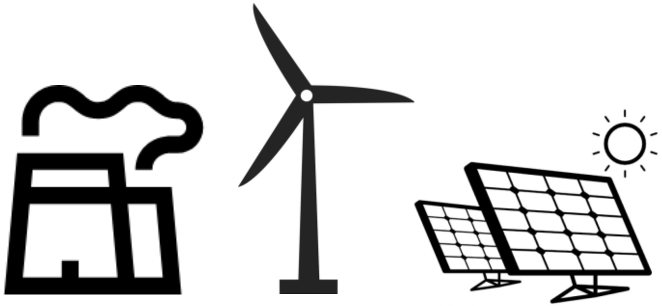
DR.2 The system shall fall within the **budgetary restrictions** set by the government of Annapolis.

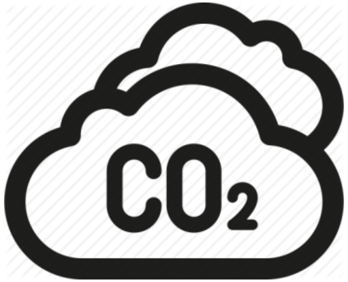
DR.3 The system shall replace select vehicles with **electric vehicles**.

DR.4 The system shall not increase **taxes on residents**.

Utility Function

$$\frac{\text{Carbon Neutral Power Generated}}{\text{Total Power Needed}} \times 0.5 + \frac{CO_2 \text{ Reduction}}{\text{Original } CO_2 \text{ Level}} \times 0.5 = \textbf{Utility}$$





Feasible Types of Carbon-Neutral Energy

SOLAR

WIND

NUCLEAR

Land Required for Wind Farm

- The required size would be around **2,000 acres to produce 35 MW** based on existing local wind farms (Based on Dominion Power estimate)
- The largest available land within 70 miles is 270 acres, with the potential to generate 5 MW
- The additional 30 MW may be generated using different sources

Solar Trees

- **Solar trees may be installed on the top deck of parking garages to ensure maximum sun exposure.**
- **Solar trees are an important symbol of the city's *Commitment***

Land Required for Solar Farms

- In order to generate 35 MW of electricity, an estimated **230 acres** is required based on local solar farms

- The radius for the farm from Annapolis is assumed to be 50-70 miles

Why Nuclear Power Must be Included

- **Bridges the gap between non-carbon producing energy and reliable energy production**
- **Ensures power needs will be met**
- **Weather conditions do not affect the nuclear generation process (in a properly designed reactor unit)**
- **Single pebble sized pellet c**
    - **1,780 pounds of coal**
    - **149 gallons of fuel oil**
    - **17,000 cubic feet of natural gas**

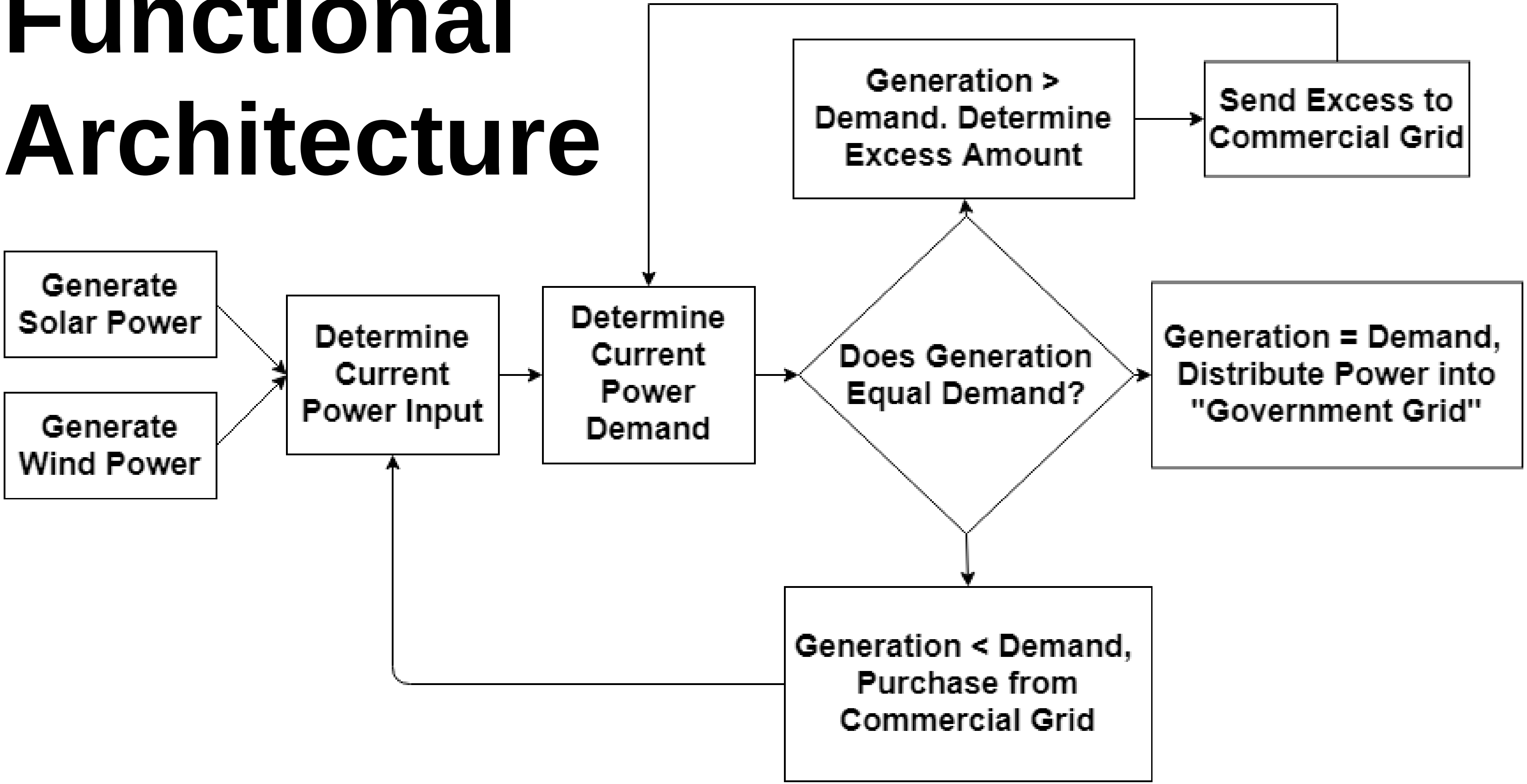
Purchased Power

- If total generated power < power demand, gap must be met by purchasing power
- Carbon neutral sources include Conowingo Dam, Muddy Run pumped storage, Calvert Cliffs nuclear plant

CO_2 Produced

- Includes all carbon production from system operation
- Construction of new facilities will incur a “one time” carbon cost, but the facilities will prevent the recurring carbon costs.

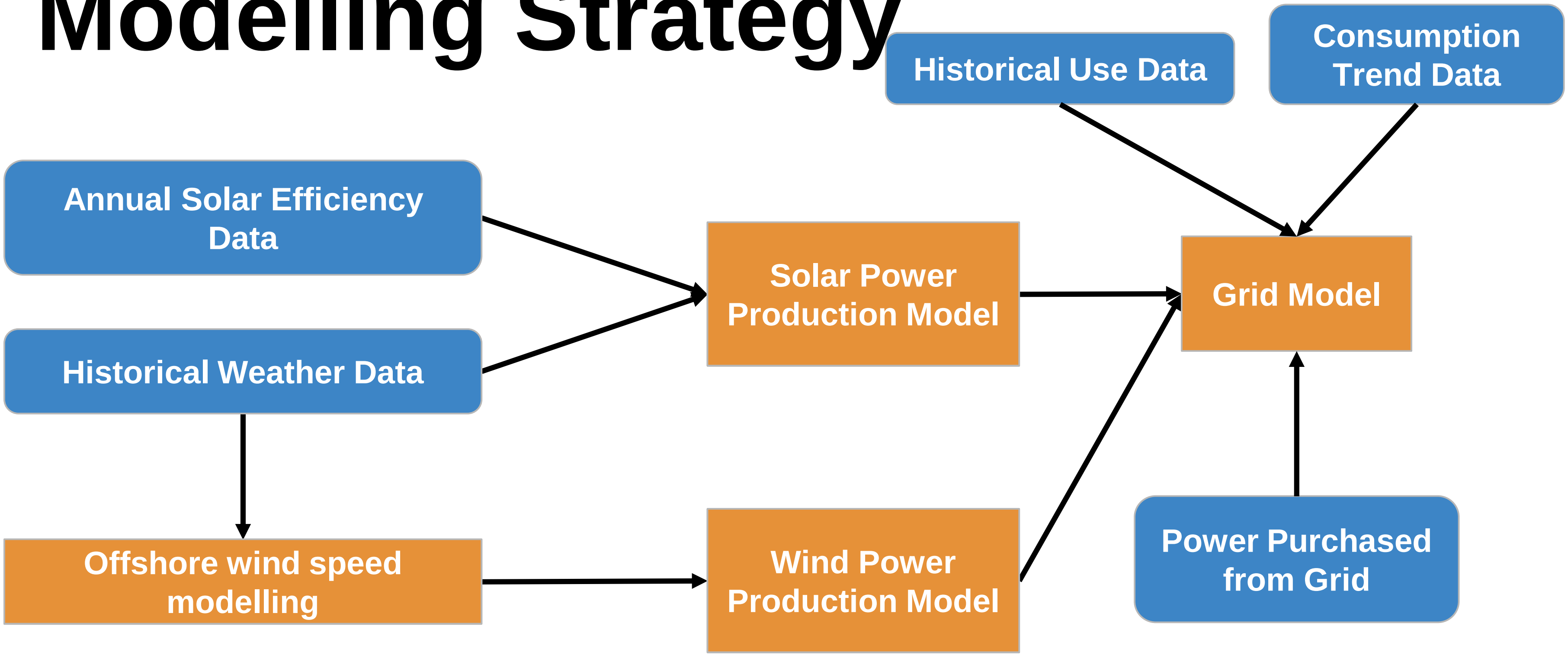
Functional Architecture



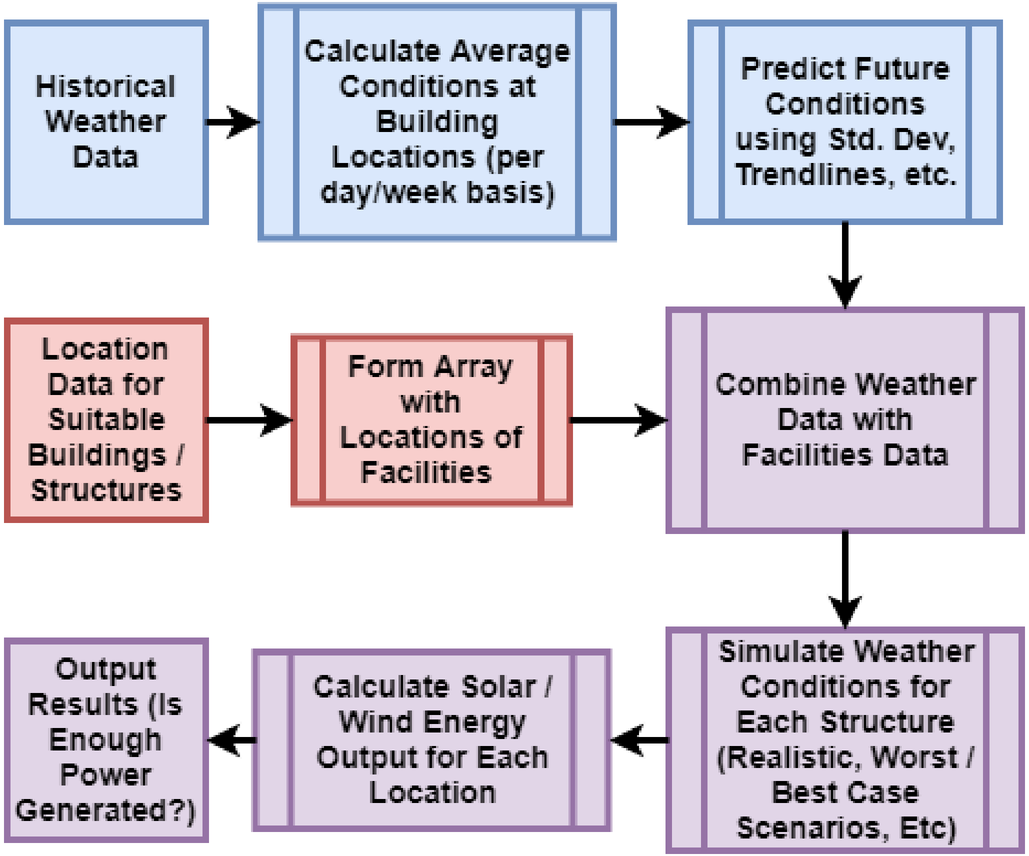
Physical Architecture

- Power generated from solar farm, localized panels, and wind farm Power Purchase Agreement (PPA)
- When needed, excess power purchased from grid
    - Available from Constellation
    - Power generated from Calvert Cliffs or other carbon neutral sources
    - Reduces cost to city government - Constellation builds facilities / enters PPA
- Power flows over common lines to city buildings
    - Flow is regulated to match the power draw of city buildings
    - Excess power is sold back into grid
    - “Profits” can be used when purchasing power back

Modelling Strategy



Modelling Strategy - Wind and Solar



Evaluation Procedure

Formulas:

- Models based on physical formulas
- Include site/efficiency variables that vary by product

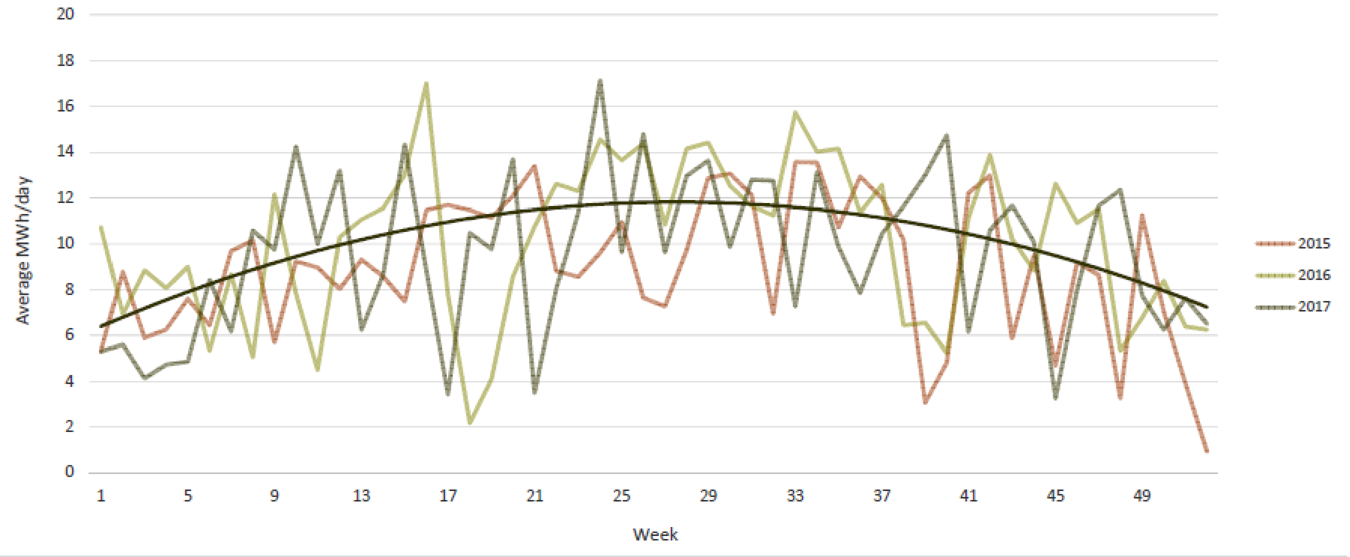
Evaluation:

- Solar compared to NREL PV Calculator
- Wind compared to estimated yearly output of an industrial windmill
  - No local sites to compare to

Alternatives Evaluation:

- Data from the model is used in the alternatives analysis

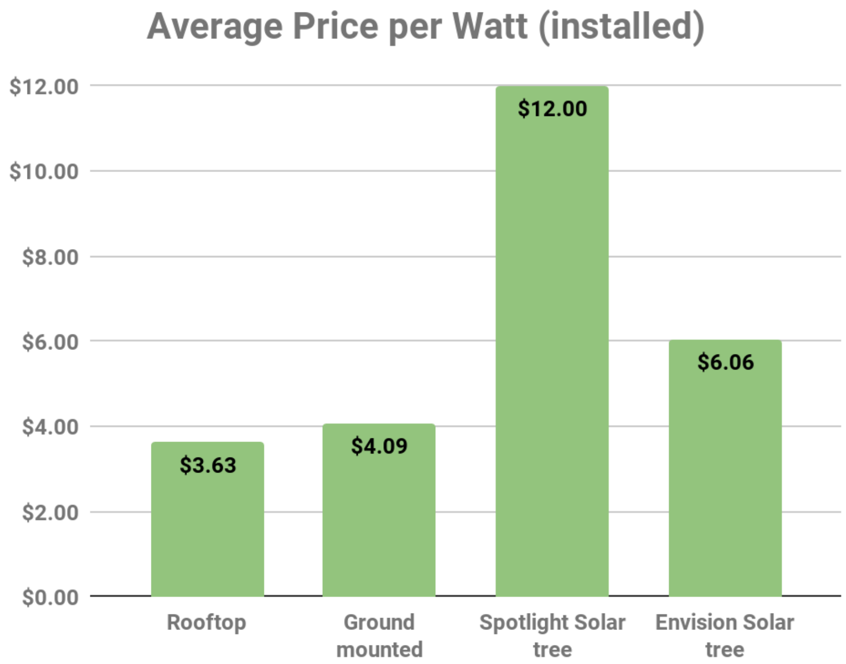
Results: Weekly Average MWh/ Day

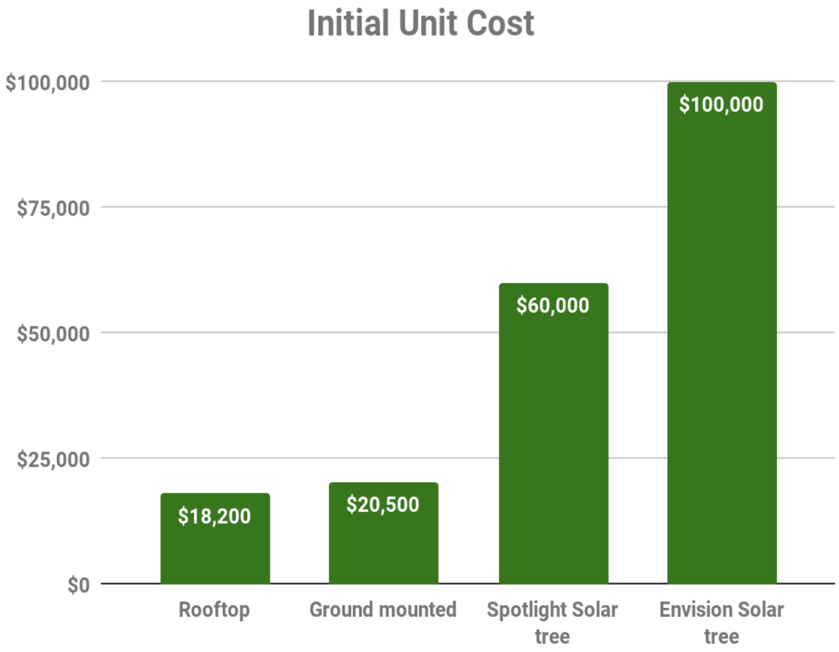


Both wind and solar farms have a **minimum weekly output over the course of a year near 0 kWh,** meaning that nuclear will need to be part of the solution

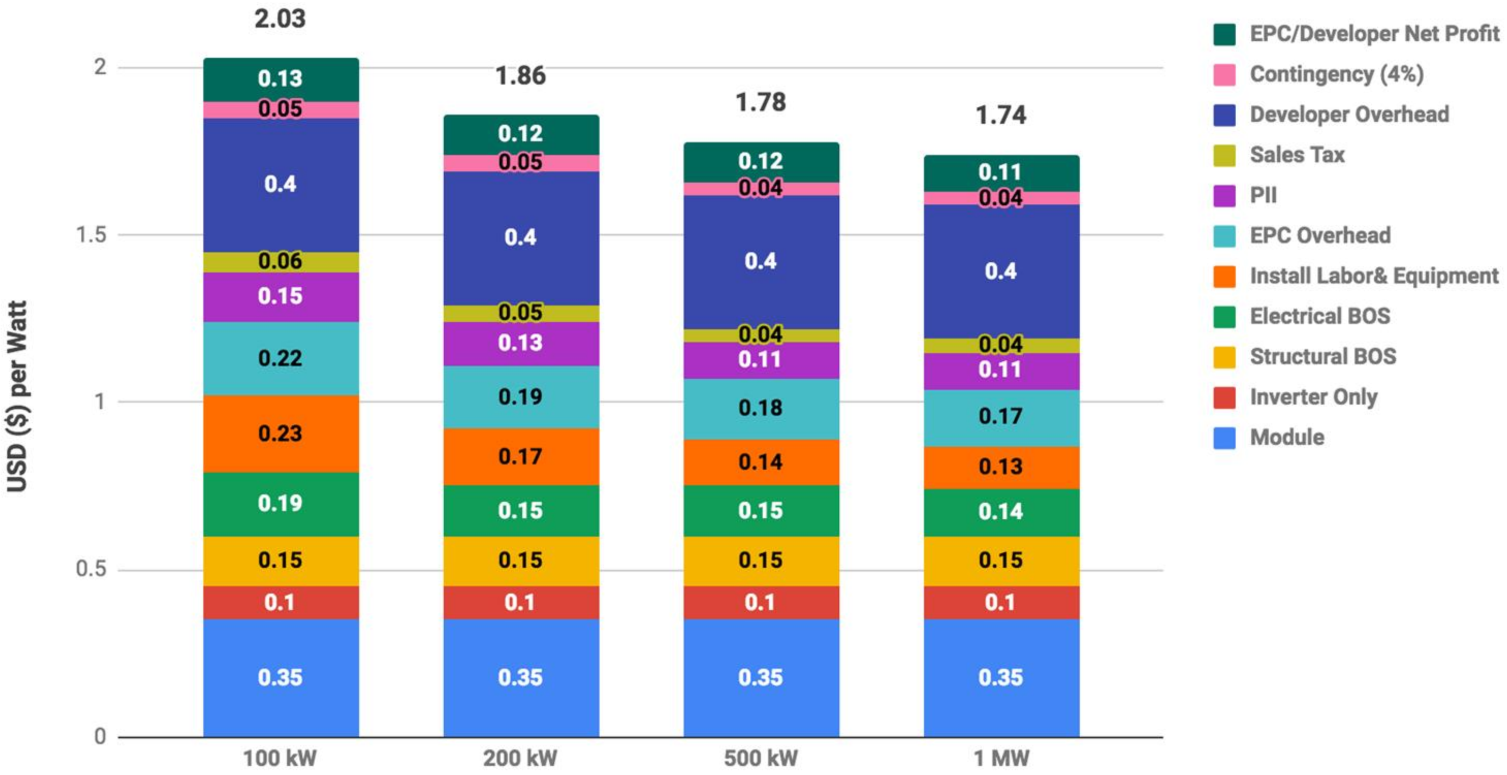
Small Scale Solar Panel Cost

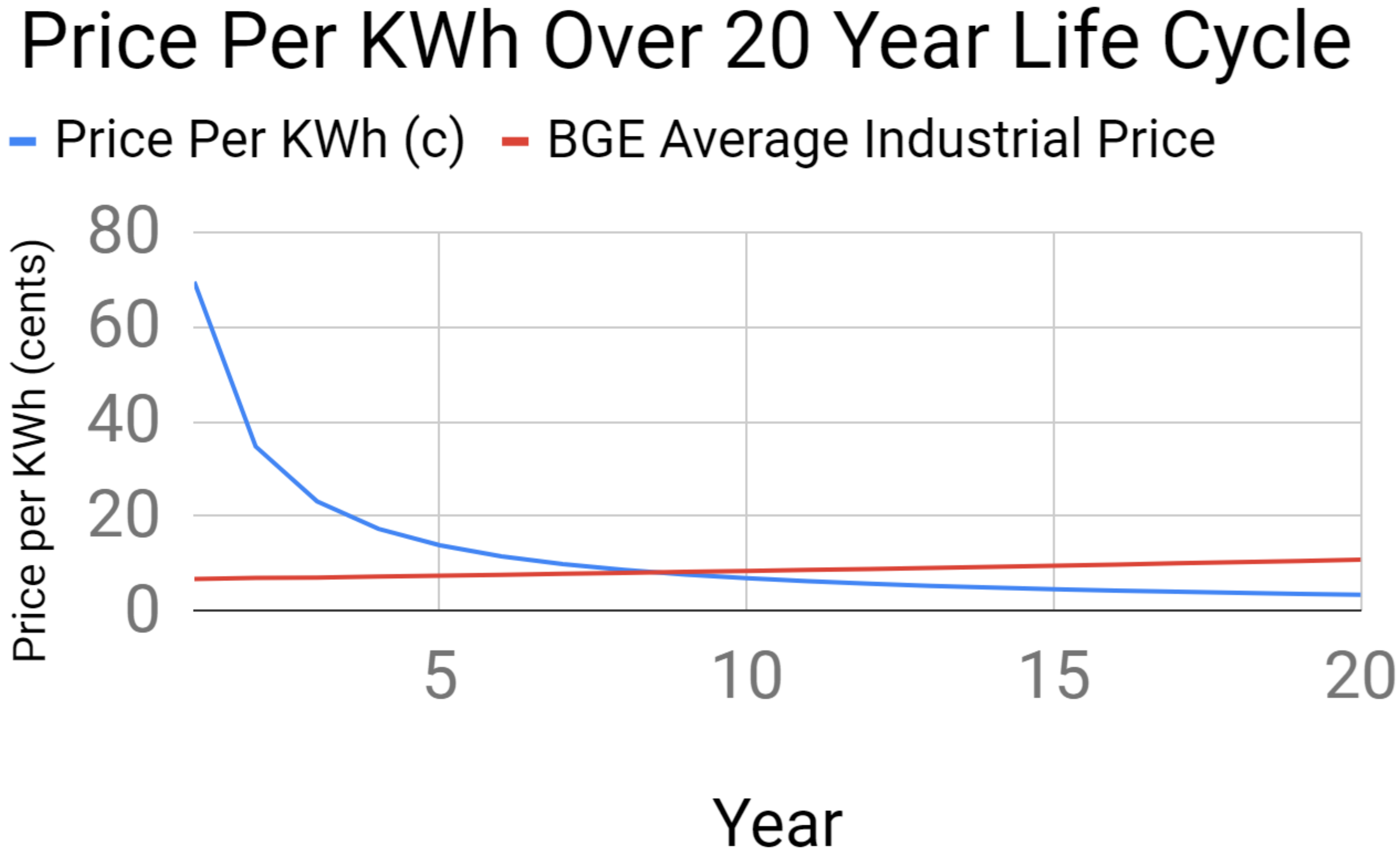
As of mid-2017, the average price for solar panels in Annapolis was $3.20 per watt (installed).





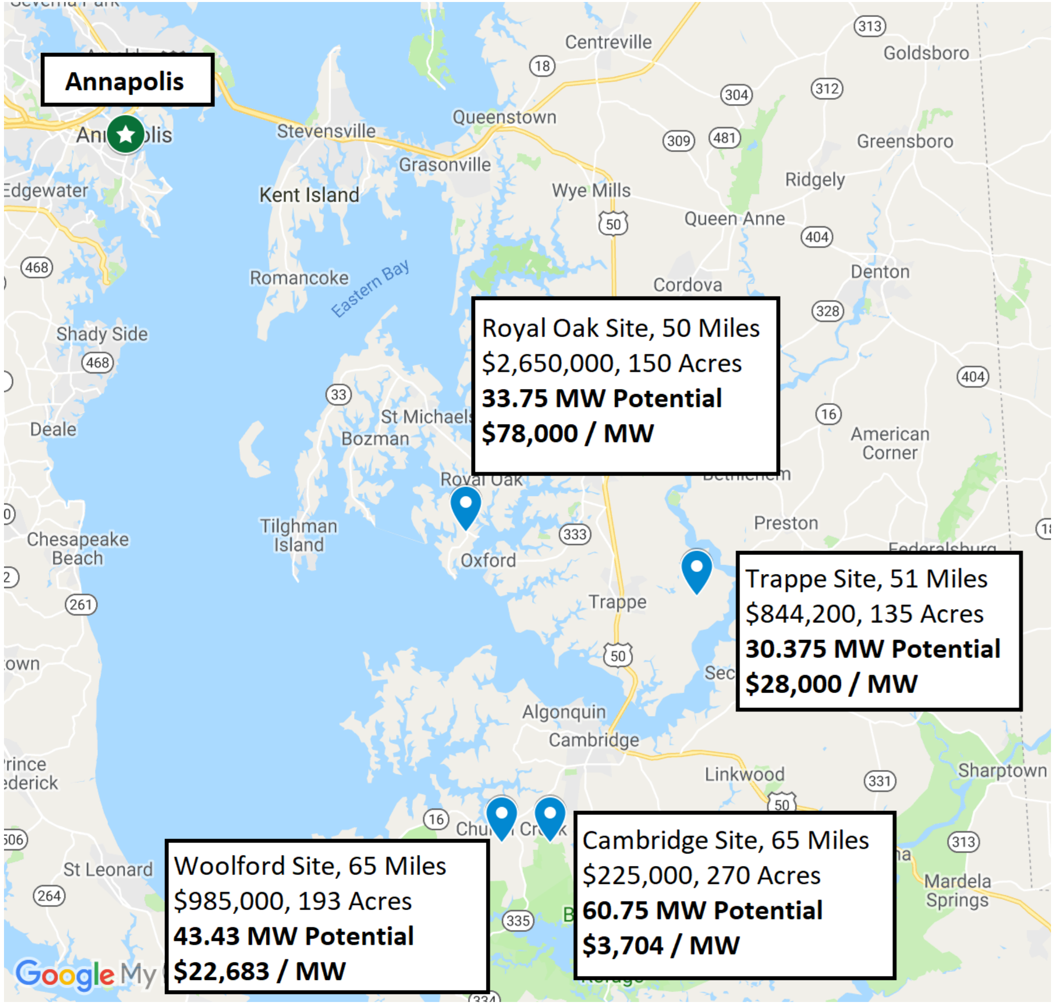
2017 NREL Photovoltaic System Cost




Price Per KWh Over 20 Year Life Cycle
Price Per KWh (c)
BGE Average Industrial Price
Price per KWh (cents)
80
60
40
20
0
5
10
15
20
Year

Future Solar Farms

- Cambridge Site is most ideal, highest potential with lowest cost
- All sites undeveloped, development cost not included
- All sites would be part of Power Purchase Agreement



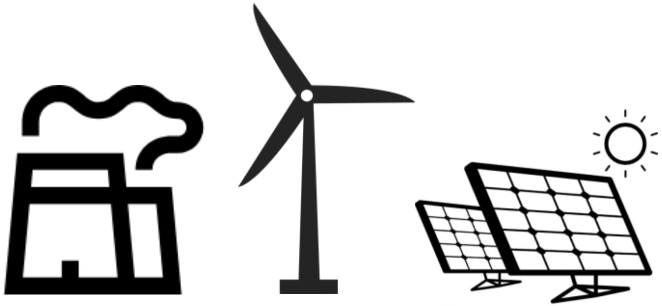
PHASING Options to Consider

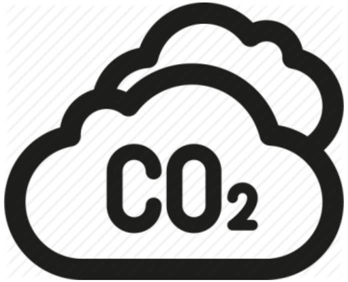
- A. Power for All City Buildings & Street Lights: 5,000 tons CO_2/yr @ 13MWH
- B. Replace Selected City Owned Vehicles: 900 tons CO_2/yr @ 0 MWH
- C. Power for Water & Sewage Plant: 2,000 tons/yr @ 9MWH
- D. Power for All Systems, Replace All Eligible Vehicles: 7,900 tons/yr @ 35MWH
- E. Do nothing

- MWH are on a daily basis
- + At an Est Carbon Tax rate of $40/ton = $440,000/yr societal cost which are NOT CURRENTLY BEING PAID!

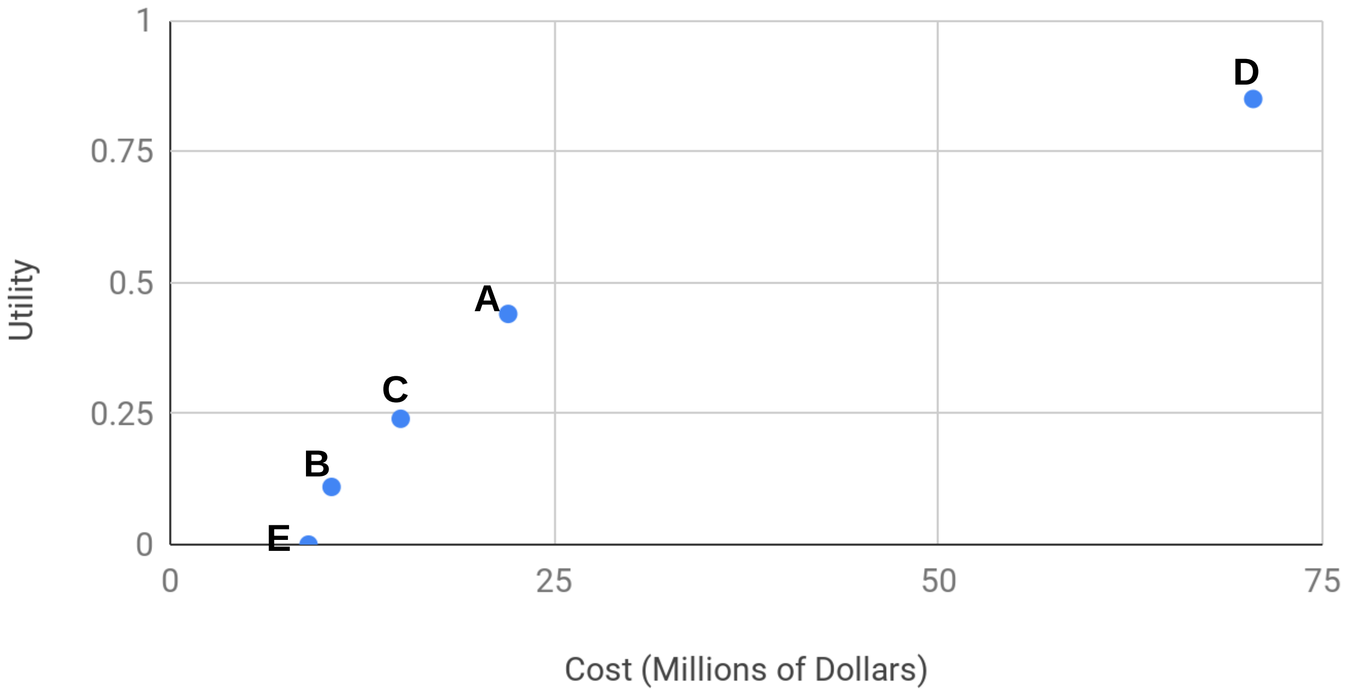
Utility Function

$$\frac{\text{Carbon Neutral Power Generated}}{\text{Total Power Needed}} \times 0.5 + \frac{CO_2 \text{ Reduction}}{\text{Original } CO_2 \text{ Level}} \times 0.5 = \text{Utility}$$





Cost Utility Analysis of Proposed Alternatives



Implementation Strategy

PHASE 1:	PHASE 2:	PHASE 3:	PHASE 4:
1 YEAR	2 YEARS	5 YEARS	20 YEARS
• Begin PPA Process • Install Solar Panels on Roofs and Parking Garages • Replace Decommissioned Vehicles with Electric Vehicles • Install Electric Vehicle Charging Stations	• Power Structure is Operating • Replace Most Vehicles with Electric Vehicles	• Reassess Power Demands and Make Necessary Changes to Power Structure • Reassess Vehicles and Purchase Replacements	• Finalize All Payments • Replace components of the power structure

Preliminary Analysis Observations

- Calculations are close to expected ranges
- 7 day low of solar power is consistently near 0 at all locations, indicating need for supplementation
- Annapolis is theoretically receiving 4 MWh/day from the Annapolis Solar Park
- Wind farm scale is out of the scope of something that Annapolis should consider doing alone
- Feasible to Achieve 2030 Goal - with the exception of carbon emissions from fire trucks/construction trucks (The tech will probably exist by 2030)

Statement of Work

The project team Shall Answer the Following Questions:

1. Is it feasible to achieve carbon neutrality by 2030? Yes

2. Can we purchase the energy and from whom and at what price? Yes

BGE/Constellation @< $0.07/kwh

3. What elements of city owned energy consumers can we transition to renewable? Buildings, Vehicles, Water Treatment

4. What order should the phases in transition take and what will be the cash flow requirements? Will we save money over time or will it cost us more? Begin with local changes in Annapolis, then expand to larger projects. If a carbon tax is imposed, each alternative becomes more financially viable.

5. How much does the existing solar farm supply of our total electric needs? 4 MW/day in ideal conditions providing 16% of the yearly energy supply.

Questions?