Overview of EPA tools for supporting local-, state- and regional-level decision makers addressing energy and environmental issues

NYC MARKAL Energy Systems Model
Municipal Solid Waste Decision Support Tool

Ozge Kaplan, Ph.D.
Mine Isik, Ph.D.
U.S. Environmental Protection Agency



Integrated Energy-Water Modeling at the Community Scale using the MARKAL Modeling Framework

Ozge Kaplan, Ph.D.
Mine Isik, Ph.D.
U.S. Environmental Protection Agency

Audience

This presentation is prepared for

2017 Southeastern Environmental Conference

Orange Beach, AL, October 30, 2017 - November 1, 2017

Disclaimer

The views expressed in this presentation are those of the authors and do not necessarily represent the views or policies of the U.S. Environmental Protection Agency.

Goals

- Develop a tool to address long-term planning questions and issues related to sustainability, resilience, equity and growth in the energy and water sector:
  - Urban heat island mitigation through peak load shaving
  - Building energy and water technology evaluations
  - Micro grid and distributed energy applications
  - Resilience to sea level rise and storm surge
  - Energy and water infrastructure planning
- NYC is selected for the immense availability of data required for energy-water nexus modeling, for being an early adopter of GHG reduction goals, and for the awareness of vulnerabilities to climate change and ongoing activities in resilience efforts.

Current and Future Partnerships

- EPA Office of Research and Development partnering with EPA Regional Office and City University of New York to bring and integrate unique perspectives on short-term and long-term issues within the energy-water nexus
    - What would water demand and wastewater generation be during peak electricity loads
    - What are the drivers? Behavior, urban morphology, weather?
    - How can we mitigate intense rainstorms without overwhelming wastewater infrastructure?
    - How can we decrease risk of grid failure at peak load?
- In the future, we would like to develop further partnerships with regions to conduct case studies and applications based on immediate needs

History and current research agenda

- What is Energy Modeling? How can it be used?
- MARKAL (MARKet ALlocation) energy systems modeling framework
- EPAUS9r and EPANYC5r MARKAL databases
- Energy and water modeling in the EPANYC5r database
- Preliminary energy and water calibration results
- Possible outputs and case studies

United States Environmental Protection Agency

What is energy systems modeling?

- The process of building computer models of energy systems for utilization for systems operation, engineering design, and energy and environmental policy development
  - Technical and economic conditions of the energy infrastructure
  - Reports the system technology levels, air emissions, cumulative financial costs, natural resource use, and energy efficiency
  - International, regional, national, municipal, or stand-alone scope

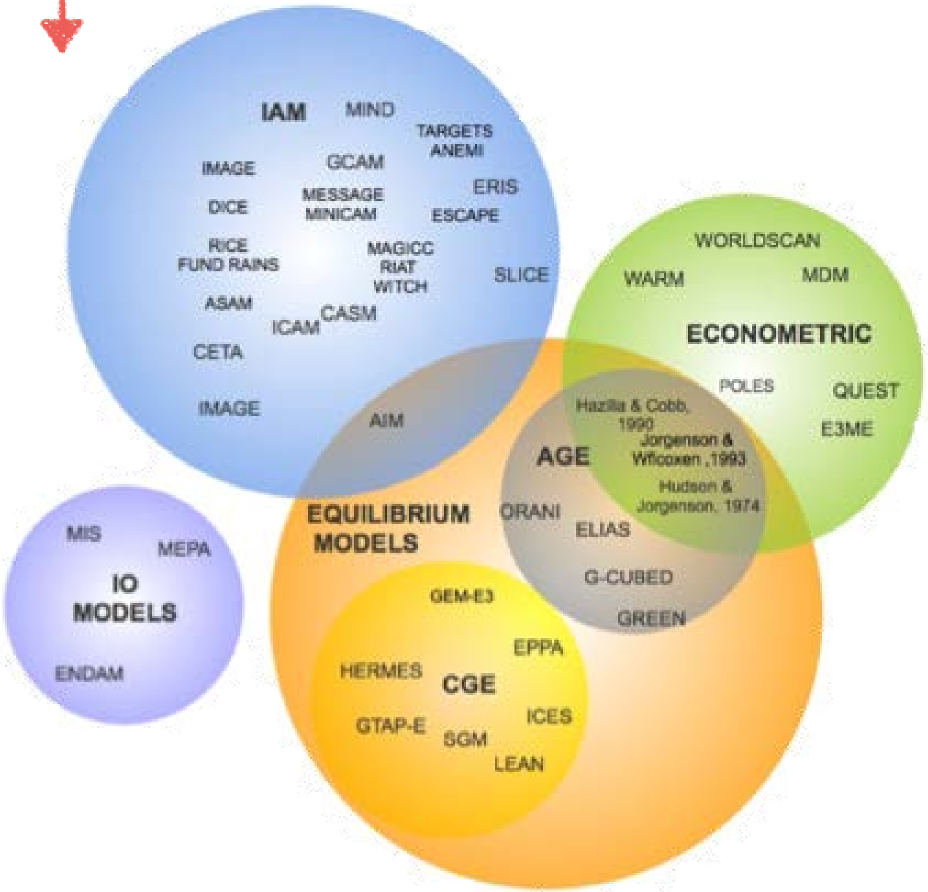
Top Down

Market equilibrium approach	Optimization approach
Higher sectoral aggregation	Better engineering / technology description
Endogenous representation of most macroeconomic parameters like prices and demand elasticities	Better for policy analysis involving impact assessment of technology and fuel mix within a sector

Bottom Up

Example models

Top Down



Bottom Up

MARKAL/TIMES History

- Developed in late 70s in Brookhaven National Laboratory (BNL) via initiation through International Energy Agency (IEA) post-oil crisis
- The Energy Technology Systems Analysis Program (ETSAP)
  - the longest running Technology Collaboration Programme of the IEA
  - facilitates continuous development and improvement of tools
  - recently stopped providing support for MARKAL
- EPA Regional MARKAL for U.S. (maintained and distributed by USEPA)
  - led to development of CA-TIMES, NESCAUM's NE-MARKAL, Ohio-MARKAL
- EPA NYC Metro MARKAL/TIMES
  - only community scale MARKAL in US

Modeling Technology Change with MARKAL

- MARKAL is a dynamic, bottom-up, large-scale, linear optimization modeling framework for energy systems

- It is designed to be deployed on a multi-period horizon to minimize the total discounted energy system cost.

- Quantities and prices of various fuels and other necessary commodities of the energy sector come to equilibrium in each period

- MARKAL can evaluate alternative future technologies

Modeling Technology Change with MARKAL

- Reference case projections of end-use energy service demands are provided by the user for each region.
  - e.g., residential lighting, commercial space heating, vehicle miles traveled in light duty transportation, steam demand in pulp and paper sector

- The user provides estimates of the existing stock of energy related technologies in all sectors in the base year, and the characteristics (i.e., capital and O&M costs, fuel efficiency) of available future technologies, future sources of primary energy supply and their potentials.

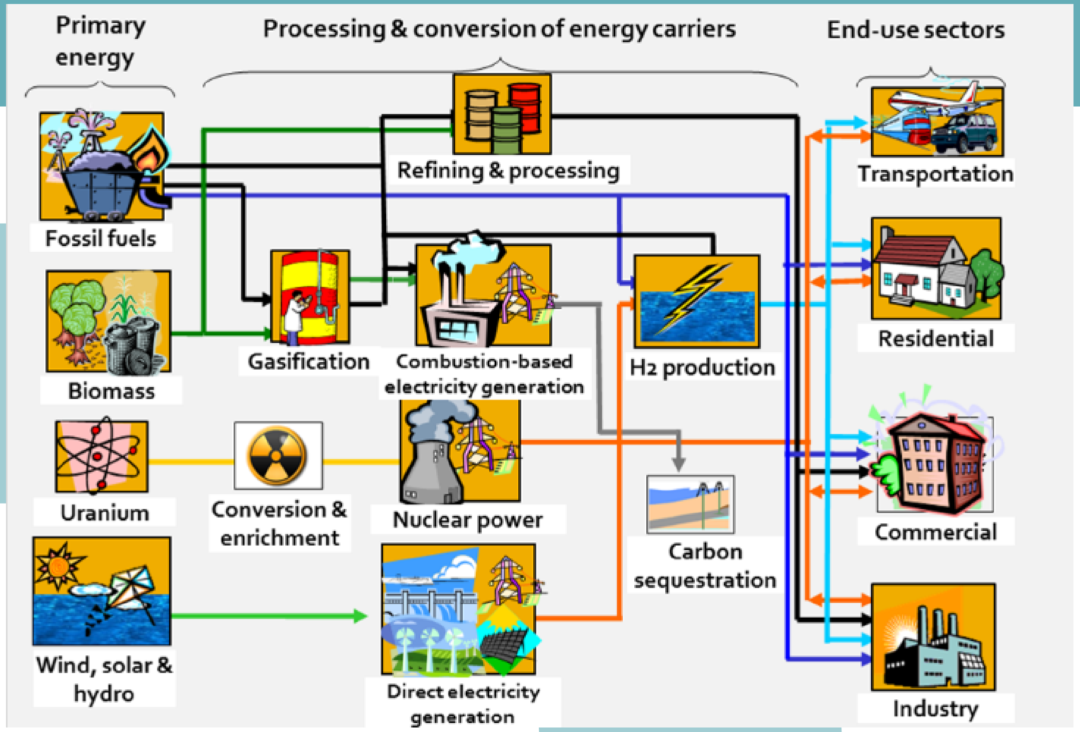
Modeling Technology Change with MARKAL Framework

Inputs:

- Future-year energy service **demands**
- Primary energy **resource supplies**
- Current & assumptions on future **technology characteristics**
- Emissions and energy **policies**

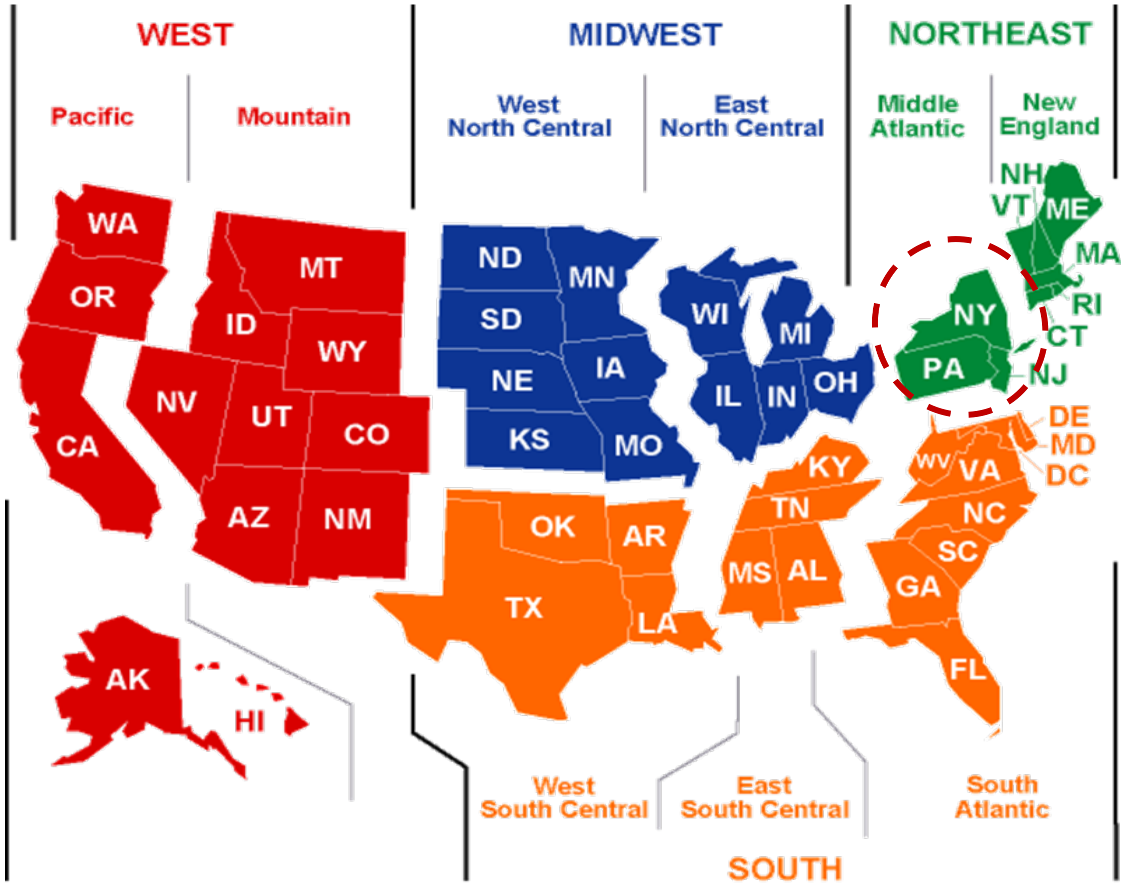
Outputs:

- **Technology penetrations** for meeting industrial, residential, commercial, and transportation end-use demands
- **Fuel use** by type and region
- Sectoral and system-wide **emissions**
  NO_x, SO_2, PM_{10}, $PM_{2.5}$, CO, VOC, CO_2, CH_4, N_2O, BC, OC, water consumption in the utilities
- Marginal fuel and emissions reduction prices



- An optimization model
  - Perfect foresight over the modeled time horizon
- Spatial resolution is the 9 US Census Divisions
- 2005 - 2055 in 5-yr time-steps
- Simplified load duration curve via 12 time-steps including seasonal day-AM, day-PM, night-time, peak

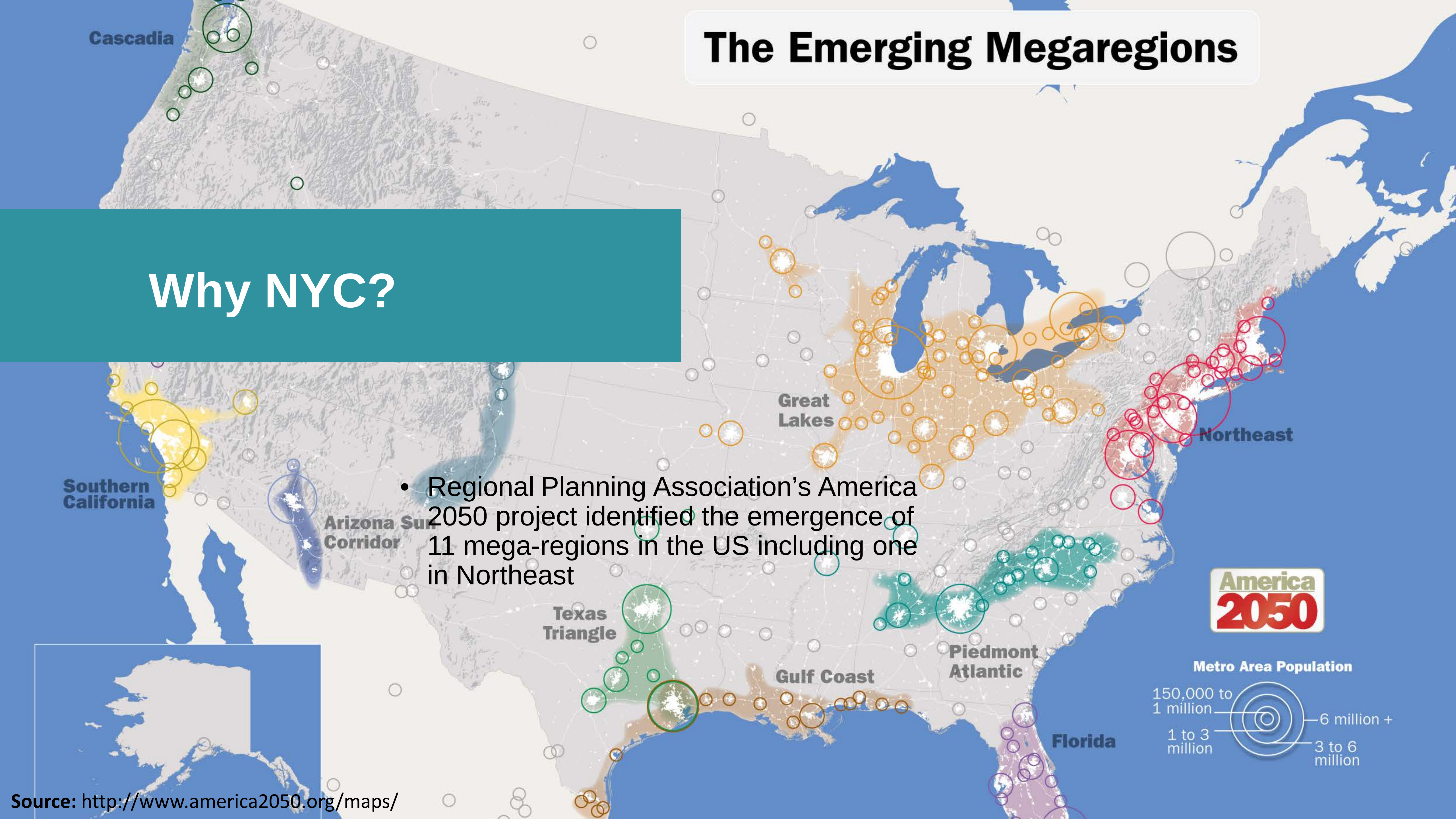
U.S. EPA MARKAL Regional Database



- **Coverage**: U.S. energy system
- **Spatial resolution**: Nine Census divisions
- **Modeling horizon**: 2005 to 2055 in five year increments
- **Sectors**: Electricity production, transportation, industrial, residential, commercial, biomass
- **Main data source:** Annual Energy Outlook (2016)
- **Pollutants**: NO_x, SO_2, PM_{10}, $PM_{2.5}$, CO, VOC, CO_2, CH_4, N_2O, BC, OC, water use for electricity generation
- **Maintenance:** Updated and calibrated to Annual Energy Outlook every two years; housed at EPA/ORD; publicly available; currently 2016 version is available

Why NYC?

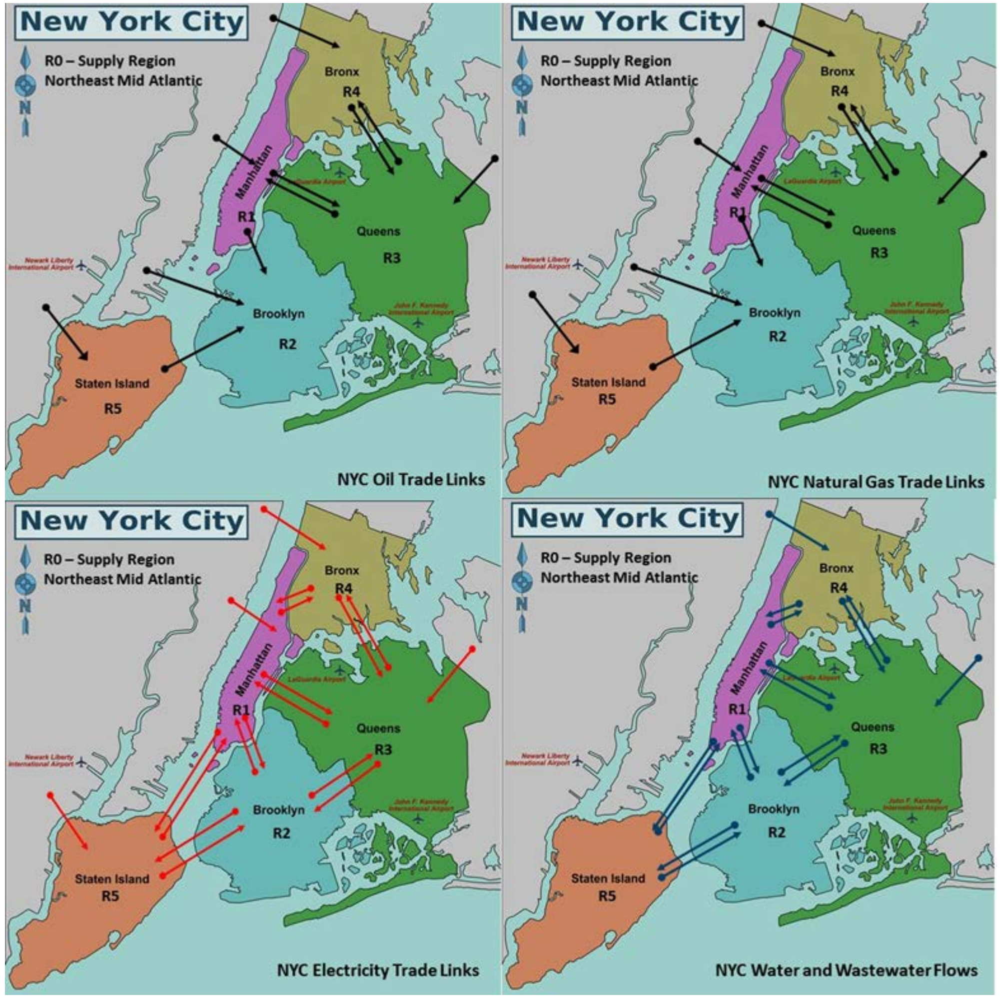
- Regional Planning Association's America 2050 project identified the emergence of 11 mega-regions in the US including one in Northeast



Source: http://www.america2050.org/maps/

United States Environmental Protection Agency

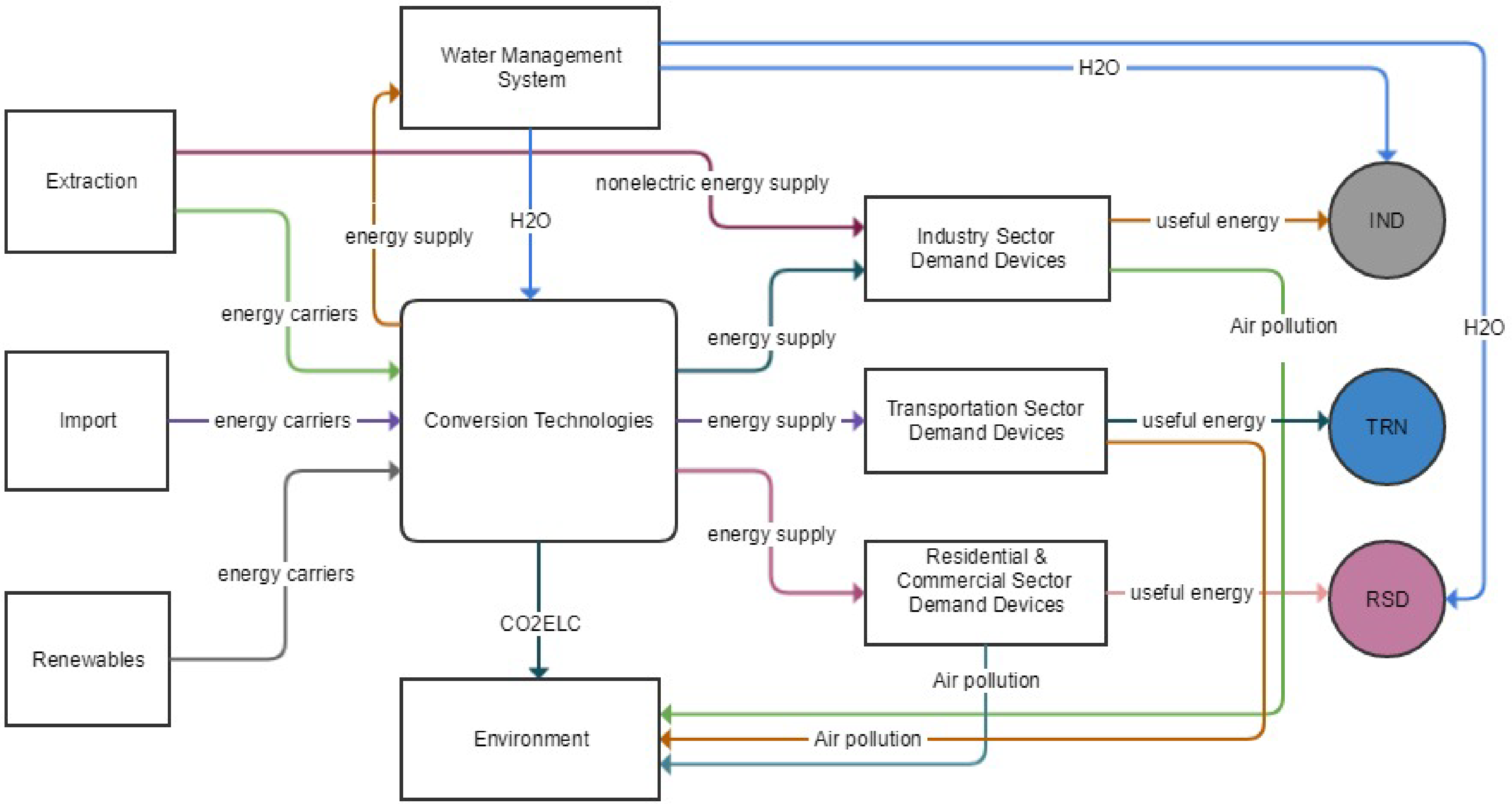
Community Scale MARKAL Database- New York City (EPANYC5r)



- **Coverage**: NYC and surrounding regions
- **Spatial resolution**: Five boroughs of NYC
- **Modeling horizon**: 2010 to 2055 in five year increments
- **Sectors**: Electricity production (including MSW), transportation, buildings sector (energy and water consumption)
- **Main data source:** EPAUS9r DB for technology characterization, PlutoDatabase, NYC GHG inventory
- **Pollutants**: GHG and criteria air pollutants
- **Maintenance:** will be housed at EPA/ORD and made publicly available

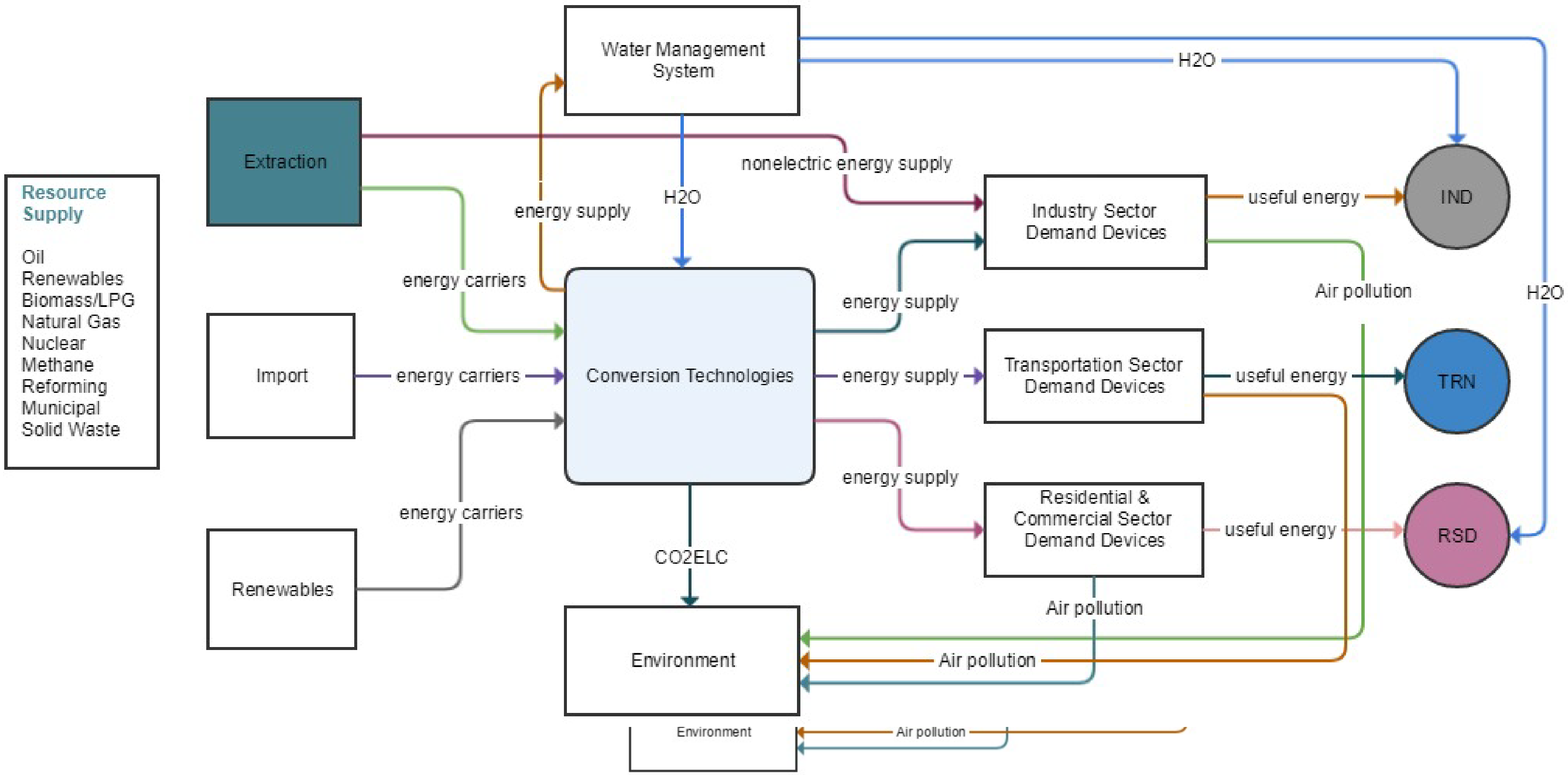
United States Environmental Protection Agency

Water Energy System in MARKAL

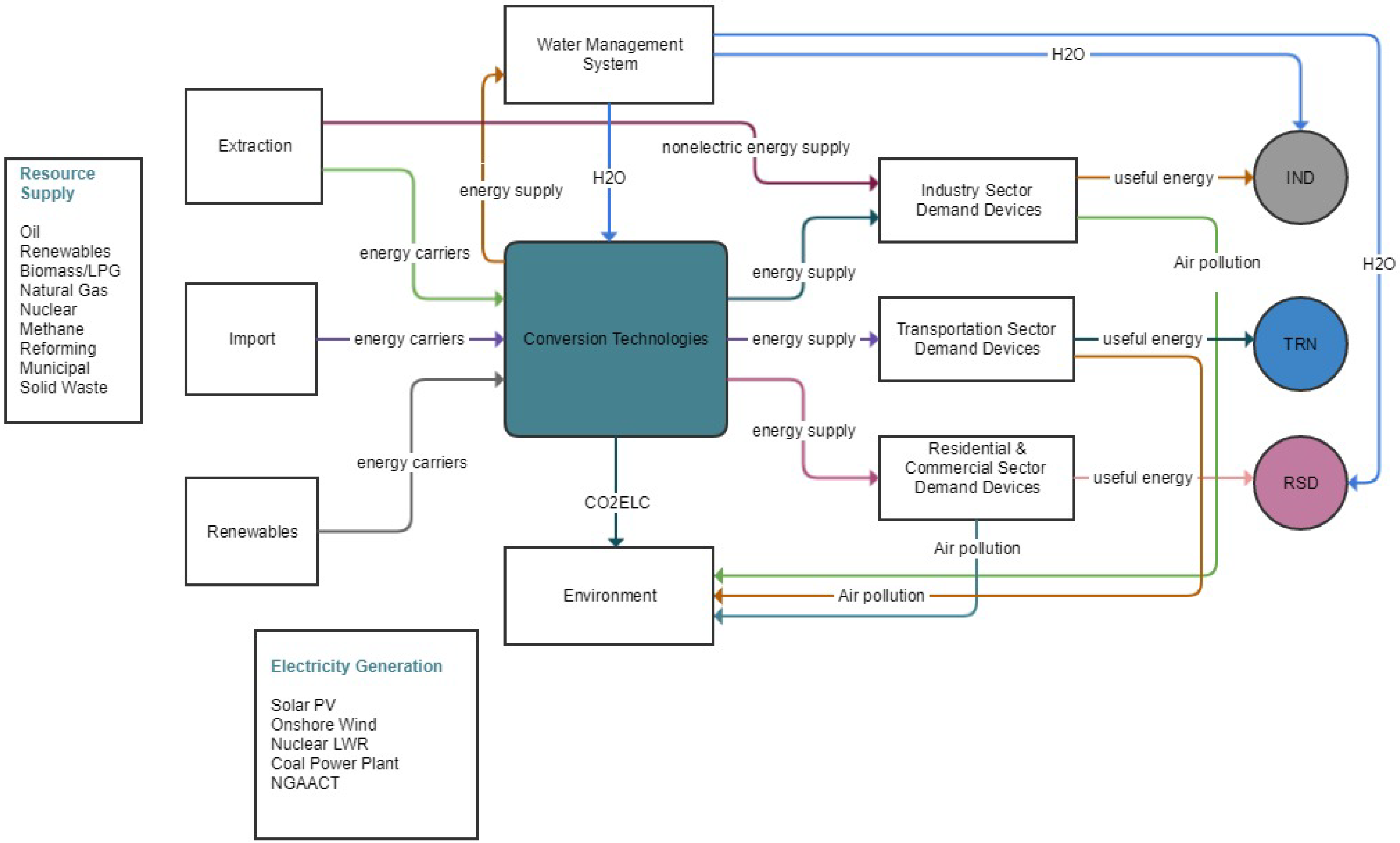


United States Environmental Protection Agency

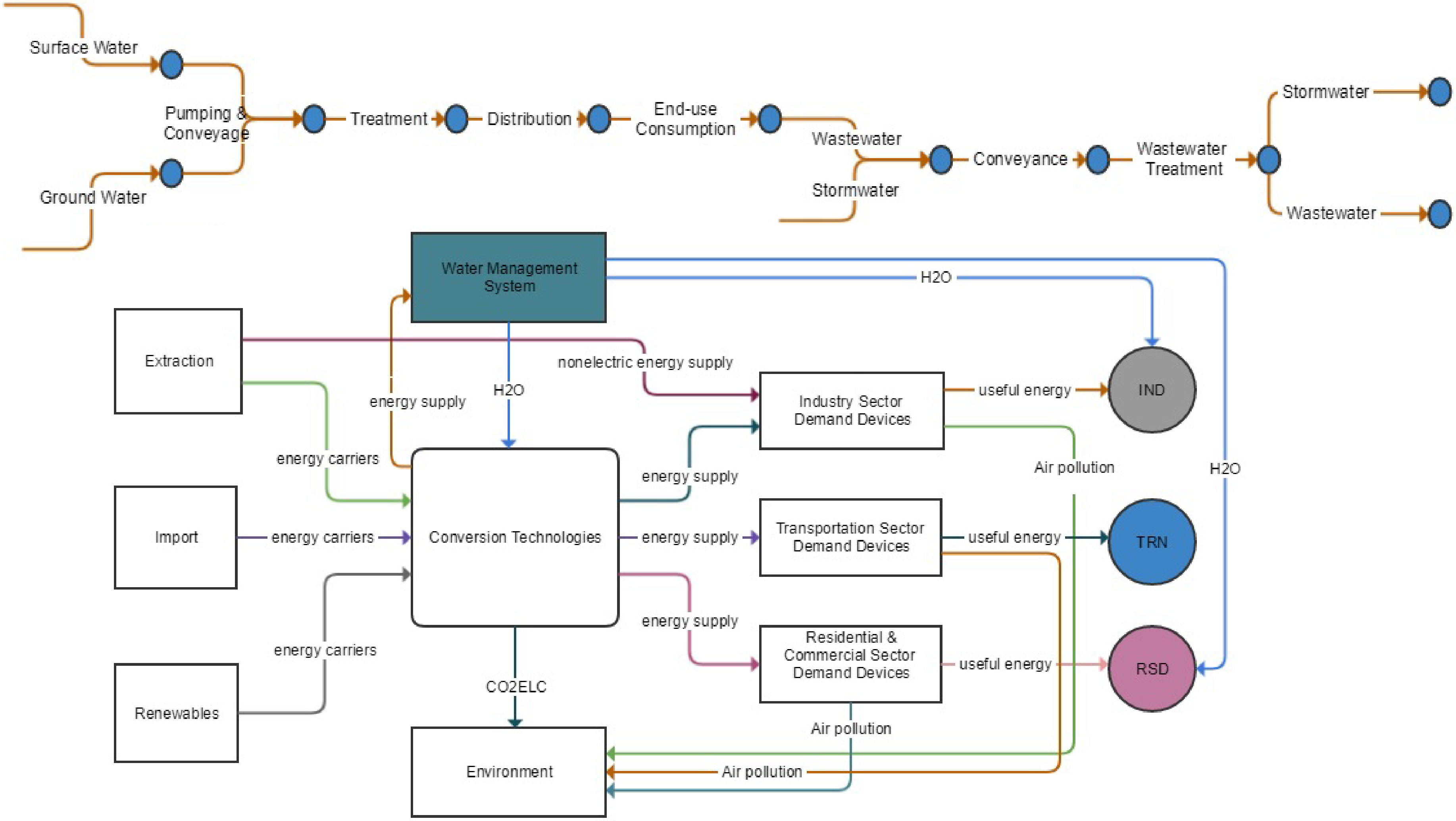
Water Energy System in MARKAL



Water Energy System in MARKAL



Water Energy System Modeling



United States Environmental Protection Agency

Technology Detail: Residential Space Heating

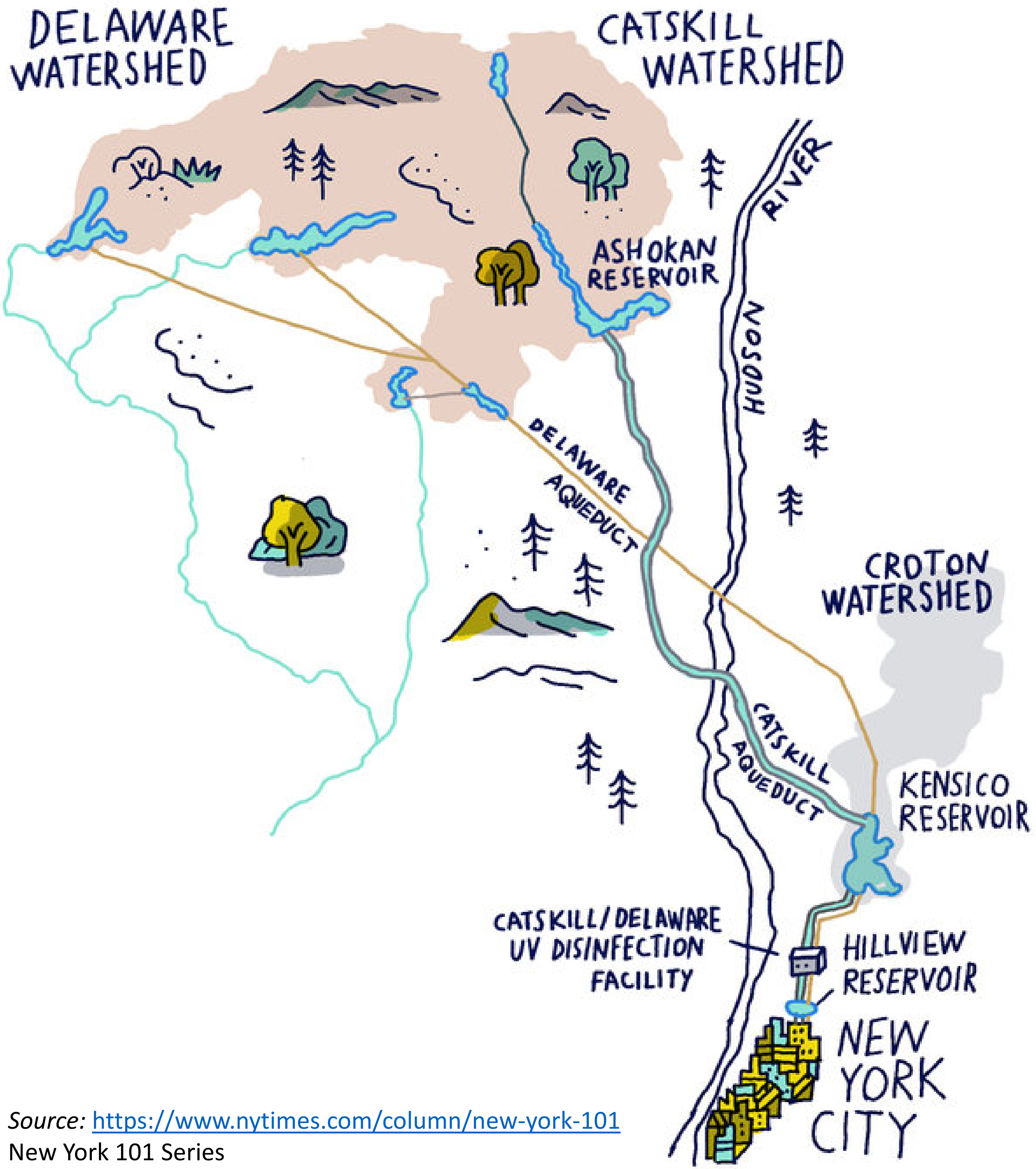
FUEL	TECHNOLOGY	DEMAND

Grid
PV

Geothermal
Electricity
Natural Gas

Furnace
Heat Pump
Radiant
Wood

Freezing
Lighting
Space Heating
Space Cooling
Refrigeration
Water Heating
Other



Source: https://www.nytimes.com/column/new-york-101
New York 101 Series

Drinking water system

Catskills-Delaware Watershed → UV treatment

Croton Watershed →Croton Filtration Facility
Multiple pumping stations

Water for multiple end-uses:

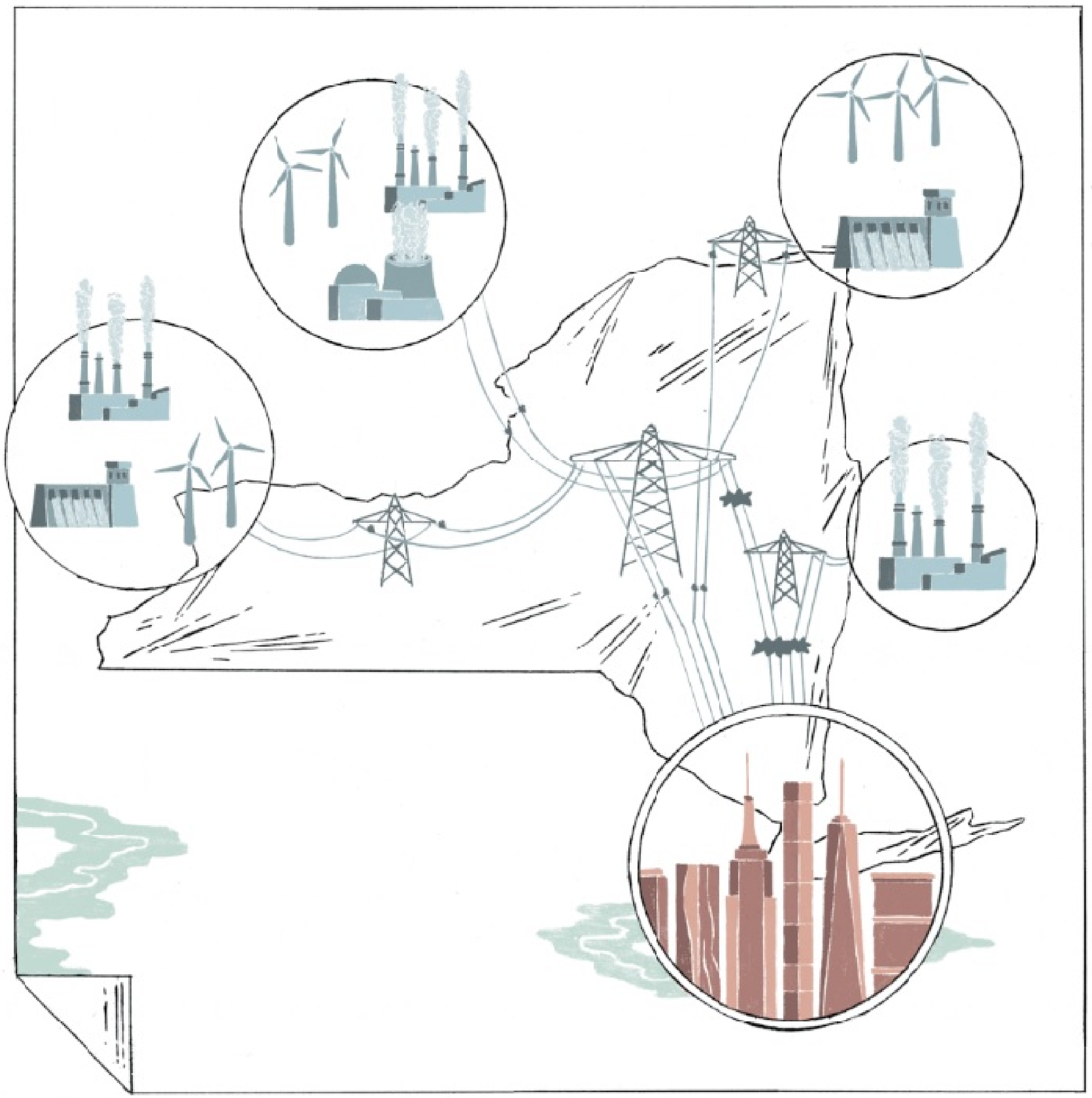
- Residential, commercial and industrial

Multiple wastewater treatment plants:

- Combined wastewater and stormwater

Green infrastructure projects:

- Mitigate stormwater; increase retention time: Greenroofs, rain gardens

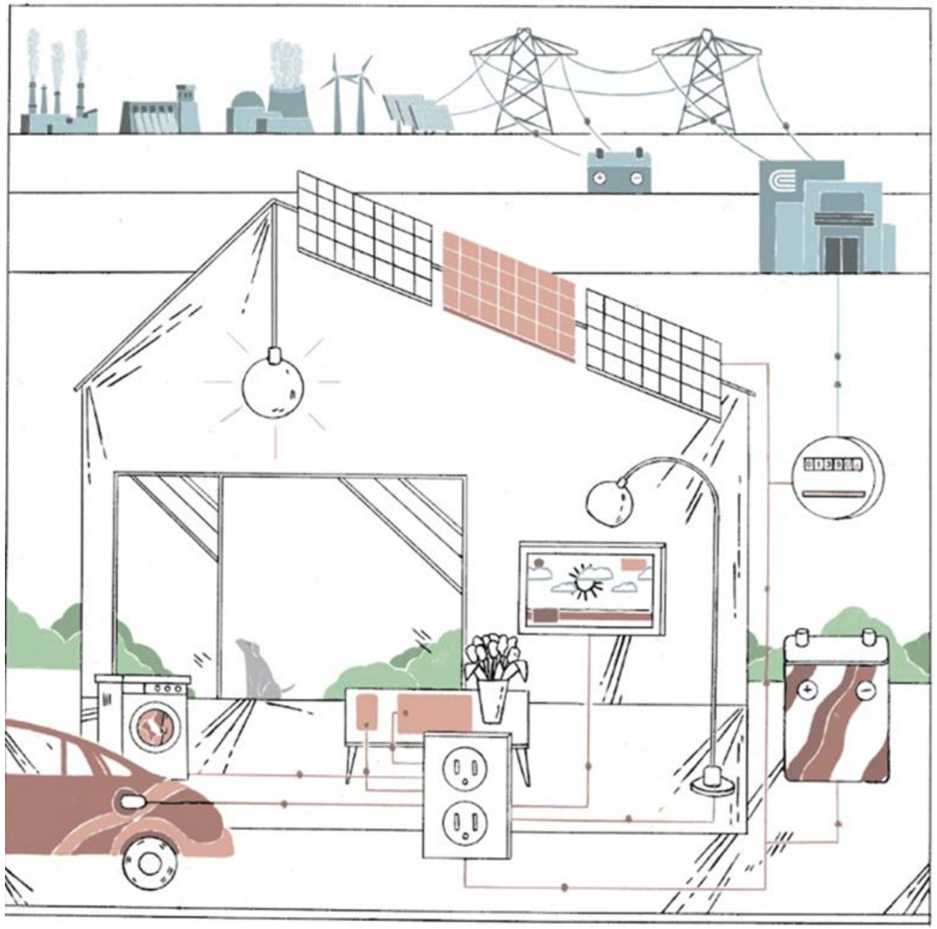


Energy System

- Nearly 60 percent of the state's electricity is consumed in the New York City area
  - 64 natural gas plants (~50%)
  - 4 nuclear reactors (33%)
  - 180 hydroelectric plants (19%)
  - 1 utility scale solar
  - 16 peaking units near the city
- Cities could be influential in their policies on where and what type of electricity they are purchasing for consumers.
  - Centralized vs. distributed generation

Source: https://www.nytimes.com/column/new-york-101 New York 101 Series, 2/10/2017.

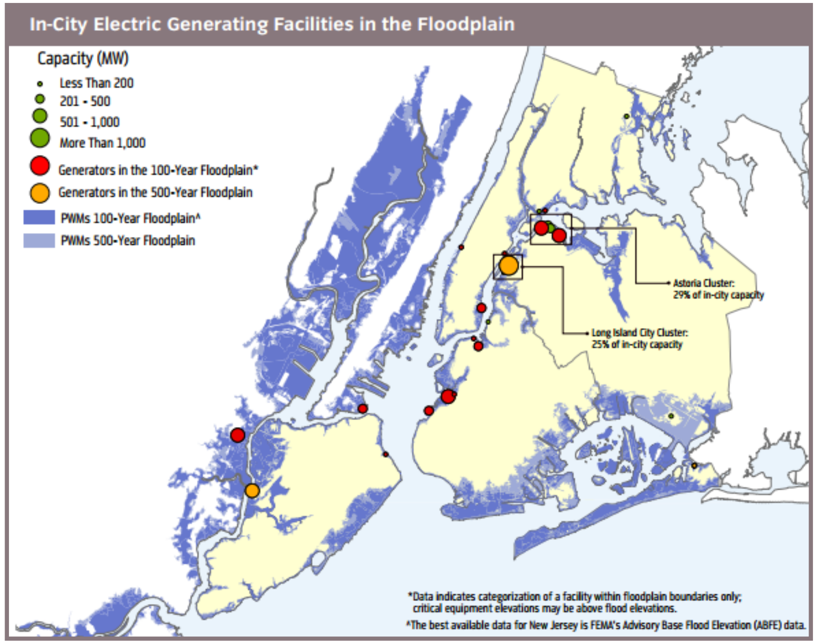
Water and energy linkages



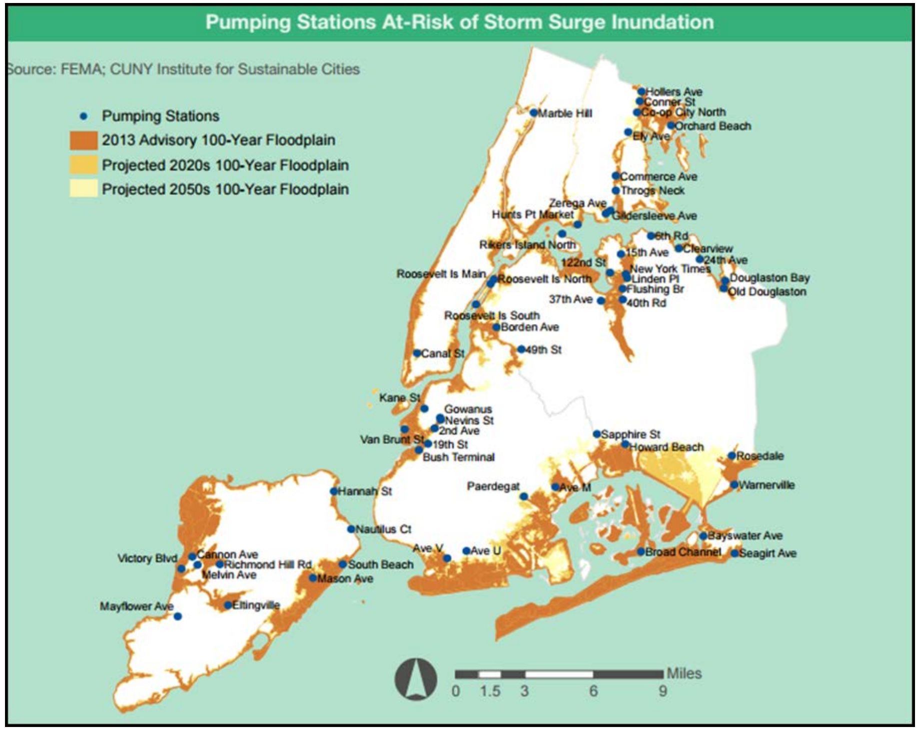
- Water for energy
  - In addition to electricity, oil & natural gas delivered to the city via pipelines to be used in buildings, transportation sector
- Energy for water
  - Treatment of water, and wastewater, pumping of water, household appliances, etc
- Distributed generation
  - Trade-offs and synergies among green roofs, white roofs, black roofs, solar PV, combined heat and power units
  - Resilience to power outages, demand management, cooling effects, water management, local air quality

Source: https://www.nytimes.com/column/new-york-101 New York 101 Series, 2/10/2017.

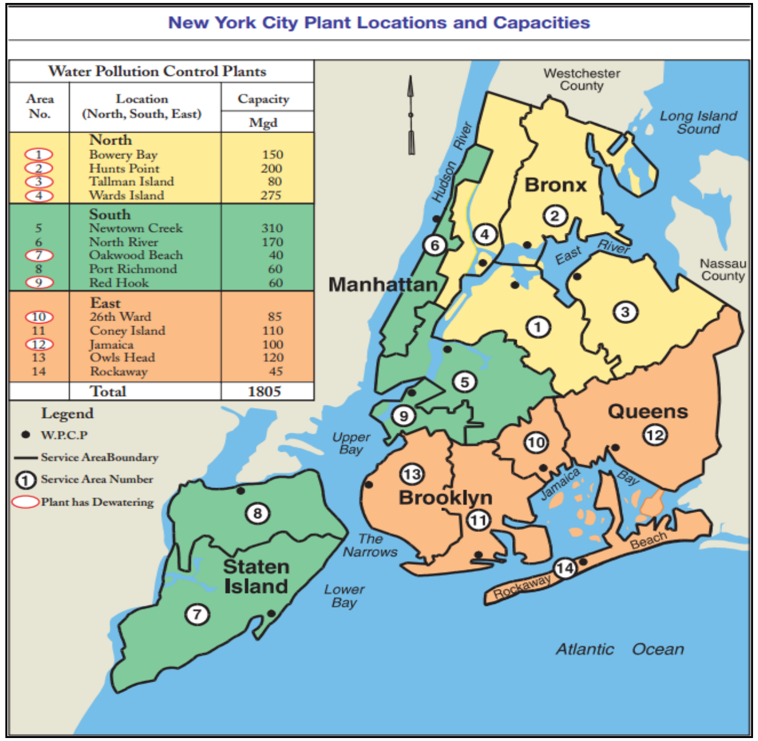
NYC water and electric power infrastructure



Represented fuel consumption, emissions, efficiency, capacity and total electricity generation



Represented fuel and/or electricity consumption, efficiency, capacity



Water Pollution Control Plants		
Area No.	Location (North, South, East)	Capacity Mgd
	North	
1	Bowery Bay	150
2	Hunts Point	200
3	Tallman Island	80
4	Wards Island	275
	South	
5	Newtown Creek	310
6	North River	170
7	Oakwood Beach	40
8	Port Richmond	60
9	Red Hook	60
	East	
10	26th Ward	85
11	Coney Island	110
12	Jamaica	100
13	Owls Head	120
14	Rockaway	45
	Total	**1805**

Represented fuel and/or electricity consumption, efficiency, capacity

United States Environmental Protection Agency

How can MARKAL be used…?

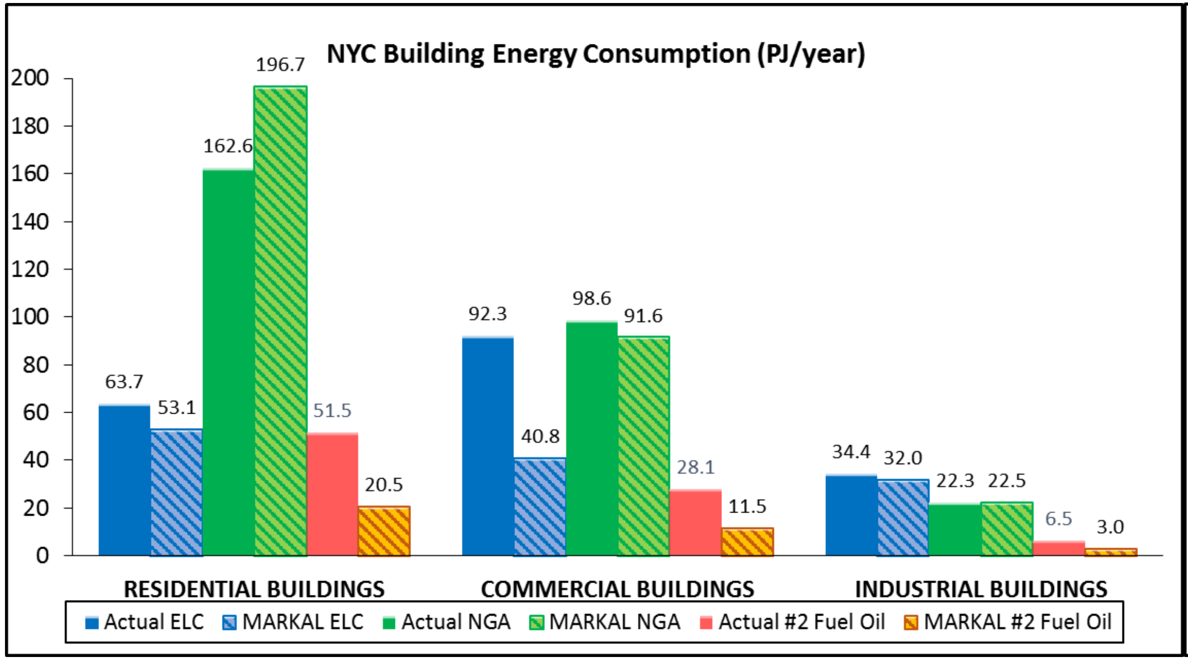
Several options:

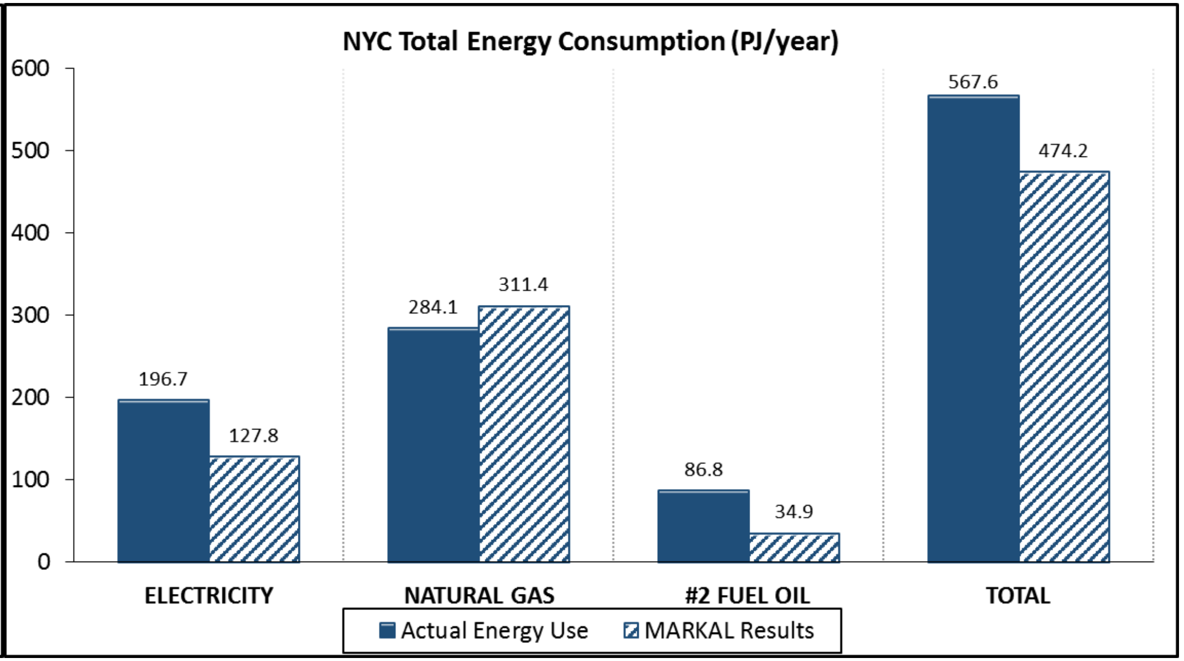
1. Model a **pre-specified** energy system scenario
   - Technology penetrations are determined *a priori*
   - MARKAL tracks outputs, e.g., fuel use, GHG and pollutant emissions, water use
2. To **prescribe** a least cost energy system
   - User provides constraints (e.g., emission limits, energy demands)
   - MARKAL identifies the least cost strategy for meeting the constraints
3. Examine the **sensitivity** of the least cost pathway to the:
   - application of **new policies**
   - introduction of **new technologies**
   - changes to **fuel prices** or **fuel availability**
4. Examine very different **scenarios** of the future

MARKAL Applications

- Cost and benefit analysis of community-scale renewables, micro-grids
- Energy management and planning for water and wastewater treatment plants
- Stormwater management alternatives
- Supporting building energy efficiency benchmarking programs
- Evaluation of emission reduction strategies
- Evaluation of renewable energy and energy efficiency (RE/EE) strategies
- Evaluation and analysis of distributed generation in the city
  - (air quality, climate change, energy and resilience implications)
- Town/Port Applications on ozone, NOx and SO_2 and PM 2.5

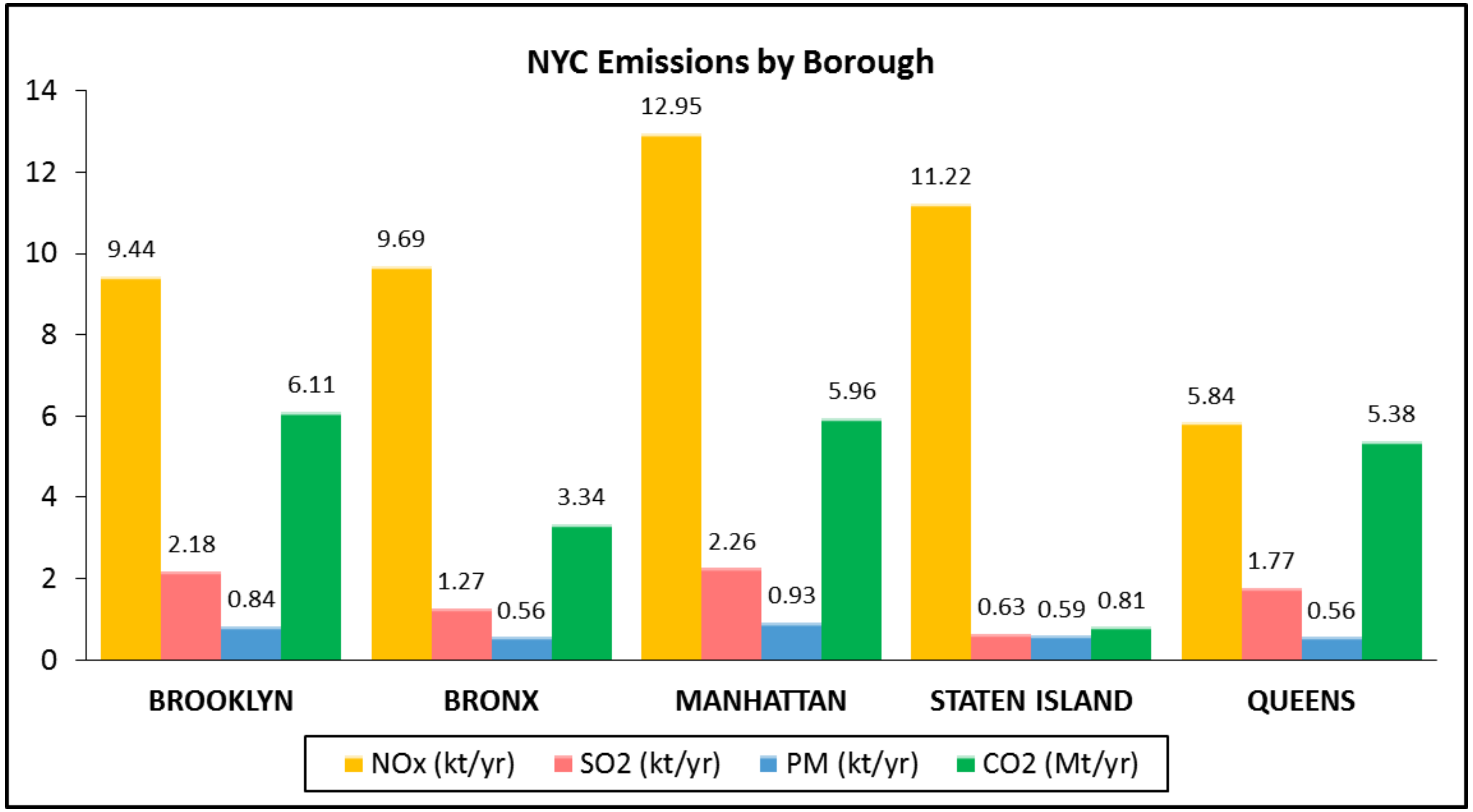
Preliminary calibration results





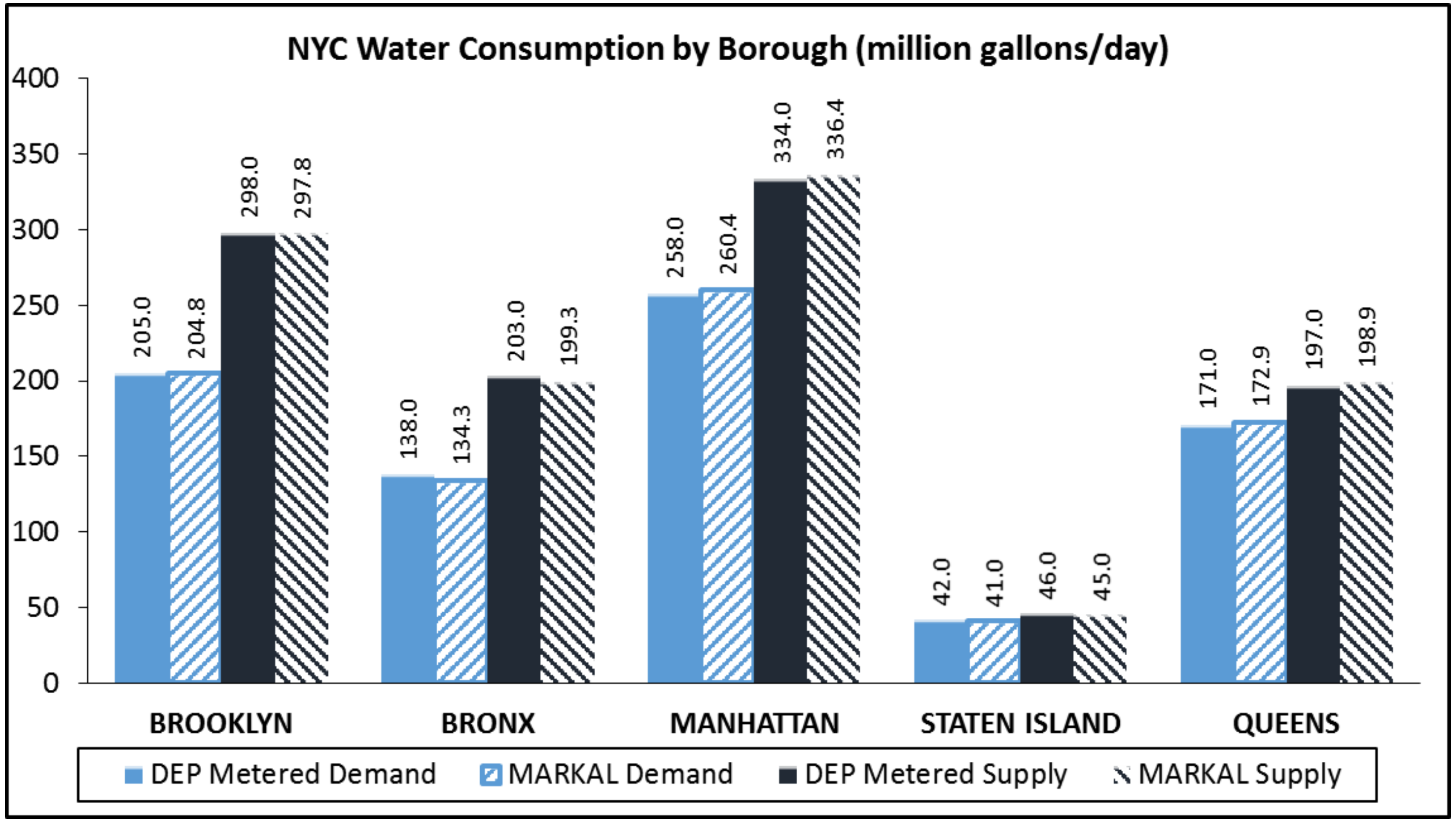
- Calibrated to 2010 energy consumption data reported in the 2012 NYC GHGI
  - Inventory reports an aggregate figure for building energy consumption
  - Utilized 2011 data from the 2013 NYC GHGI to calculate sector specific consumption figures

Preliminary calibration results



- Calibrated to 2010 reported GHG data in the 2012 NYC GHGI
- NOx, SO2, PM emissions are associated with fuel and electricity consumption in buildings sector

Preliminary calibration results



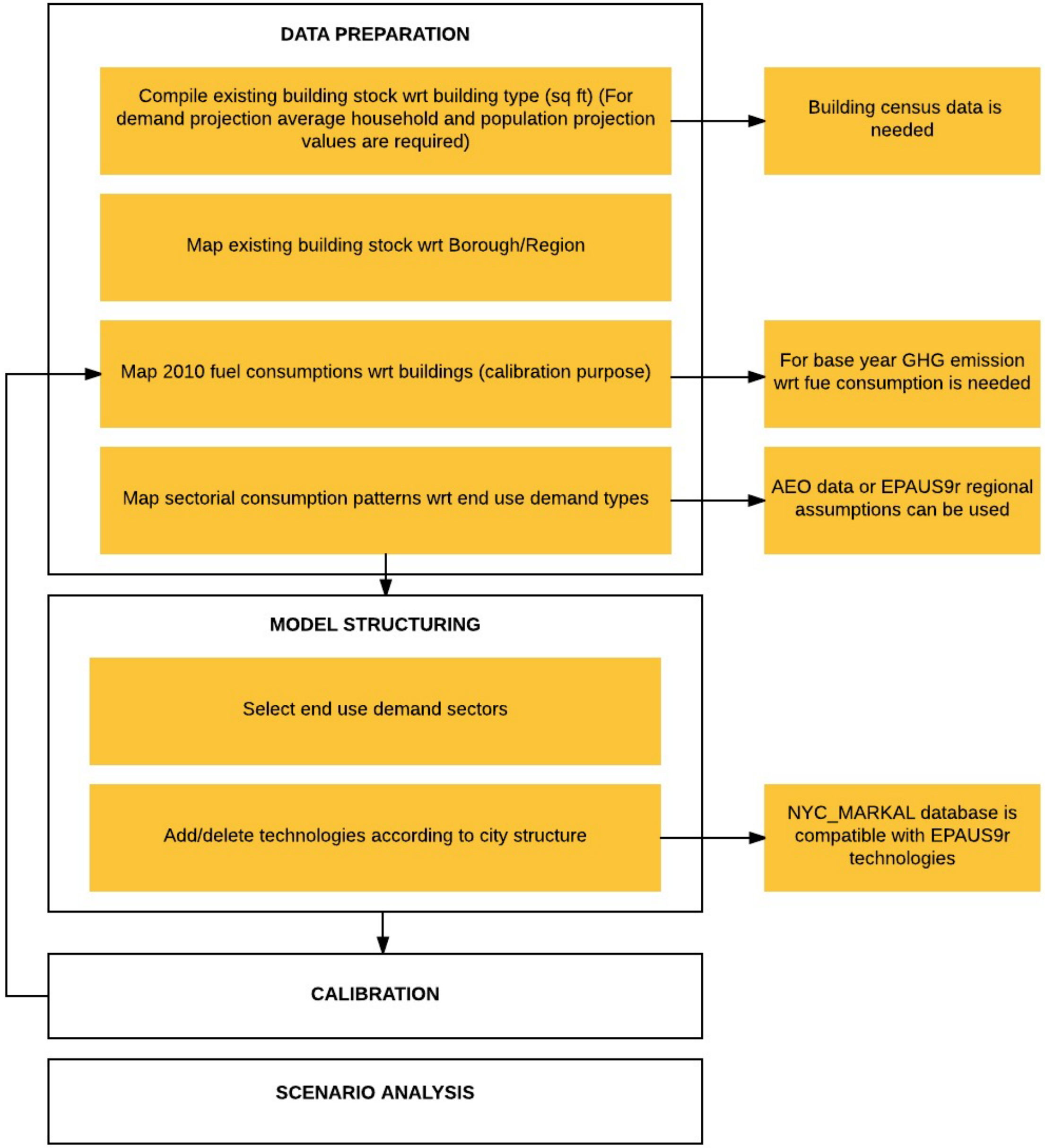
- Calibrated to 2010 water consumption data reported by NYC DEP

Potential study results might include, but not limited to…

- Total fuel and electricity consumption by borough for 2010-2055
- Fuel use by various end-use technologies by borough for 2010-2055 (e.g., natural gas consumption by furnaces)
- Emissions growth associated with technology and fuel choices
- Fuel consumption patterns in buildings
  - e.g., How much natural gas used for heating, cooling, cooking, etc? What technologies used? At what efficiencies? At what costs?
- Combined heat and power plants and solar PV penetration under different policies
- Energy implications of water and wastewater treatment plant efficiency improvements

United States Environmental Protection Agency

Model Building Steps



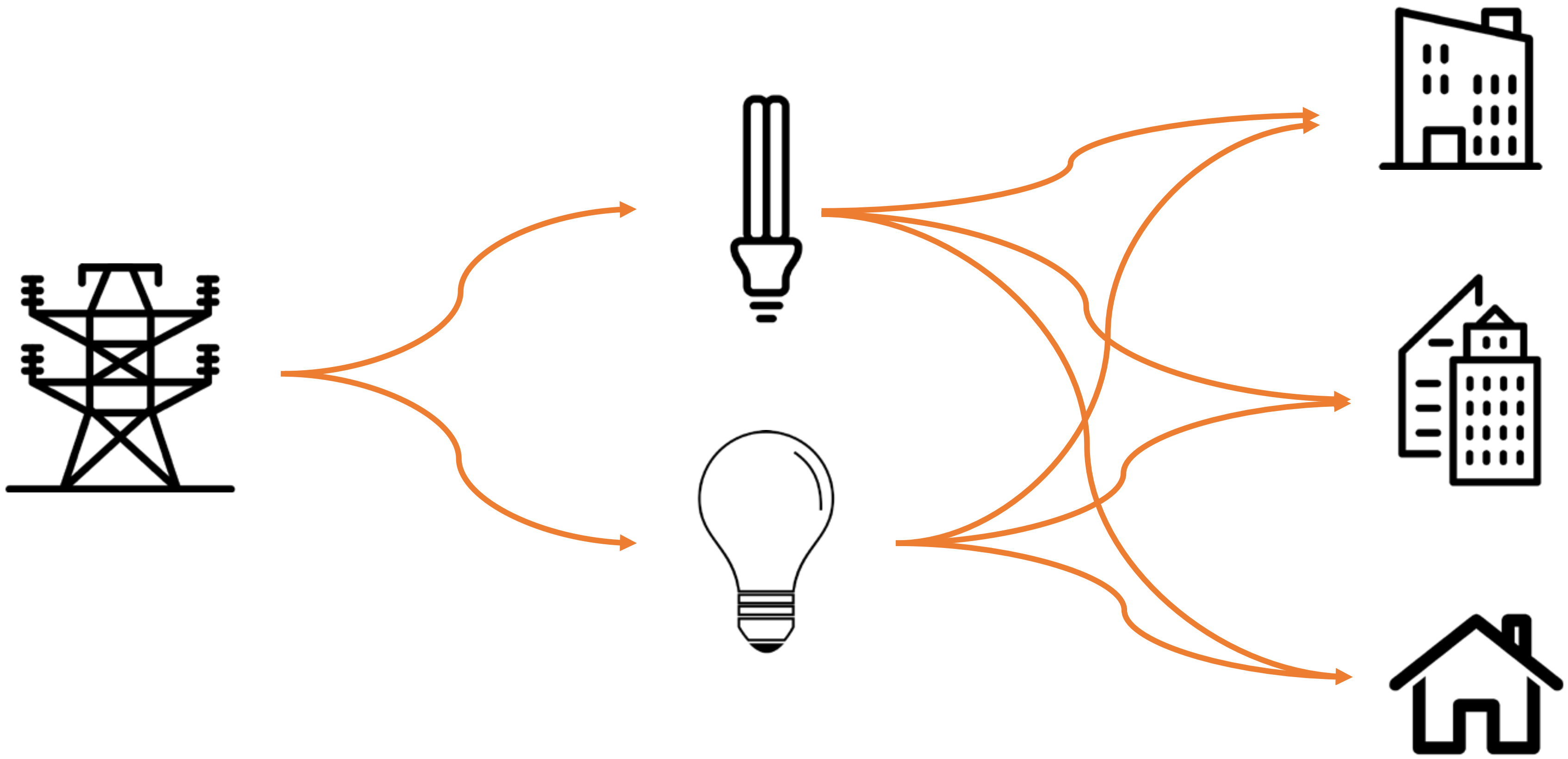
United States Environmental Protection Agency

Residential and Commercial Building Energy Demands

Demand	Units	Descriptor
RSC	PJ/yr	Space Cooling
RSH	PJ/yr	Space Heating
RWH	PPJ	Water Heating
RLT	billion lumens/yr	Lighting
RRF	million units	Refrigerators
RFZ	million units	Freezers
ROE	PJ/yr	Other -Electricity
ROG	PJ/yr	Other -Natural Gas

Demand	Units	Descriptor
CSH	PJ/yr	Space Heating
CSC	PJ/yr	Space Cooling
CWH	PJ/yr	Water Heating
COF	PJ/yr	Office Equipment
CCK	PJ/yr	Cooking
CLT	billion lumens/yr	Lighting
CMD	PJ/yr	Misc -DSL
CME	PJ/yr	Misc -ELC
CMN	PJ/yr	Misc -NG
CRF	PJ/yr	Refrigeration
CVT	tcfm-hr	Ventilation

Buildings Lighting Demand

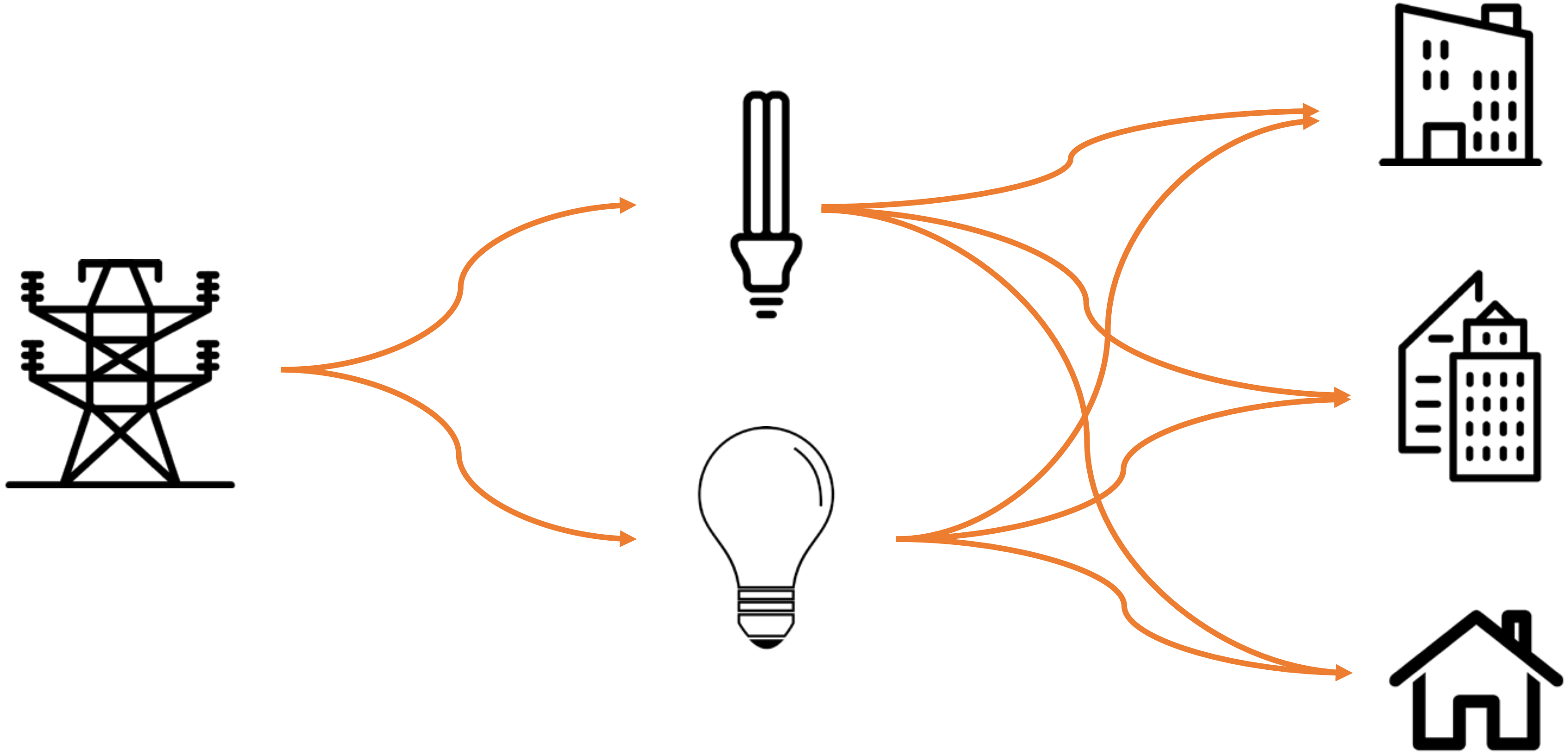


STEP 1:

- Existing building stock is divided wrt type including 1 to 4 multifamily, commercial, industrial etc.

Icons are from www.thenounproject.com

Buildings Lighting Demand



STEP 1:

- Existing building stock is divided wrt type including 1 to 4 multifamily, commercial, industrial etc.
- Building and lot information is from the Primary Land Use Tax Lot Output (hereafter PLUTO) data file from the New York City Department of City Planning

Icons are from www.thenounproject.com

Buildings Lighting Demand

STEP 2:

The LL84 (building benchmarking) data was then merged with the building stock

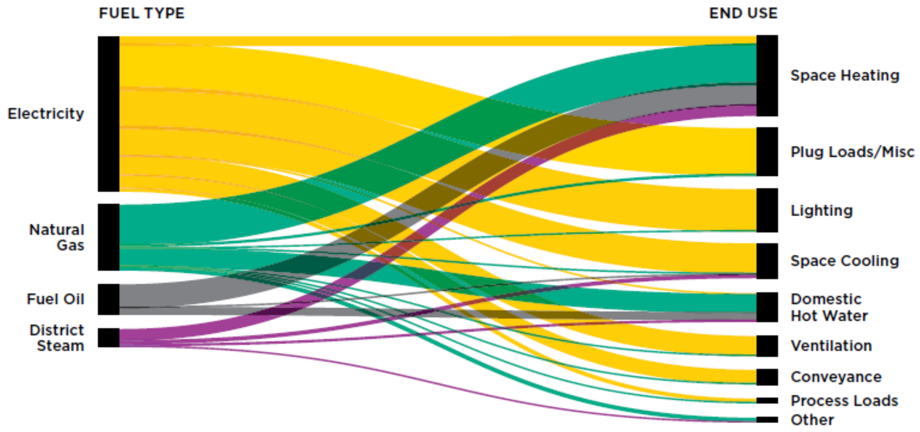
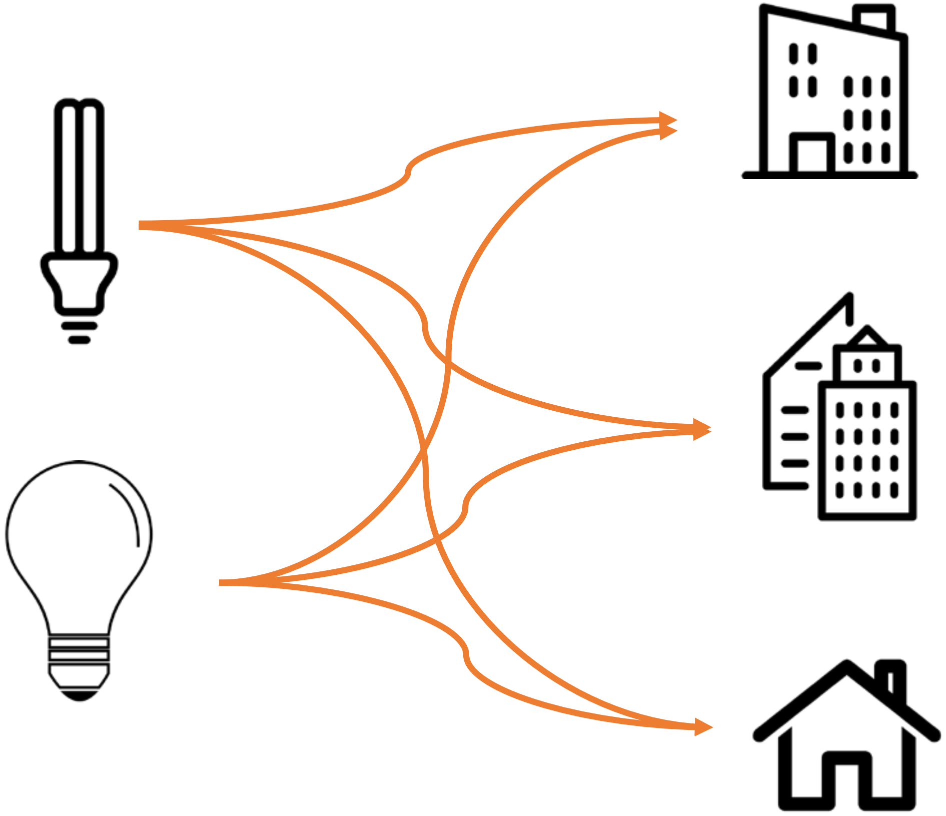
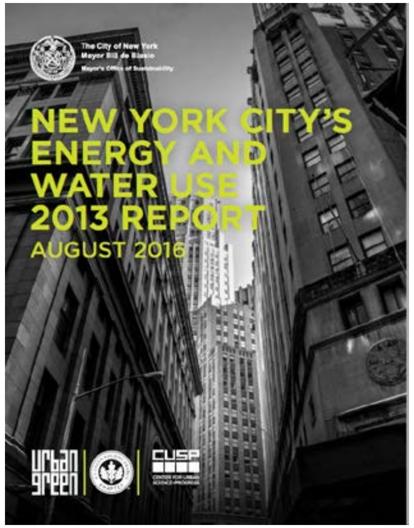


Figure 4: Flow of Fuel Types to End Use (LL84 and LL87 data) [14]
Electricity represents more than half of the audited source energy, while space heating, fueled mainly by natural gas, represents the largest end use. (Urban Green Council)



Source



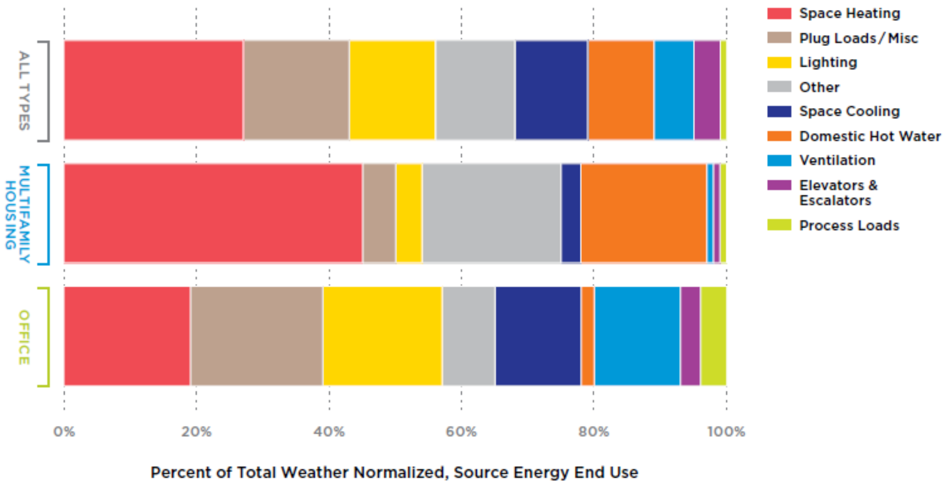
Total energy consumption that can be attributed to lighting demand wrt building types are gathered

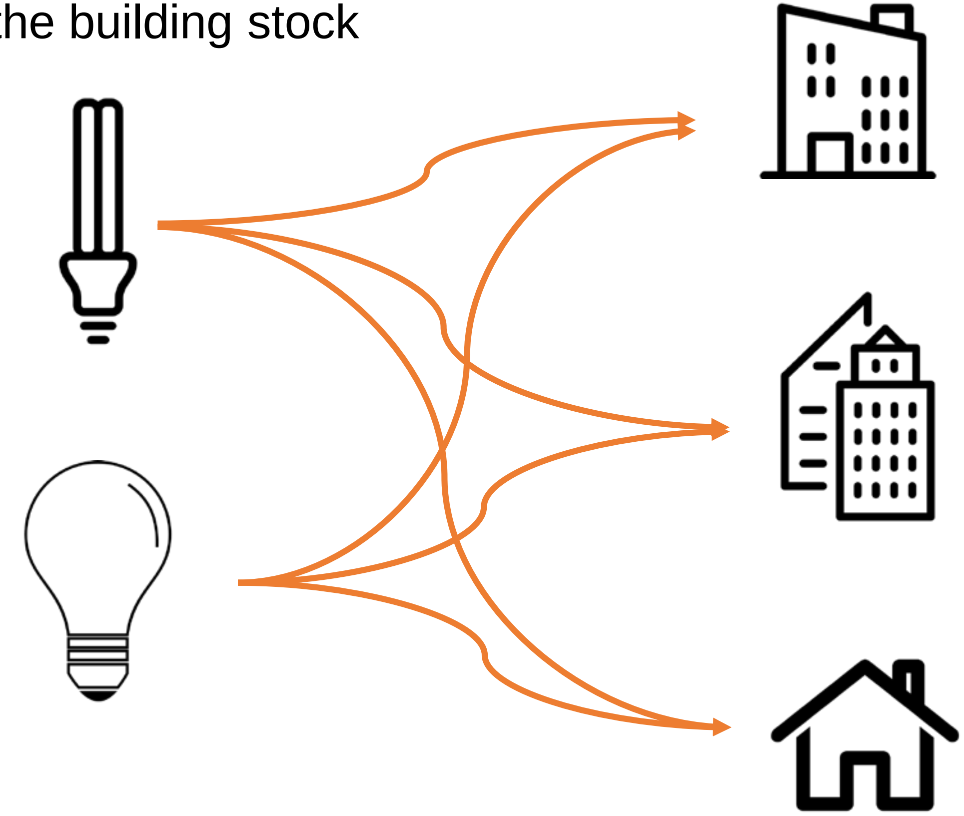
Buildings Lighting Demand

STEP 2:

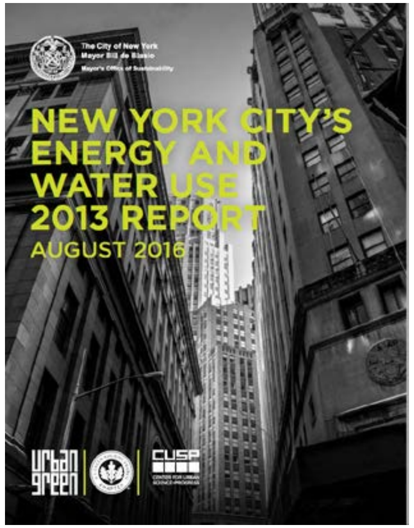
The LL84 database was then merged with the building stock

Figure 3: Energy End Uses by Sector and Overall (LL87 data)
Space heating, plug loads, and lighting are the largest consumers of source energy in large New York City buildings. (Urban Green Council)





Source



Total energy consumption that can be attributed to lighting demand wrt building types are gathered

Buildings Lighting Demand

STEP 3: Total energy consumption data that can be attributed to the demand sectors is taken from NYC GHG report

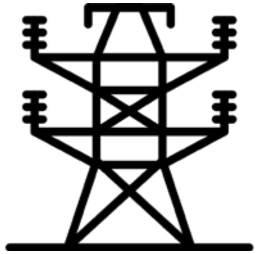
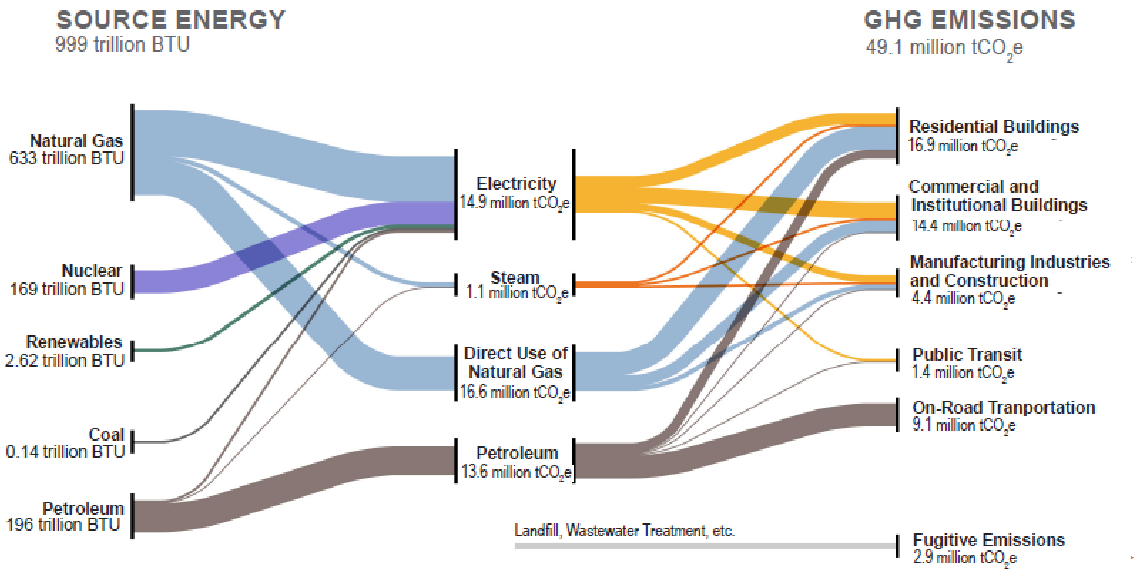
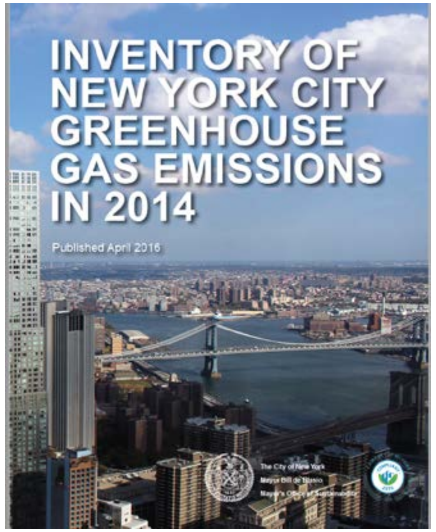


Fig. 1: 2014 New York City Energy Consumption and Greenhouse Gas Emissions



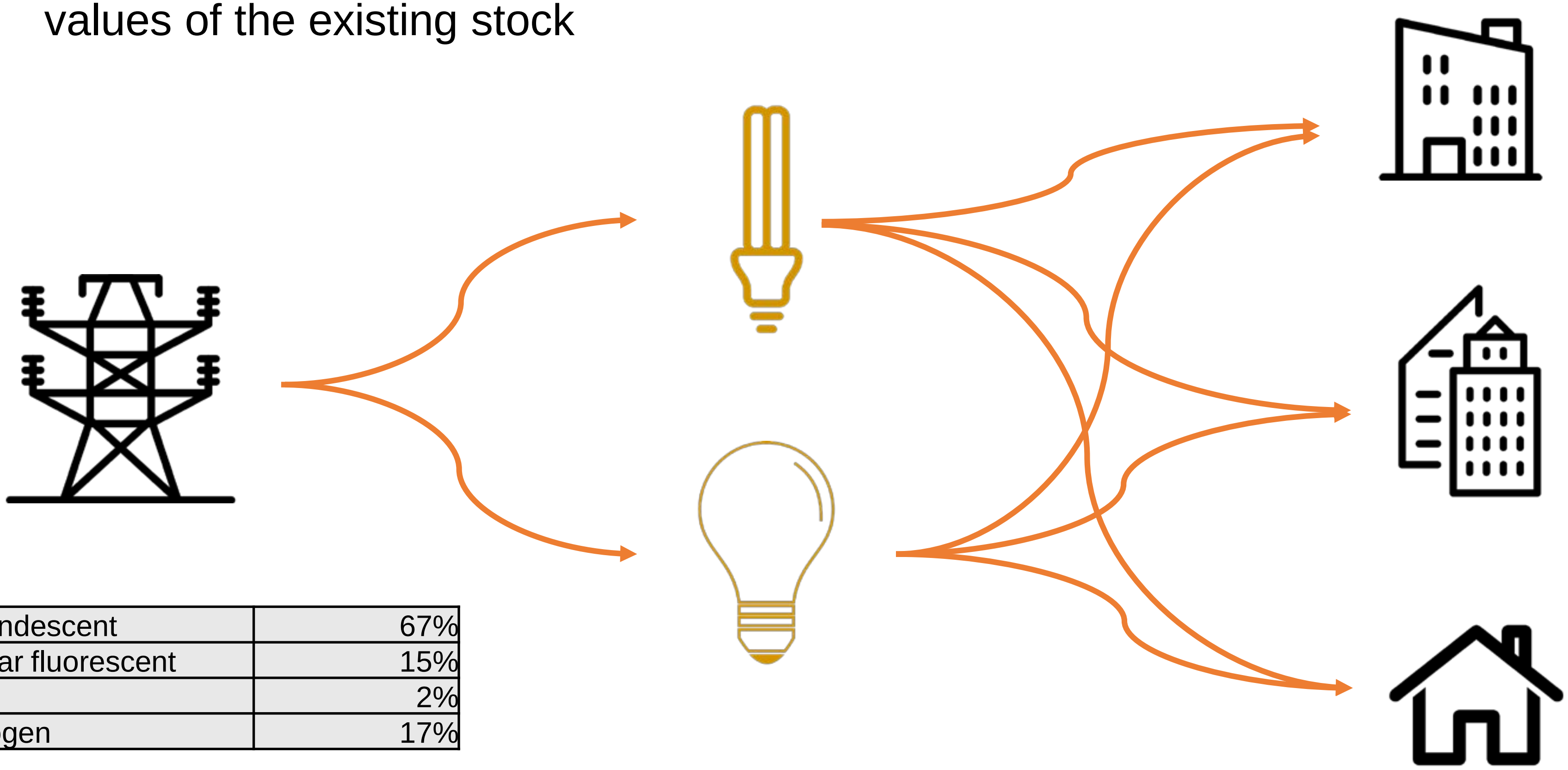
Source



Total fuel consumptions are calculated for each building type and borough

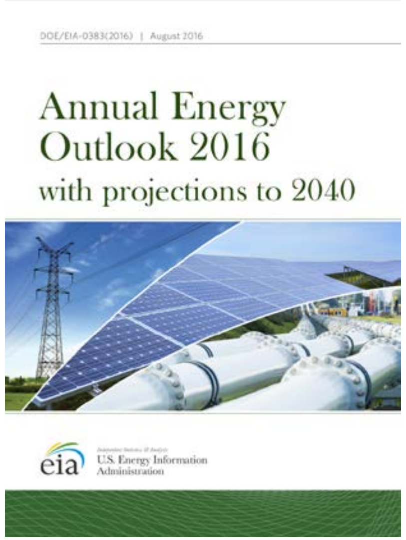
Buildings Lighting Demand

STEP 4: From the AEO 2016 documentation, Lighting Market Characterization data provides the percent values of the existing stock



Incandescent	67%
Linear fluorescent	15%
CFL	2%
Halogen	17%

Source



Total lighting demand is calculated wrt the efficiency values of existing stock

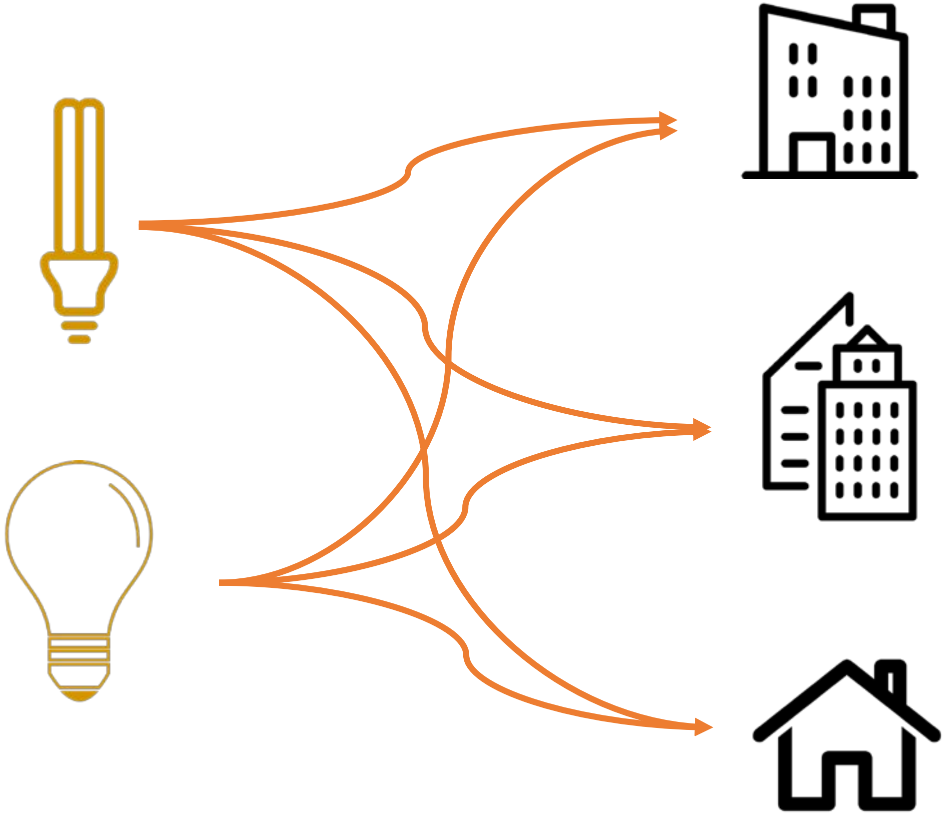
Buildings Lighting Demand

United States Environmental Protection Agency

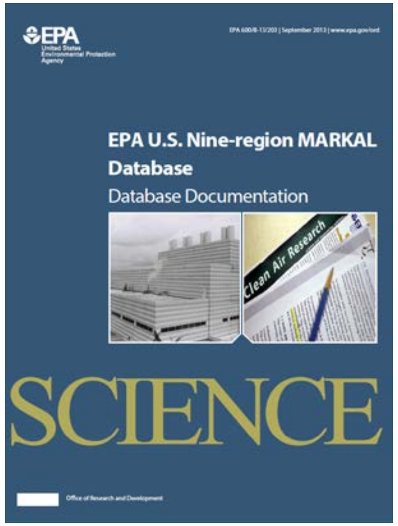
STEP 5: Future technology options are taken from EPAUS9r database: Corresponding region

Table 3.11: Residential Technology and Fuel Combinations

End Use Demand	Technology Type	Fuel				
Space Heating	Radiant	Electric	Natural Gas	Distillate		
	Heat Pump	Electric	Natural Gas	Geothermal		
	Furnace		Natural Gas	Distillate	Kerosene	LPG
	Wood					
Space Cooling	Room AC	Electric				
	Central AC	Electric				
	Heat Pump	Electric	Natural Gas	Geothermal		
Water Heating		Electric	Natural Gas	Distillate	LPG	Solar
Refrigeration		Electric				
Freezing		Electric				
Lighting	Incandescent	Electric				
	CFL	Electric				
	LED	Electric				
	Halogen	Electric				
	Linear Fluorescent	Electric				
	Reflector	Electric				



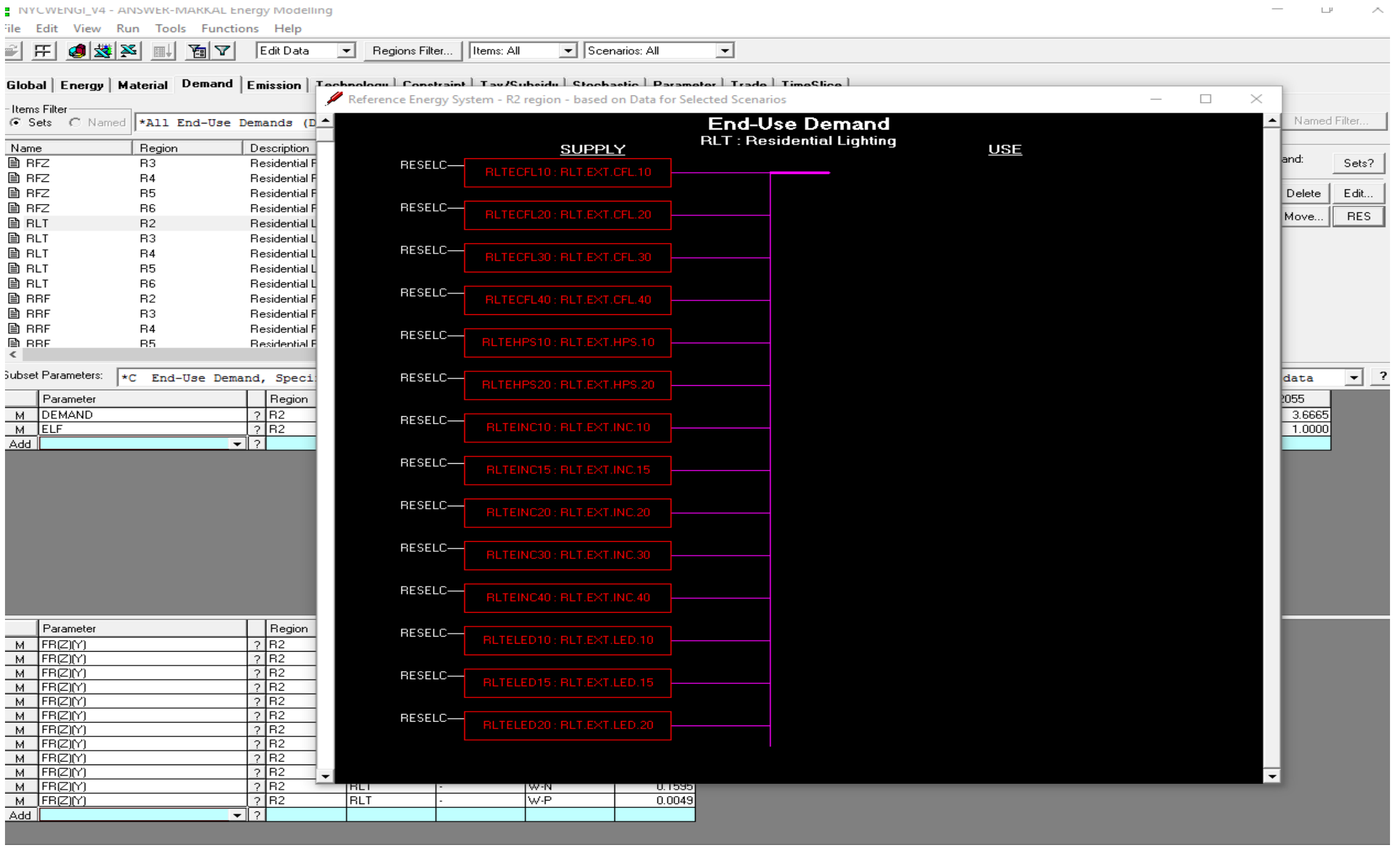
Source



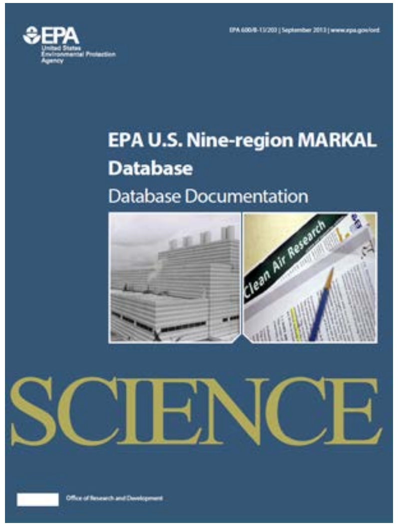
For parameters that cannot be calculated by using the data on hand, Region 2 values are taken for NYC_MARKAL

Buildings Lighting Demand

STEP 5: Future technology options are taken from EPAUS9r database



Source



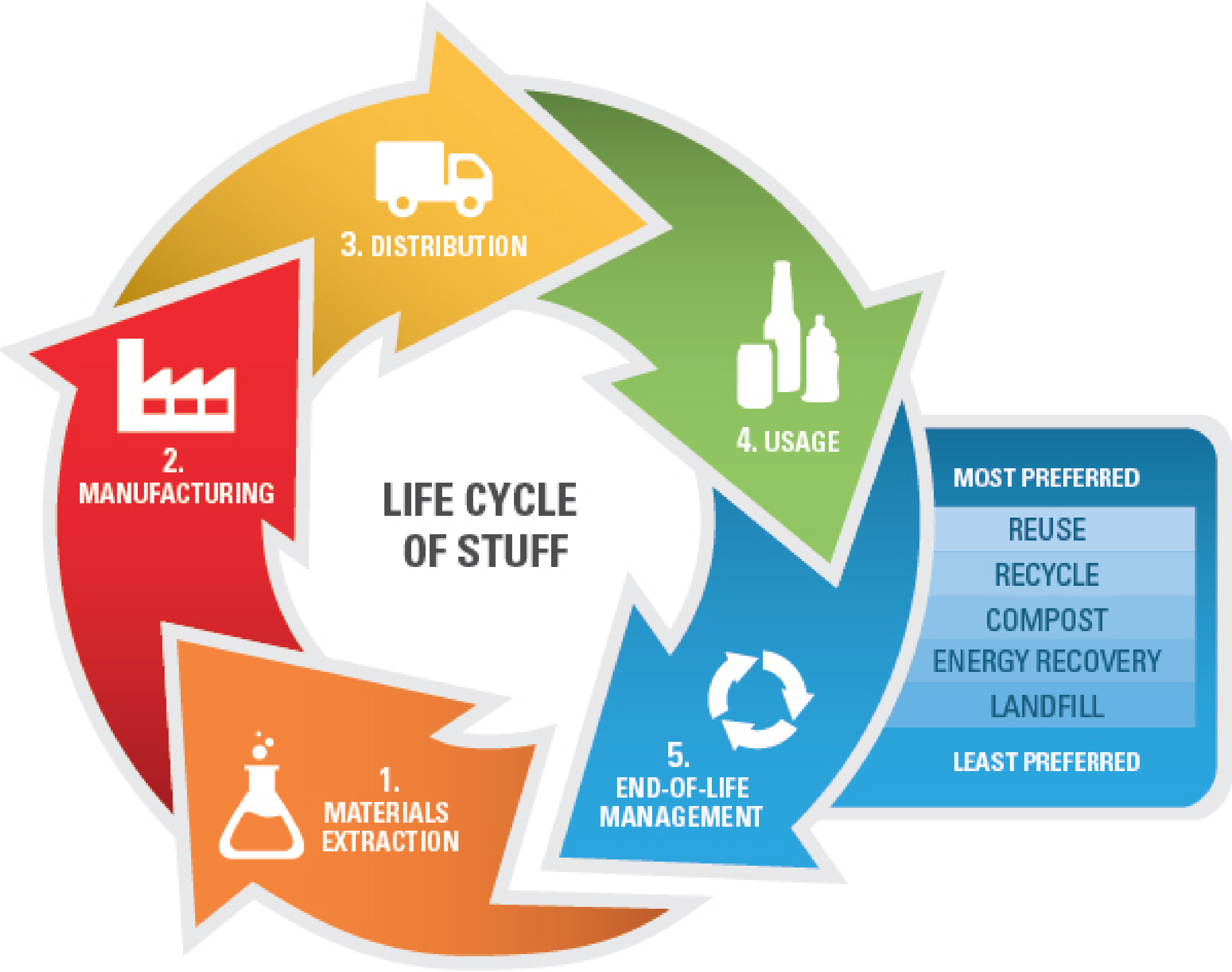
For parameters that cannot be calculated by using the data on hand, Region 2 values are taken for NYC_MARKAL

EPA
United States Environmental Protection Agency

Data Sources & References

- U.S. DOE Cool Roofs Calculator
- NYC Dept. of City Planning’s MapPLUTO data set
- NYC Open Data Portal for Energy & Water Consumption
- NYC Local Law 84 data sets and compliance reports
- NYC Greenhouse Gas Inventory 2014
- NYC SIRR Report on Utilities & Liquid Fuels 2013
- NYCDEP Water Demand Management Plan 2014
- NYCDEP Wastewater Resiliency Plan 2013
- Pacific Institute Commercial Water Use
- U.S. Dept. of Energy’s CBECS & RECS data sets
- Morning Star NYC Natural Gas Forecast 2014
- ICF International NYC Natural Gas Market 2011
- WERF Best Practices in WWTP Energy Efficiency

Municipal Solid Waste-Decision Support Tool



Summary of the MSW DST

- MSW-DST freely available with full documentation, publications and tutorials
- Represents almost 20 years of collaboration among
  - EPA-ORD, North Carolina State University, Research Triangle Institute, and others
- Developed via stakeholder driven process
- Designed to evaluate integrated management of **municipal solid waste**
- Used as a detailed planning tool with optimization capabilities
  - Place-based analysis with multiple options for each step of the SWM
- Outputs include **full cost accounting**, **lifecycle emissions** and limited information on social aspects such as land usage and use of local infrastructure
- Wide user profile
  - universities, NGOs, state environmental departments, cities, international organizations
- Expertise through various case studies conducted with the tool

United States Environmental Protection Agency

Sustainable materials management

- Sustainable materials management (SMM) is the use and reuse of materials in the most productive and sustainable method across the entire life cycle.

- SMM conserves resources, reduces air emissions and waste going to landfills, and minimizes the environmental impacts of the materials we use.

- Use of the municipal solid waste decision support tool (MSW-DST) helps communities identify more holistic and sustainable solutions for managing materials once they enter the waste stream

Questions Considered When Developing Management Plans

How do we ensure

- Cost efficient waste management?
- Meeting state mandated recycling goals?
- Most efficient waste collection systems?
- Continued improvement of the environment?
- Fast, objective analysis of options?

Environmental Aspects

- Local air quality impacts
- Energy consumption and offsets
- Greenhouse gas emissions
- Benefits from materials recycling and source reduction

Economic Social Aspects

- Municipal budgets
- Need for new facilities
- Household convenience

Developed via stakeholder driven process

American Forest and Paper Association
American Iron and Steel Institute
American Plastics Council
American Public Works Association
American Society of Mechanical Engineers
Association of County Commissioners for Georgia
Association of State and Territorial Solid Waste Management Officials
Audubon
Bes-Pack, Inc.
Browning-Ferris Industries, Inc.
Can Manufacturers Institute
Chemical Manufacturers Association
City of Austin
City of Los Angeles
City of Madison, WI
City of Philadelphia
City of Portland
City of San Jose
Corporations Supporting Recycling
Santa Barbara County Waste Mgmt Division
Delaware Solid Waste Authority
E. Tseng & Associates
Electronic Industries Association
Electro-Pyrolysis, Inc.
Energy Answers Corporation, Inc. Environment Canada
Environmental Defense Fund
Environmental Industry Associations
Glass Manufacturing Industry Council
Glass Packaging Institute
Indiana Institute of Recycling
Institute of Scrap Recycling Industries, Inc.
Integrated Waste Services Association
International City/County Management Association
International Joint Commission
Keep American Beautiful
Lucas County Solid Waste Management District
Minnesota Office of Environmental Assistance
Monterey Regional Waste Management District
MSW Management
National Association of Counties
National Conference of State Legislatures
National Council of the Paper Industry for Air & Stream Improvements, Inc.
National Recycling Coalition
National Resources Defense Council
National Solid Waste Management Association
New York City Department of Sanitation
New York State Energy Research and Development Authority
North Carolina Department of Environment and Natural Resources
Ogden Martin
Owens-Illinois, Inc
Procter & Gamble Company
Resource Recycling Systems, Inc.
Solid Waste Association of North American
Sound Resource Management Group
South Carolina Institute for Energy
State of Florida
State of Georgia
State of Iowa
State of New Hampshire
State of Pennsylvania
State of Wisconsin
Steel Recycling Institute
The Aluminum Association
The City of San Diego
The Coca-Cola Company
Union Carbide
U.S. Conference of Mayors
U.S. Navy
Virginia Association of Counties
Waste Industries, Inc.
Waste Management, Inc.

EPA United States Environmental Protection Agency

Important milestone

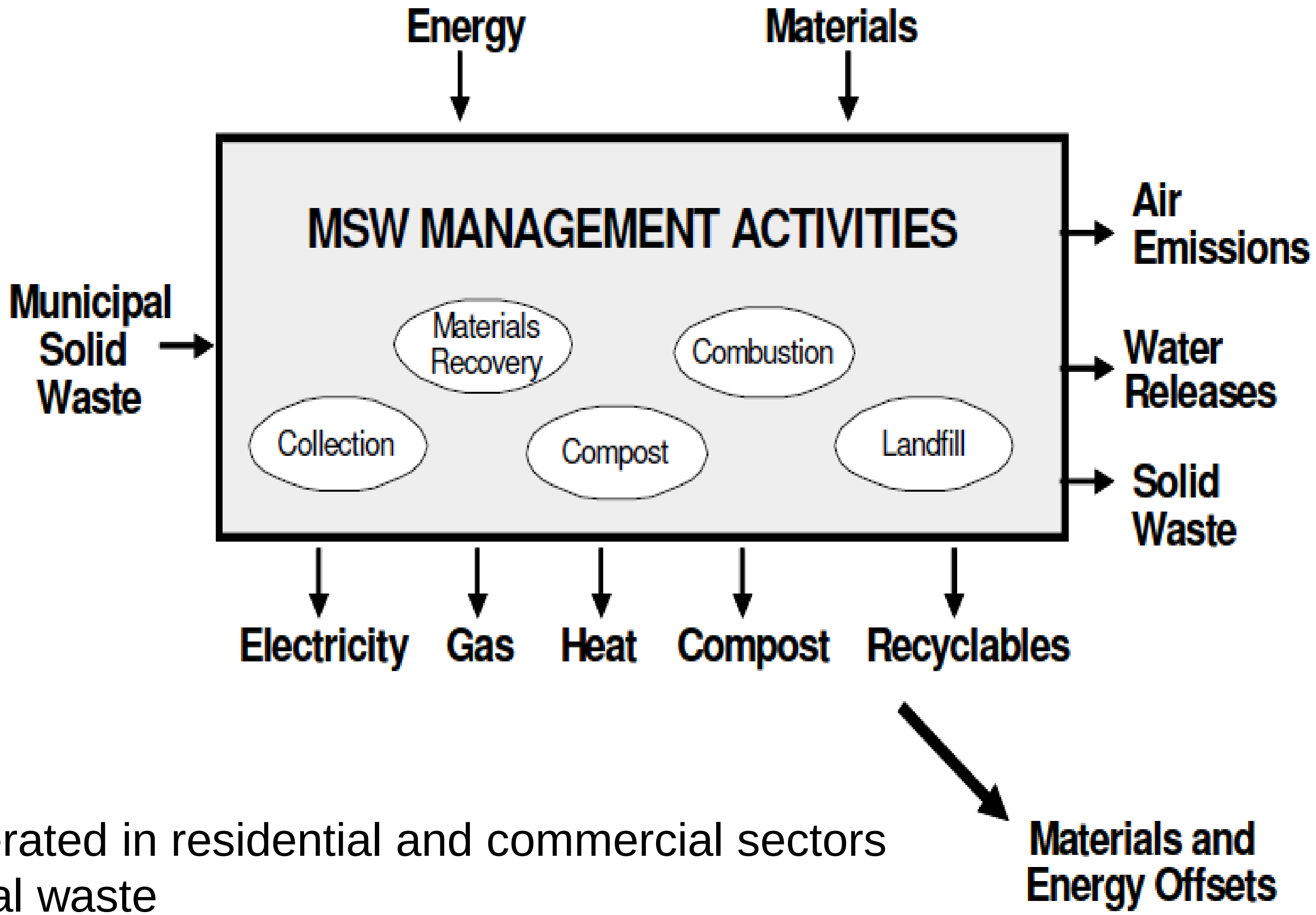
- Although, the input spreadsheets were always available to public, the wide distribution of the tool was hindered by use of expensive optimization software.
- On June 1st, 2013, the MSW-DST was officially launched and made accessible through web for free.
- Currently, we are in development of 2nd generation version which will look at evolution of a MSW system
- Has been used in over **300** studies by industry, academia, **World Bank, NGOs, and state and local governments.**
- To access the MSW-DST log-in @ https://mswdst.rti.org

United States Environmental Protection Agency

Tutorials and other resources

- Website includes:
  - Basic information
  - Technical documentation
  - Tutorials
  - Research papers
- The "basic" tutorial that includes installation instructions, basic operation, and functions of the MSW DST: http://developer.erg.com/~kcabral/beta/player.html
- There are also the following topical tutorials:
  - 1) Modifying Landfill Gas Generation and Management Parameters: http://developer.erg.com/~kcabral/msw-dst/gas/player.html
  - 2) Analyzing Recycling Systems: http://developer.erg.com/~kcabral/msw-dst/recycle/player.html
  - 3) Changing the Electricity Grid Mix of Fuels: http://developer.erg.com/~kcabral/msw-dst/electricity/player.html
- Brochures, documentation for the individual process models included in the MSW DST, and research papers: https://mswdst.rti.org/resources.htm

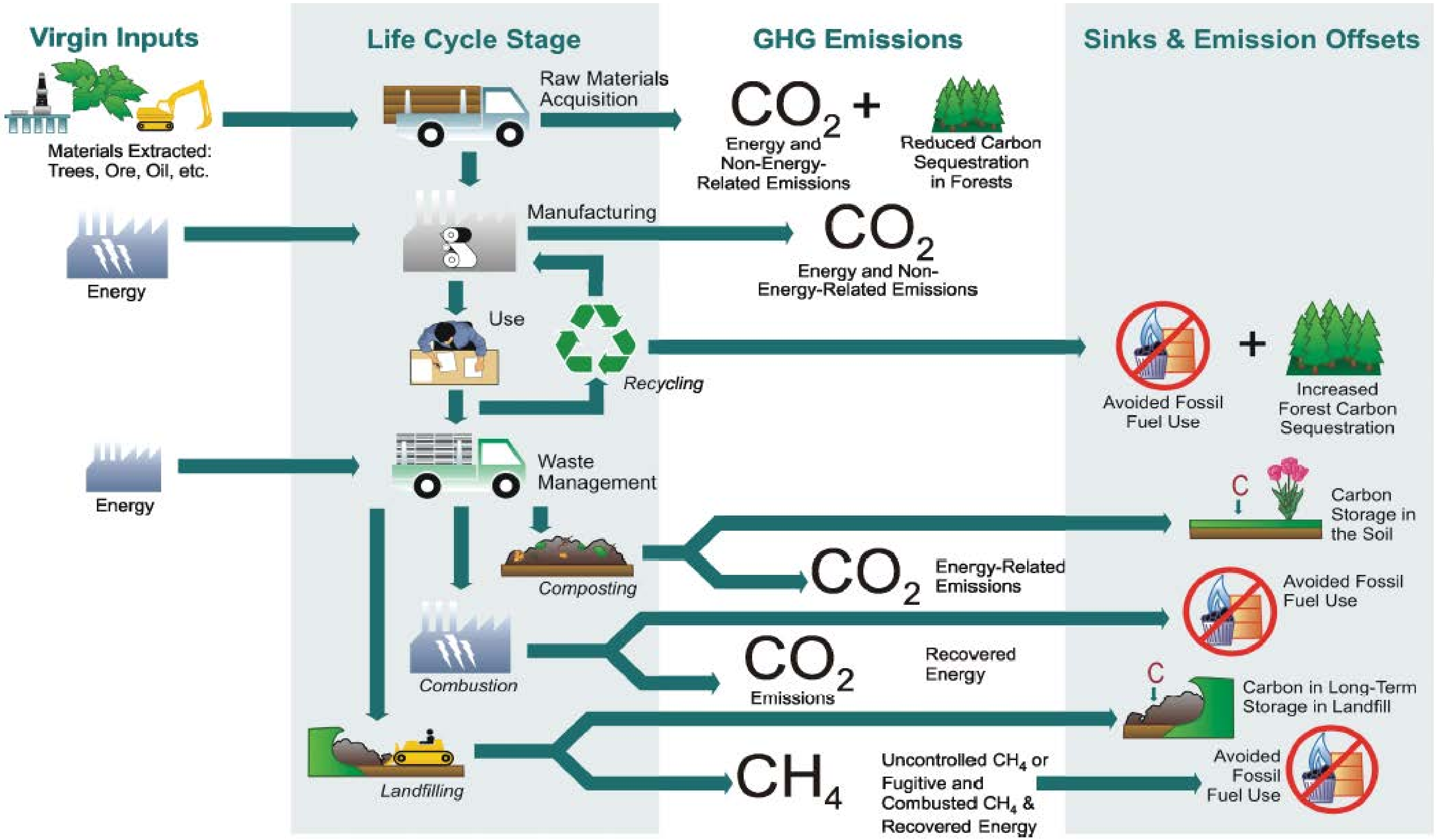
Life-Cycle of MSW Management



MSW includes waste generated in residential and commercial sectors

•No industrial or agricultural waste

Greenhouse Gas Emissions And Solid Waste Management



United States Environmental Protection Agency

System definition

- Consider municipal solid waste (MSW) as defined by the US EPA
  - residential and commercial waste
    - no industrial, agricultural waste
- One ton of MSW as set out for collection
  - focus on waste a municipality manages
    - excludes backyard composting

United States Environmental Protection Agency

Waste generation and composition

- Waste generation is categorized by residential, multifamily, commercial
- Waste composition is defined for following material categories:

Yard Waste (grass, leaves, branches)
Food Waste
Ferrous (cans, other, non-recyclable)
Aluminum (cans, other (2), non-recyclable)
Glass (clear, brown, green, non-recyclable)

Plastics (t-HDPE, p-HDPE, PET bvg, other(5), non-recyclable)
Paper (ONP, OCC, OFF, phone books, OMG, 3rd class mail, other (5) , non-recyclable)
User Defined Mixtures of Paper, Plastic and Glass

Life-cycle based Process models

- A process model of a solid waste unit operation is designed to calculate the cost and life cycle inventory (LCI) of emissions as a function of:
  - waste quantity, waste composition, user defined, site-specific input data

Each Major Solid Waste Unit Operation

- collection
- MRFs (sorting plants)
- transfer stations
- composting (yard and mixed waste)
- waste-to-energy
- landfills (conventional, bioreactor, ash)
- refuse-derived fuel

Each Supporting Unit Operation

- electrical energy
  consumption and recovery
- long distance transportation
- remanufacturing
  the conversion of recyclable materials into new products

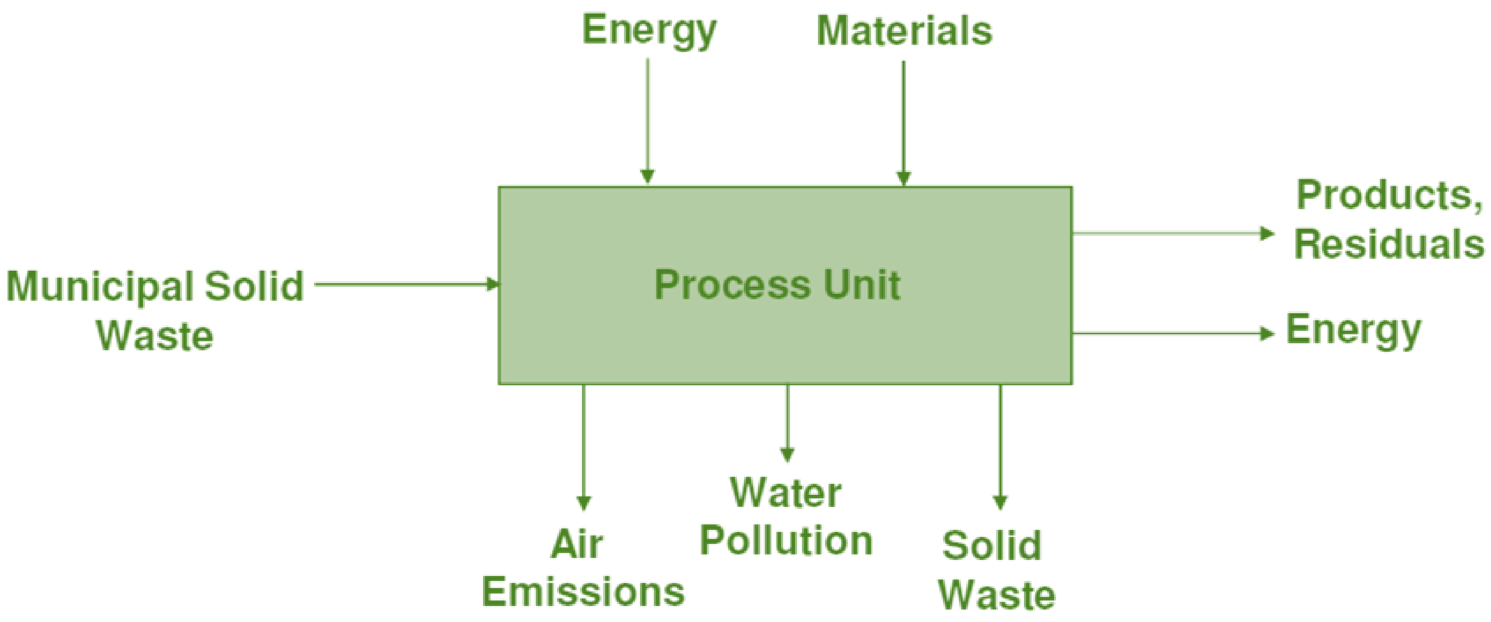
Life-cycle methodology is applied to process models: energy and material balance

- Allocation of emissions to the components processed in a specific unit operation
  - cost, emissions and energy consumption

Collection: allocation by volume

MRF: magnet for Fe metals recovery

Landfill: gaseous emissions due to biodegradable compounds only



Process Models: Typical Input Data

- **Collection Model**

– collection frequency
– truck capacity
– waste density
– time at each stop (location)
– houses per stop
– time between stops

- **Landfill gas model**

– gas generation rate
– gas management (3 periods)
vent, flare, energy recovery
– gas collection efficiency (vary annually)
–waste density
– leachate generation as % of rainfall

Remanufacturing

- Where recyclables are converted to new products:
  - –resource consumption and emissions are associated with recyclables collection and remanufacture
  - –some manufacture from virgin is **avoided**

- The model accounts for the difference:

Offset Analysis
Recycle process emissions - virgin process emissions

Process Model Outputs

- Each process model has a routine to allocate costs, energy and emissions specific waste components
  - – This makes it possible to evaluate changes in a solid waste program
- Recycling compared to combustion of plastics

$, kg CO_2 , BTU ., . . . ton

of glass ton of grass ton of HDPE

HDPE - high density polyethylene

Waste Flow Equations

- Represent all feasible flow paths for solid waste
- Preserve a mass balance
- Solve with an objective function
  - –minimize a particular variable (cost or LCI)
    - subject to specified constraints
      - –block or require a unit operation
      - –diversion requirement
- Optimization is a unique feature of this model

Model Parameters

- Cost & Energy
- Gaseous: CO_2-f, CO_2-b, PM, NO_x, SO_x, CH_4, Greenhouse equivalents (GHE)
- Liquid: BOD, COD, SS, NH_3, PO_4, oil, 10 metals
- Solid Waste: Five categories

Requirement for uniform data
5 + no data ≠ 5

MSW-DST Applications -Delaware

- State of Delaware
  - –Request assistance in their solid waste management planning
- Generated and analyzed variety of scenarios including
  - –Curbside recycling, composting and combustion
- Quantified GHG reductions and energy consumption and cost trade-offs

United States Environmental Protection Agency

MSW-DST Applications -Minnesota

State of Minnesota

- –Request assistance in evaluating specific scenarios of interest to quantify GHG reductions for different management options

• Emphasis in source reduction and materials recovery programs (in quantifying potential benefits)

• Constructing incremental analysis through close interaction with State officials

• State has excellent set of data and other information to work with

- –This is the third project that the MSW-DST has been used to assist the State

United States Environmental Protection Agency

MSW-DST Applications – Wisconsin and Washington States

- State of Wisconsin
  - –Have conducted several different studies with emphasis primarily on helping to quantify potential benefits of ongoing materials recovery programs
  - –Also interest in understanding how the benefits or burdens compare for different materials
- State of Washington
  - –Assisted in evaluating different programs for curb-side collection considering differences in geographical areas (e.g., waste composition, transportation differences)
  - – Interested in understanding differences in implementation of programs between rural and urban regions

MSW-DST Applications -California

- Evaluated different waste conversion technologies (gasification, hydrolysis, catalytic cracking).
- This was specific to waste composition, geography, and technologies.
  - —Follow-up project to use the MSW-DST for study specific to Los Angeles and San Diego
- Evaluated options to achieve its targeted GHG reduction goals while striving towards zero waste.
  - – identify organics diversion alternatives and quantify the GHG emission reductions and associated as well as associated beneficial “offsets” using a life-cycle approach
  - – conduct an economic analysis of GHG reduction options to identify cost effective organics management program activities along with recycling strategies that can achieve optimum GHG emission reductions

MSW DST Applications –World Bank

- Assisting World Bank in study to compare the life-cycle environmental tradeoffs for 10 different cities
  - 8 are in economically developing countries
  - Compared differences in waste management practices, composition, geography, and policies
  - Major emphasis was to develop data and location specific information
    - Funded by the Japanese Trust Fund
  - RTI supported the Japanese firm who is conducting the data collection for this study

United States Environmental Protection Agency

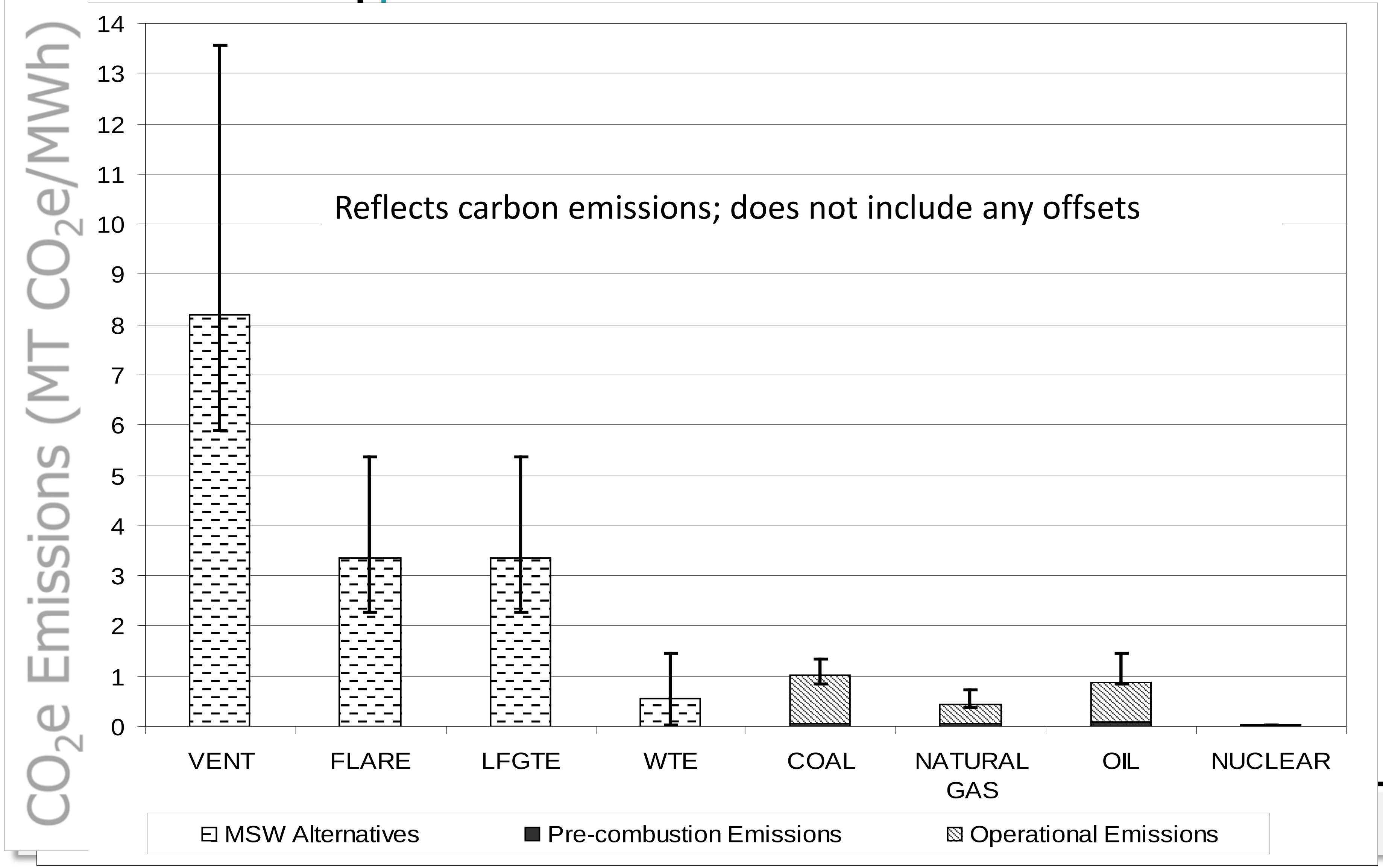
Burn vs. Bury Study

- When comparing electricity (kWh) per ton of municipal waste, WTE is on average six to eleven times more efficient at recovering energy from wastes than landfills.
- For even the most optimistic assumptions about LFGTE, the net life-cycle environmental tradeoffs is 2 to 6 times the amount of GHGs compared to WTE.
  - GHGs for WTE ranged from 0.4 to 1.4 MT MTCO2e/MW h where as the most aggressive LFGTE scenario is resulted in 2.3 MTCO2e/MWh.
- In addition, WTE also produces lower NOx emissions than LFGTE, whereas SOx emissions depend on the specific configurations of WTE and LFGTE.

Kaplan, P. O.; DeCarolis, J.; Thorneloe, S., Is It Better To Burn or Bury Waste for Clean Electricity Generation? *Environmental Science & Technology* **2009, 43 (6), 1711-1717.**

United States Environmental Protection Agency

Comparison of MSW discards management to conventional electricity generating technologies



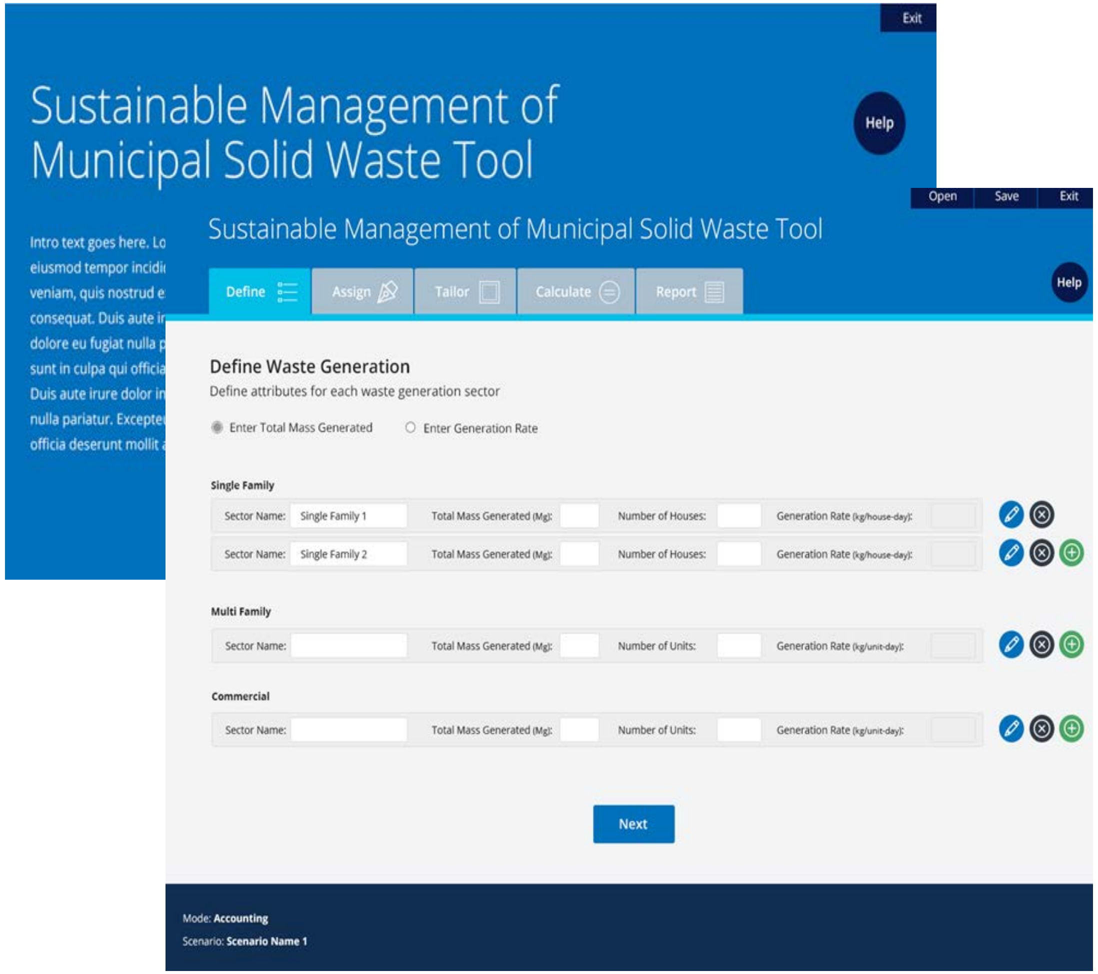
Current Projects – ORD and EPA Regional Collaboration

- Will update 2012 US EPA report conducting LCA of pyrolysis, anaerobic digestion, gasification and other technologies that are emerging in the US for MSW management –
- Goal is to develop decision makers guide for communities being marketed new technologies and providing a means to compare to technologies in use
- Working across several EPA Regions to reflect special needs of tribal and Island communities as well as other communities considering newer technologies
- Landfills continue to be the most difficult source to model due to the difficulty in measuring fugitive emissions, temporal and spatial variability in emissions, changes in the design and operation of the waste management process and changes in waste composition

EPA United States Environmental Protection Agency

Development of 2nd Generation Tool

- All process models have been updated –
  - New process models added including anaerobic digestion
  - Being translated to OpenLCA as part of the Federal Commons
  - Detailed documentation of process models, transparency, and access to code
- Visualization interface is being developed to track performance and communicate potential benefits of more sustainable strategies to community leaders
- Accounting and optimization mode
  - Ability to dynamically reflect changes over time for the energy grid mix and waste composition and quantity
- Anticipated completion 2019



United States Environmental Protection Agency

Benefits from using these tools

- Purpose of using these tools
  - Have standardized process for evaluation that is internally consistent and can reflect the net LCA environmental tradeoffs, costs, and other societal aspects
  - Assess the potential roles of specific technologies or strategies to meet policy goals
  - Identify important system interactions and potential unintended consequences
  - Consider uncertainties in fuel prices, technologies, and policy
  - Provides information to benchmark and track environmental performance over time
- Reflecting differences in how the energy system evolves over time which will have profound impacts on our environment, including climate, air and water

Challenges of using these tools

- Recognizing that there are multiple metrics and priorities that may differ across stakeholder groups
- Assisting communities in translating results as part of potential action plans
- Access to data and information on the parameters that (both cost and LCA environmental tradeoffs) need to be tailored to local or regional values
- Importance of updated waste composition on as generated and as discarded to document
- The variability in energy prices and material market fluctuations

Select Publication List

- Barlaz M.A., Camobreco V., Repa E., Ham R.K., Felker M., Rousseau C. & Rathle J. (1999a) Life-Cycle Inventory of a
- Modern Municipal Solid Waste Landfill, Sardinia 99, Seventh International Waste Management and Landfill Symposium, Vol III, 337-344, Oct 4-8.
- Barlaz M.A., Ranjithan S.R., Brill E.D. Jr., Dumas R.D., Harrison K.W. & Solano E. (1999b) Development of Alternative
- Solid Waste Management Options: A Mathematical Modeling Approach,Sar 99, Seventh Int. Waste Management & Landfill Symp., Vol I, 25-32, Oct 4-8.
- Barlaz, M. A., Kaplan, P. O, S. R. Ranjithan and R. Rynk, 2003, "Evaluating Environmental Impacts of Solid Waste Management Alternatives, Part I", Biocycle, Sept., p. 60 - 66.
- Barlaz, M. A., Kaplan, P. O, S. R. Ranjithan and R. Rynk, 2003, "Evaluating Environmental Impacts of Solid Waste Management Alternatives, Part II" Biocycle, Oct., p. 52 - 56.
- Ecobalance (1999) *Life-Cycle Inventory of a Modern Municipal Solid Waste Lan*dfill; Prepared for the Environmental Research and Education Foundation, Washington, D.C.
- Ham R.K. & Komilis D. (2003) *A Laboratory Study to Investigate Gaseous Emissions and Solids Decomposition During Composting of Municipal Solid Waste*, EPA-600/R-03/004.
- Harrison K.W., Dumas R.D., Solano E., Barlaz M.A., Brill E.D. & Ranjithan S.R. (2001) Decision Support Tool For Life-
- Cycle-Based Solid Waste Management, *Journal of Computing In Civil Engineering*, Jan.
- Jambeck, J., Weitz, K.A., Solo-Gabriele, H., Townsend, T., Thorneloe, S., (2007). CCA-treated Wood Disposed in Landfills and Life-cycle Trade-Offs With Waste-to-Energy and MSW Landfill Disposal, *Waste Management* , Vol 27, Issue 8, Life-Cycle Assessment in Waste Management.
- Kaplan, O.; Ranjithan S.R.; Barlaz M.A. (2006) The Application of Life-Cycle Analysis to Integrated Waste Management Planning for the State of Delaware, Prepared for Delaware Solid Waste Authority, May.

Select Publication List (Cont.)

- Kaplan PO, Ranjithan SR, Barlaz MA (2009) Use of Life-Cycle Analysis To Support Solid Waste Management Planning for Delaware. Environmental Science & Technology 43 (5):1264-1270.
- Solano E., Ranjithan S.R., Barlaz M.A., Brill E.D. (2002a) Life-Cycle-Based Solid Waste Management. I. Model Development, Journal of Environmental Engineering, October.
- Solano E., Dumas R., Harrison K., Ranjithan S.R., Barlaz M.A., & Brill E.D. (2002b) Life-Cycle-Based Solid Waste Management. II. Illustrative Applications, J. of Environmental Engineering, October.
- Thorneloe, S.A., Weitz; K.A; Jambeck, J. (2007) Application of the U.S. Decision Support Tool for Materials and Waste Management, *Waste Management* , Vol 27, Issue 8, Pages 1006-1020, Life-Cycle Assessment in Waste Management.
- Thorneloe S.A., Weitz K.A., Barlaz M. & Ham R.K. (1999a) Tools for Determining Sustainable Waste Management Through Application of Life-Cycle Assessment: Update on U.S. Research, Sardinia 99, 7th International Landfill Symposium, Vol V, 629-636, Oct 4-8.
- Thorneloe S.A. & Weitz K.A. (2001) U.S. Case Studies using MSW DST. Proceedings Sardinia 2001, 8th Int. Waste Management & Landfill Symposium, Cagliari.
- Thorneloe S.A. & Weitz K.A. (2003) Holistic Approach to Environmental Management of Municipal Solid Waste. Proceedings Sardinia 2003, 9th International Waste Management and Landfill Symposium, CISA publisher, Cagliari.
- Thorneloe, S.A. & Weitz K.A. (2004) Sustainability and Waste Management. Proceedings from Sustainable Waste Management, Waste Management Association of Australia, Nov 24-26, 2004, Melbourne, Australia.
- Weitz K.A., Thorneloe S.A., Nishtala S.R., Yarkosky S. & Zannes M. (2002) The Impact of Municipal Solid Waste Management on GHG Emissions in the United States, Journal of the Air and Waste Management Association, Vol 52, 1000-1011.
- Weitz, K.A. (2003) *Life-Cycle Inventory Data Sets for Material Production of Aluminum, Glass, Paper, Plastic, and Steel in North America*,

https://webdstmsw.rti.org.

United States Environmental Protection Agency

Available documentation

- **Collection Model**
  - Dumas, R. D. and E. M. Curtis, 1998, “A Spreadsheet Framework for Analysis of Costs and Life-Cycle Inventory Parameters Associated with Collection of Municipal Solid Waste,” Internal Project Report, North Carolina State University, Raleigh, NC. (https://webdstmsw.rti.org/docs/Collection_Model_OCR.pdf)
- **Transfer Stations**
  - **https://webdstmsw.rti.org/docs/Transfer_Station_Model_OCR.pdf**
- **Separation of recyclables and discards**
  - ***Nishtala, S. and E. Solano-Mora, 1997, “Description of the Materials Recovery Facilities Process Model: Design, Cost and Life-Cycle Inventory,” Project Report, North Carolina State University, Raleigh, NC. (https://webdstmsw.rti.org/docs/MRF_Model_OCR.pdf)***
- **Treatment including refuse derived fuel, waste-to-energy, yard- and mixed-waste composting**
  - Nishtala, S., 1997, “Description of the Refuse Derived Fuel Process Model: Design, Cost and Life-Cycle Inventory,” Project Report, Research Triangle Institute, RTP, NC.
  - Composting process model: https://webdstmsw.rti.org/docs/Compost_Model_OCR.pdf
  - Harrison, K. W.; Dumas, R. D.; Barlaz, M. A.; Nishtala, S. R., A life-cycle inventory model of municipal solid waste combustion. J. Air Waste Manage. Assoc. 2000, 50, 993-1003.
- **Disposal including traditional and wet landfills and ash landfill**
  - Camobreco, V.; Ham, R; Barlaz, M; Repa, E.; Felker, M.; Rousseau, C. and Rathle, J. Life-cycle inventory of a modern municipal solid waste landfill. Waste Manage. Res. 1999. 394-408.
  - Eleazer, W. E.; Odle, W. S.; Wang, Y. S.; Barlaz, M. A., Biodegradability of municipal solid waste components in laboratory-scale landfills. Environ. Sci. Technol. 1997, 31(3), 911-917.
  - Sich, B.A. and M. A. Barlaz, 2000, “Calculation of the Cost and Life Cycle Inventory for Waste Disposal in Traditional, Bioreactor and Ash Landfills,” Project Report, North Carolina State University, Raleigh, NC. (https://webdstmsw.rti.org/docs/Landfill_Model_OCR.pdf)

United States Environmental Protection Agency

Available documentation (Cont.)

- **Background process models to account for energy/electricity consumption and offsets, and remanufacturing of recyclables**
  - Dumas, R. D., 1997, “Energy Consumption and Emissions Related to Electricity and Remanufacturing Processes in a Life-Cycle Inventory of Solid Waste Management,” thesis submitted in partial fulfillment of the M.S. degree, Dept. of Civil Engineering, NC State University.
  - Energy process model: https://webdstmsw.rti.org/docs/Energy_Model_OCR.pdf
  - Remanufacturing process model: https://webdstmsw.rti.org/docs/Remfg_OCR.pdf
- **Decision Support Tool, Optimization and Alternative Strategy Generation**
  - Harrison, K.W.; Dumas, R.D.; Solano, E.; Barlaz, M.A.; Brill, E.D.; Ranjithan, S.R. A Decision Support System for Development of Alternative Solid Waste Management Strategies with Life-Cycle Considerations. ASCE J. of Comput. Civ. Eng. 2001, 15, 44-58.
  - Solano, E.; Ranjithan, S.; Barlaz, M. A.; Brill, E. D. Life Cycle-Based Solid Waste Management 1. Model Development. *J. Environ. Engr*. 2002, 128, 981-992.
  - Solano, E.; Dumas, R. D.; Harrison, K. W.; Ranjithan, S.; Barlaz, M. A.; Brill, E. D. Life Cycle-Based Solid Waste Management 2. Illustrative Applications. J. Environ. Engr. 2002, 128, 993-1005.
  - Kaplan, P.O., 2006, “A New Multiple Criteria Decision Making Methodology for Environmental Decision Support,” Doctoral Dissertation, Dept. of Civil Engineering, North Carolina State University.
  - Manual: https://webdstmsw.rti.org/docs/DST_Manual_OCR.pdf
  - Tool Website: https://webdstmsw.rti.org/resources.htm
- **Uncertainty Propagation and Sensitivity Analysis Tools**
  - Kaplan, P. O., 2001, “Consideration of cost and environmental emissions of solid waste management under conditions of uncertainty,” MS Thesis, Dept. of Civil Engineering, North Carolina State University.
  - Kaplan, P. O.; Barlaz, M. A.; Ranjithan, S. R. Life-Cycle-Based Solid Waste Management under Uncertainty. J. Ind. Ecol. 2004, 8, 155-172.

Thank you for your interest

We welcome any questions and comments.

Contact:

Dr. Ozge Kaplan, Kaplan.Ozge@epa.gov, 919-541-5069 (NYC MARKAL and MSW DST)
Dr. Mine Isik (ORISE Research Fellow), Isik.Mine@epa.gov (NYC MARKAL)
Edward J Linky, Linky.Edward@epa.gov (NYC MARKAL, EPA Region 2)
Susan Thorneloe, Thorneloe.Susan@epa.gov (MSW DST, co-PI)