PROJECT: SUSTAINABLE INFRASTRUCTURE FOR ENERGY AND WATER SUPPLY (SINEWS)

PI: John C. Crittenden

Presented by: Arka Pandit

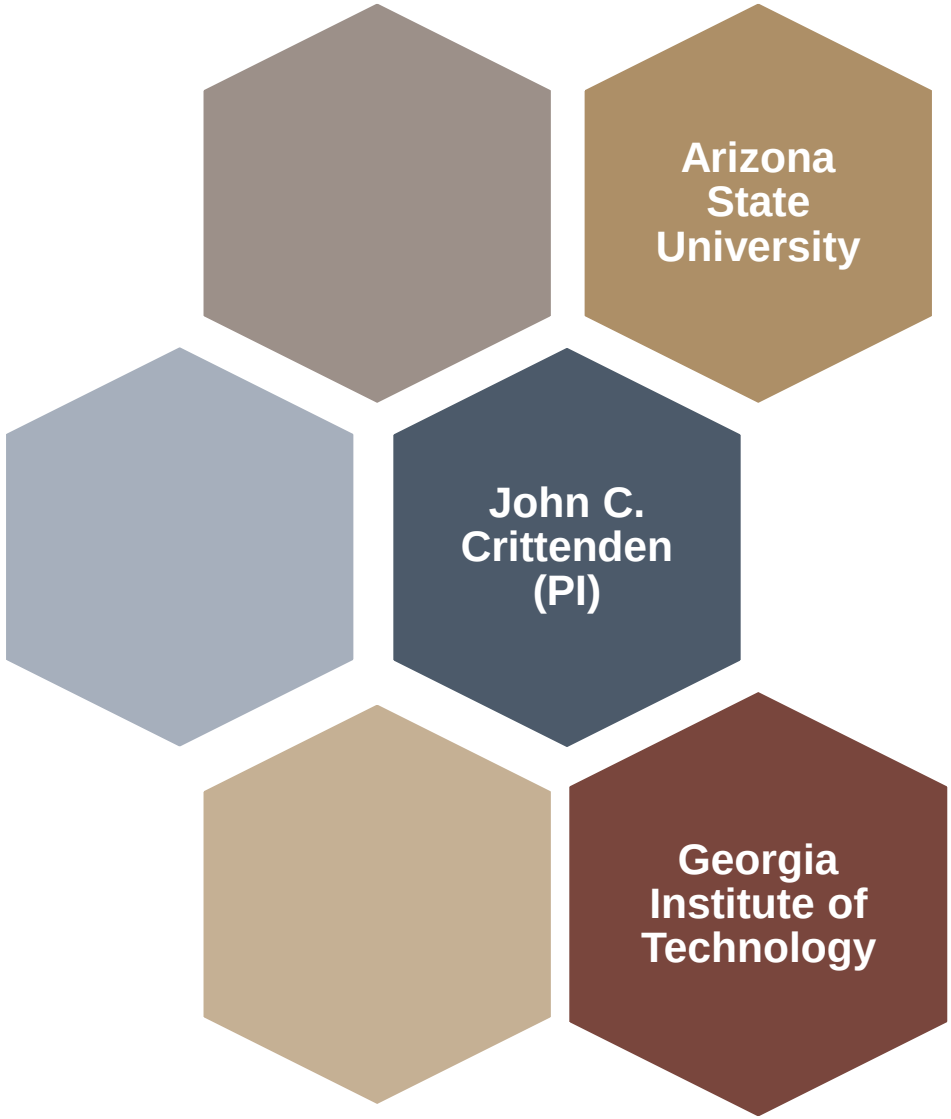
E-Mail: Arka.Pandit@gatech.edu

Brook Byers Institute for Sustainable Systems

NSF

Georgia Institute of Technology

Participants in the RESIN Project



George G. Karady
Samuel Ariaratnam
Charles Perrings
Ke Li

Bert Bras
Doglas Noonan
Miroslav M. Begovic
Marilyn Brown
Steven P French

Outline

- Infrastructure Ecology
- Decentralized Water Resource Development: Low Impact Development (LID)
- Decentralized Energy Production:
  - Combined Heat and Power (CHP)
  - Renewable Energy
- Policies for Adoption of Rain Water Harvesting and Compact Living
- Large Scale Urban Development Simulation: Water Savings and GHG Emission Reductions from LID and CHP
- Implications for Decision Making
- Summary

INFRASTRUCTURE ECOLOGY

Q: With the next generation of infrastructure, what are the implications if we design, build, and operate these systems separately, as we have done in the past?

City

People

Economy

Transportation

Energy

Water

Waste

Buildings

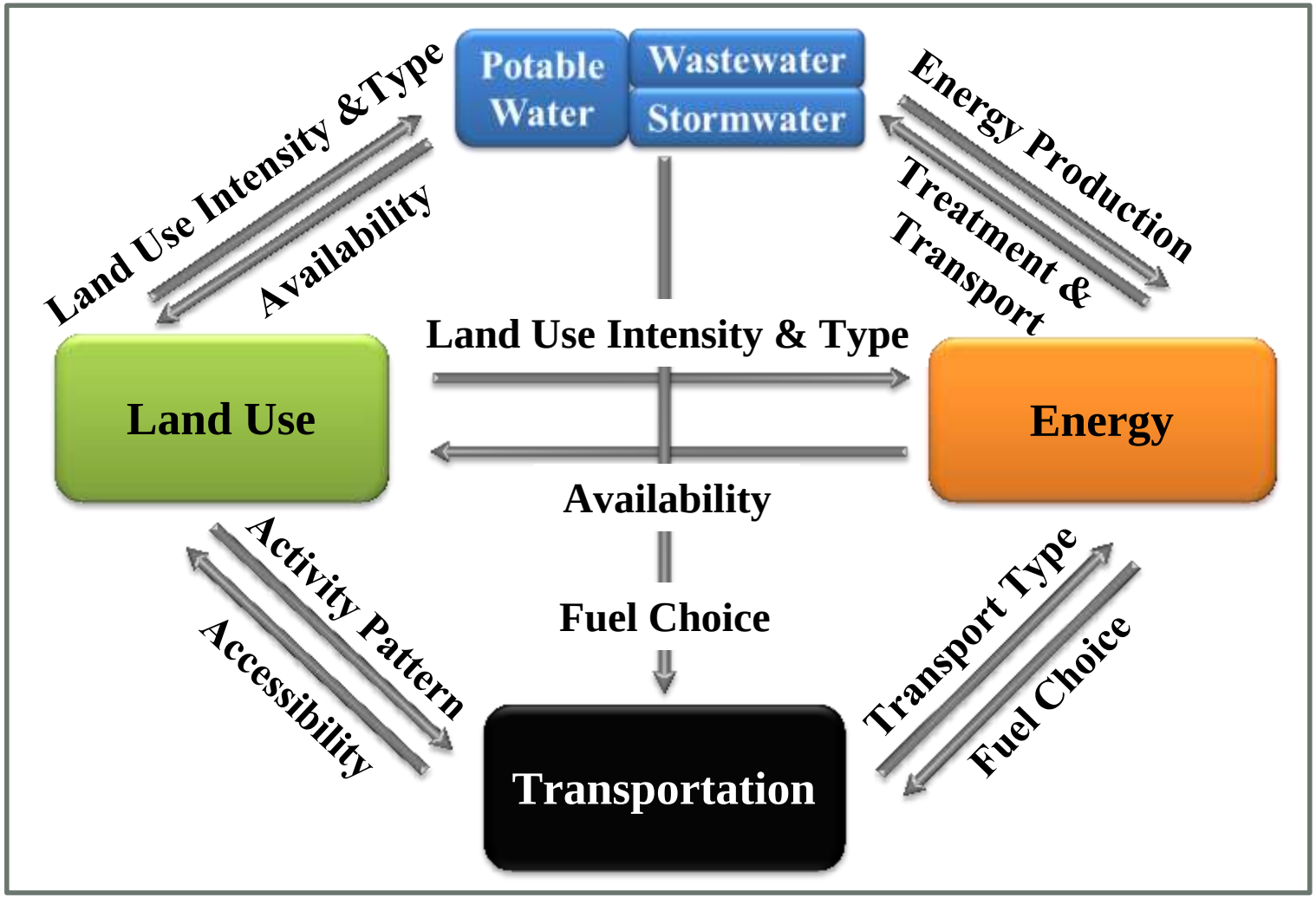
Parks

Industry

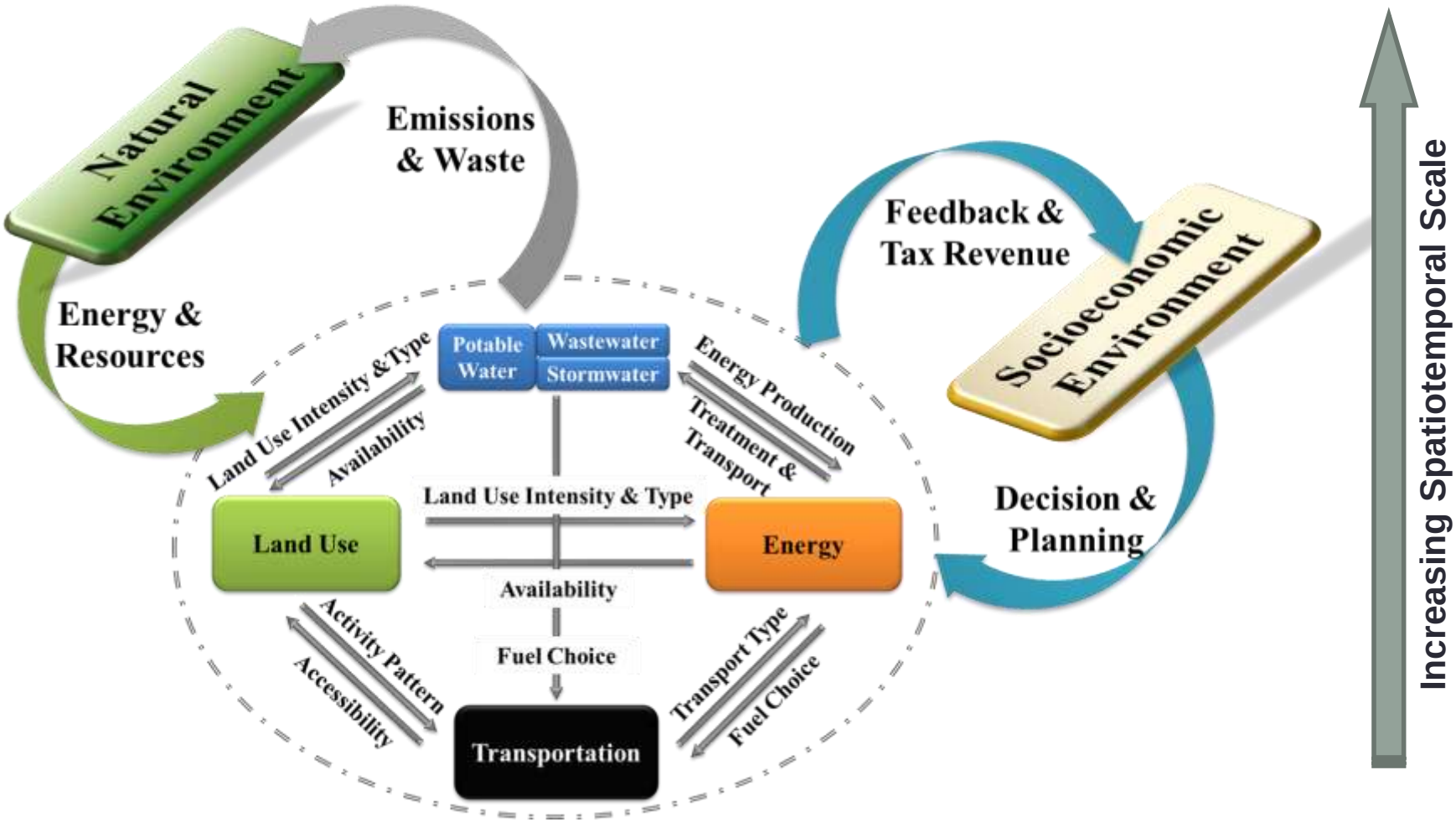
Government

And many more…

Interdependence of Different Infrastructure Components



Interconnection between Urban Infrastructure System , Natural Environmental Systems and Socio-Economic Systems



Why Infrastructure Ecology?

Analogies between UIS and Ecological Systems:

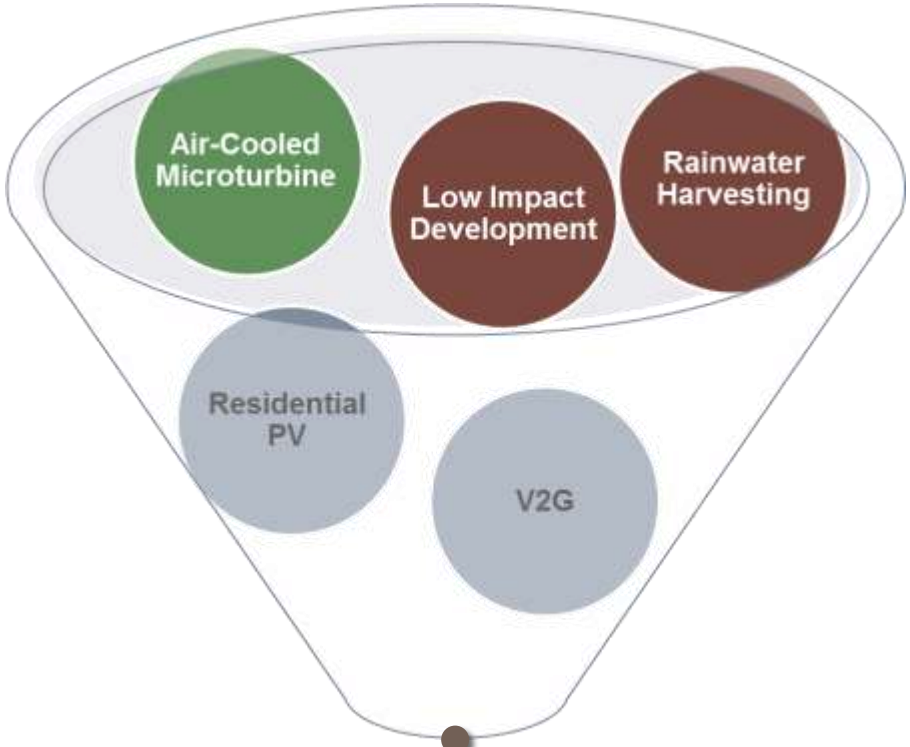
- are complex, dynamic and adaptive;
- are comprised of interconnected components;
- connect the natural and human environments;
- are scalable and show efficiency of scale;
- share some general architectural dynamics across time and space;
- create novelty; and
- cannot be evaluated by looking at any component element, but instead must be examined as a system.

Problems with current paradigm of Urban Infrastructure Planning:

1. Compartmental Optimization resulting in:
    1. Unintended Consequences
    2. Sub-optimal System Level Performance
    3. Non inclusion of macro-level emergent properties

The Synergistic Effects of *"Infrastructural Symbiosis"*

- Designing UIS using an infrastructure ecology approach alters and reorganizes energy and resource flows, allowing one to consider the potential synergistic effects arising from infrastructural symbiosis.
  - The accumulated synergistic effects of this particular model of infrastructure ecology is significant:
    - reduced water and energy consumption,
    - lower dependence on centralized systems,
    - larger share of renewables in the electricity mix,
    - reduced vehicle-miles travelled, &
    - an increase in tax revenue.



DECENTRALIZED WATER RESOURCE DEVELOPMENT: LOW IMPACT DEVELOPMENT

Implementation of Low Impact Development Techniques: Case Study of Atlanta, GA

Rain Barrel

Rain Garden

Pervious Space

- Benefits:
  - For a 3-story apartment community,
    - 40% reduction of potable water demand, about 12,000 Gal/cap/yr
    - 37% reduction in impervious area
    - 50% reduction in irrigated area
    - 20% reduction of Life Cycle Impacts

Citywide implementation of Hybrid (LID + Centralized) System would save the city ~$1.2million per year in energy costs.
Rain gardens occupying 11% - 16% of community size can control 100% of stormwater runoff generated in extreme rainfall events up to 8 in/24-hr.

DECENTRALIZED ENERGY PRODUCTION: COMBINED HEAT AND POWER (CHP)

Summary: Building Energy Requirements met by Air-Cooled Microturbines

Design Criteria

Number of buildings=
(Thermal output at max efficiency/Peak thermal load)$_{monthly}$

Heat
Cooling

Thermal Load

Electricity

Electrical Load

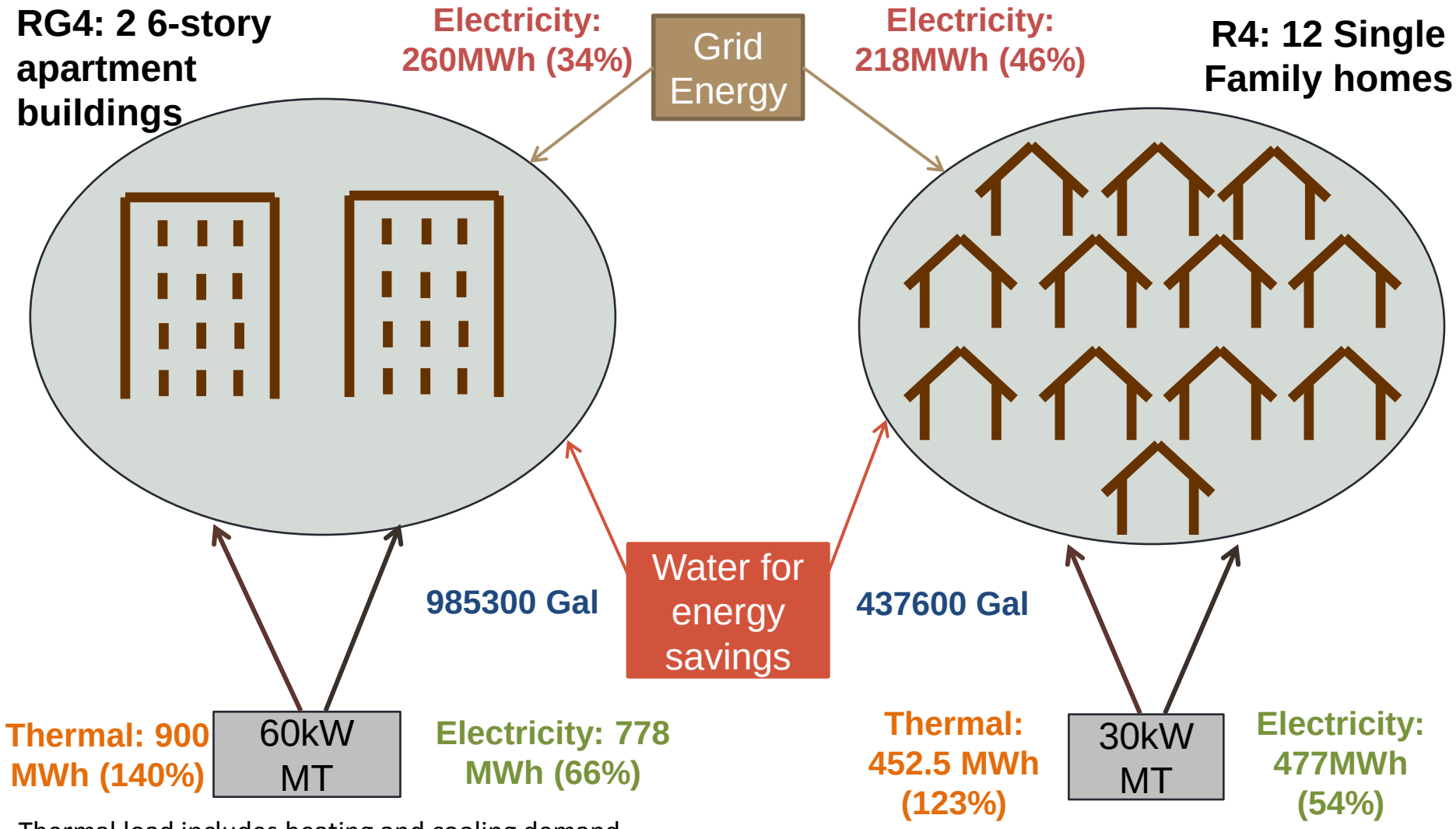
Building Types

	R4 (12 Single Family	RG4 (2 Apartment buildings)
Thermal Load – Required	346.5 MWh (100%)	540 MWh (100%)
Thermal Load – Excess	106 MWh (23%)	360 MWh (40%)
Electrical Load – Required	477 MWh (54%)	778 MWh (66%)

The design criteria for:

- R4 buildings is based on the usage of a 30kW microturbine
- RG4 buildings is based on the usage of a 60 kW microturbine

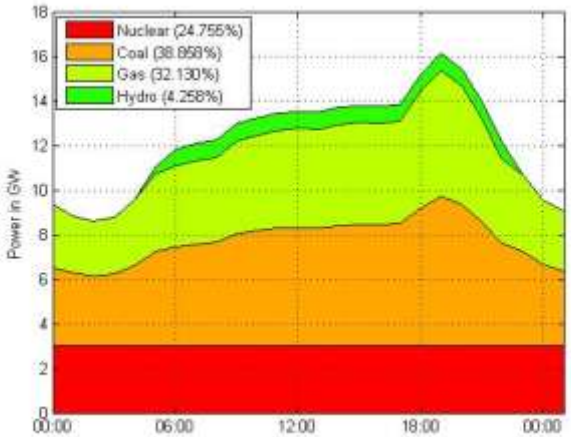
Summary of building energy requirements met by CHP



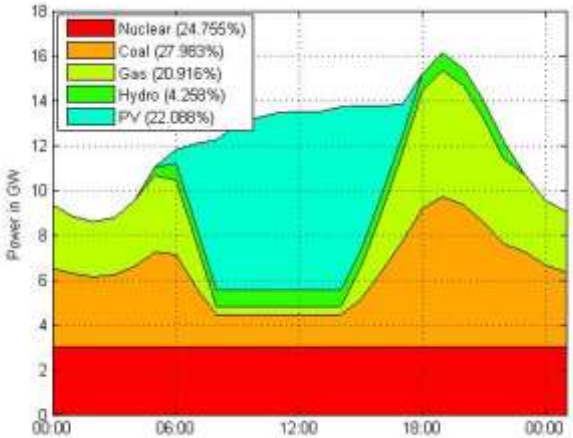
Thermal load includes heating and cooling demand

DECENTRALIZED ENERGY PRODUCTION: RENEWABLE ENERGY

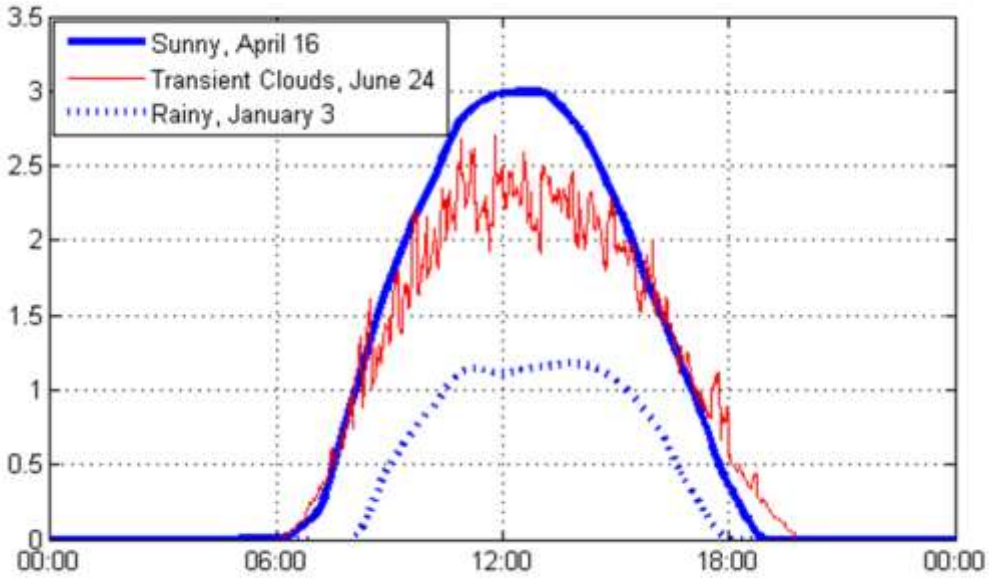
Simulation Results in Hourly Resolution



NO-PV



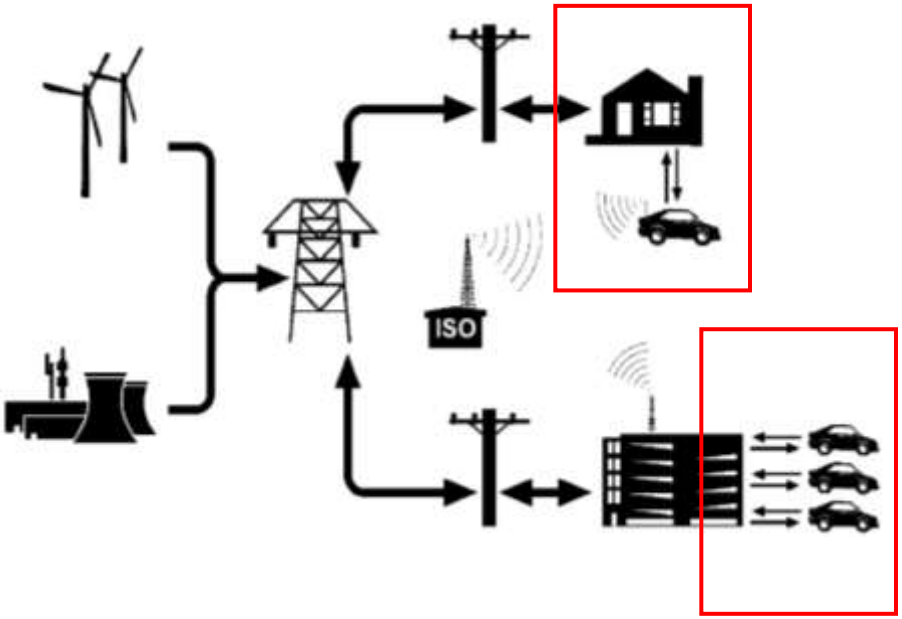
40% PV



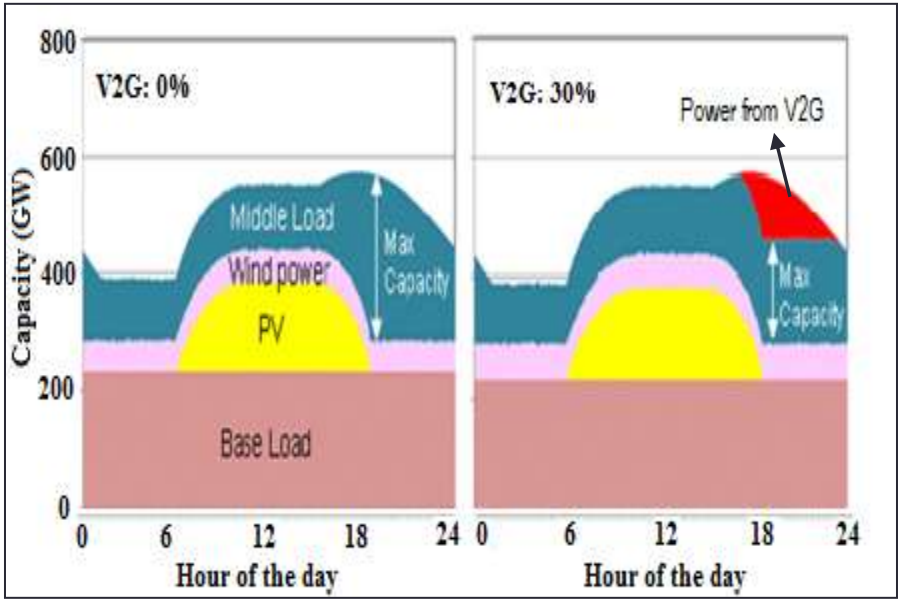
The large variation in PV output demands a higher capacity of spinning reserves

Plug-in Hybrid Electric Vehicles (PHEVs) and Vehicle-to-Grid (V2G) power

PHEVs can send power back to the grid when parked, and function as distributed storage for intermittent energy from renewable sources



Credit: Kempton and Tomić, 2005



US demand-supply balances during maximum demand with various V2G ratios in 2045

30% V2G penetration could reduce ~100 GW or about ⅓ of the total peak demand of ~300 GW in US by 2045

Source: Modelling Load Shifting Using Electric Vehicles in a Smart Grid Environment – © OECD/IEA 2010

POLICIES FOR ADOPTION OF RAIN WATER HARVESTING AND COMPACT LIVING

Interactions between Infrastructure and Socio-Economic Environment

Macro

Emergent Properties: land use, water, energy and material consumption, transportation quality, quality of life, and other sustainability metrics.

Water

Energy

Heating/ Cooling

Transportation

Infrastructure Systems

Socio-Economic Environment

Jobs

Business

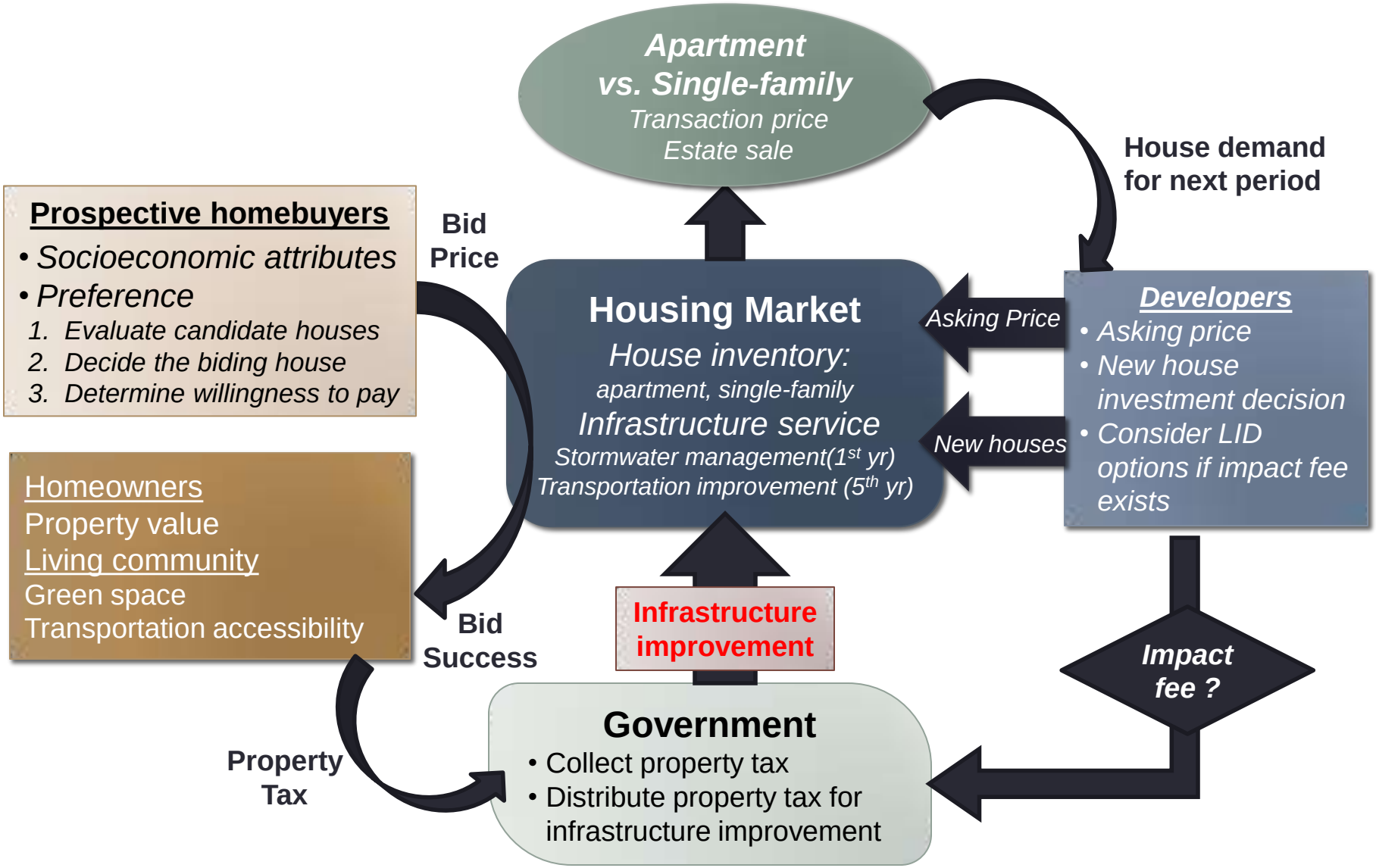
Neighborhood

Housing

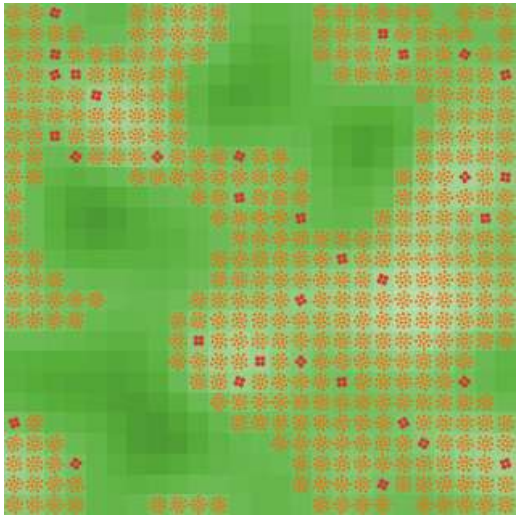
Micro

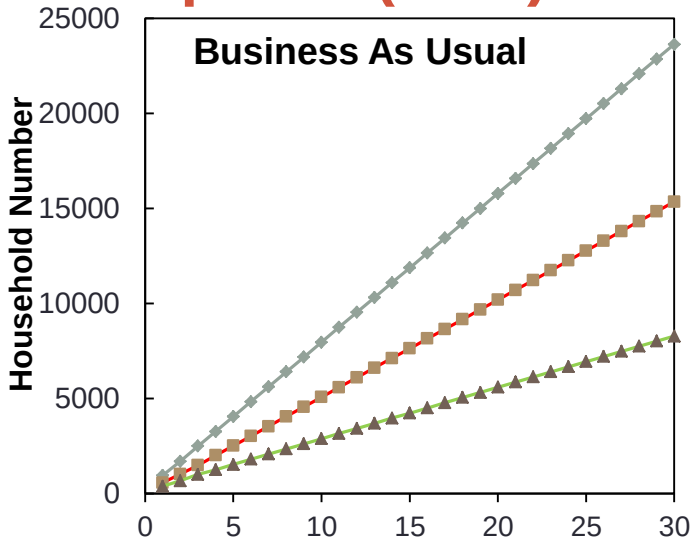
Decisions, behaviors of Individual Agents and the relationship of individual agents: location choice, traffic activity, and willingness to pay

Agent-based Housing Market Simulation

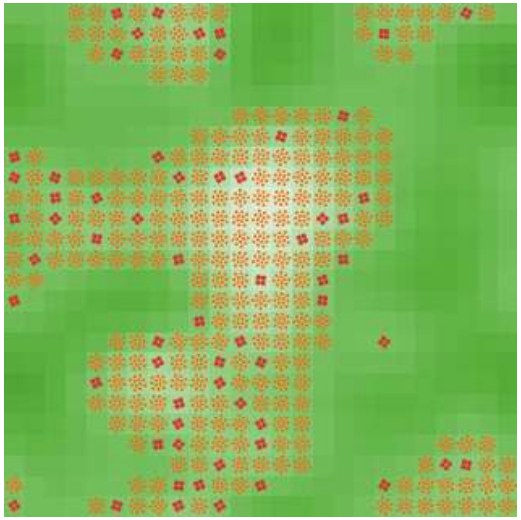


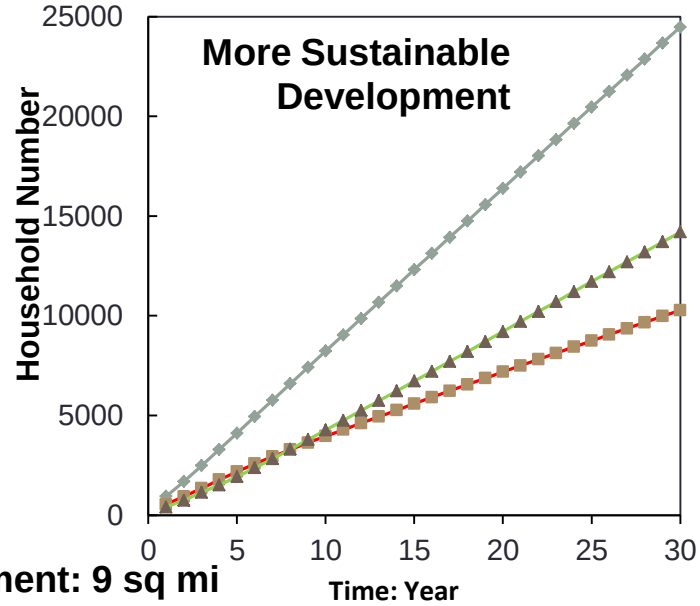
Land Use Pattern Between Business As Usual (BAU) and More Sustainable Development (MSD)





Scenarios	Total households	% of households living in apartment
BAU	23,630	35.0%
MSD	24,475	58.0%





Impact fee for LID non-compliance penalty:

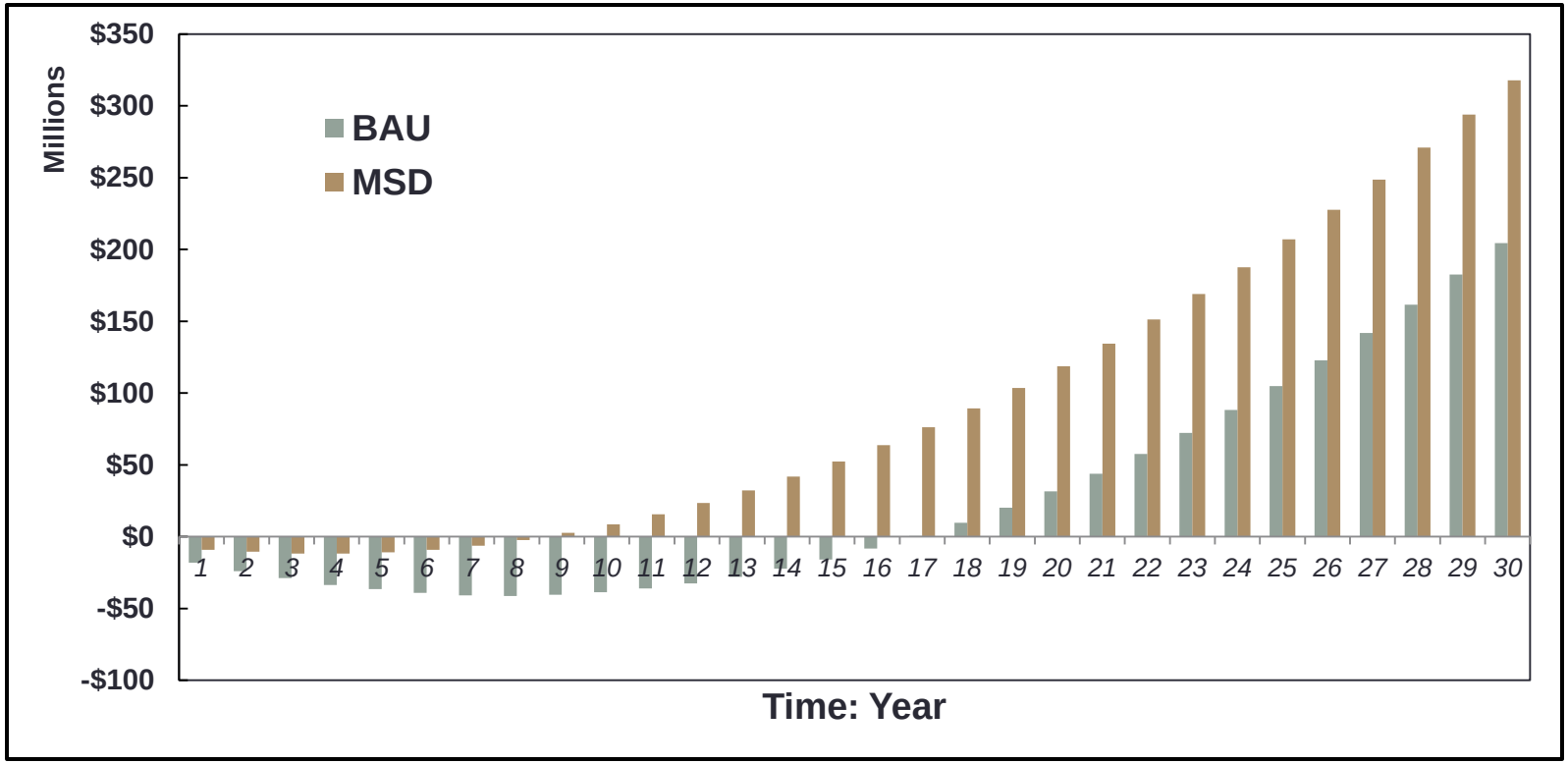
- **$13,000 per unit for single-family house**
- **$1,500 per unit for apartment home**

The total area for new development: 9 sq mi

: Single Family Homes **: Apartment Homes**

Property Tax Revenues

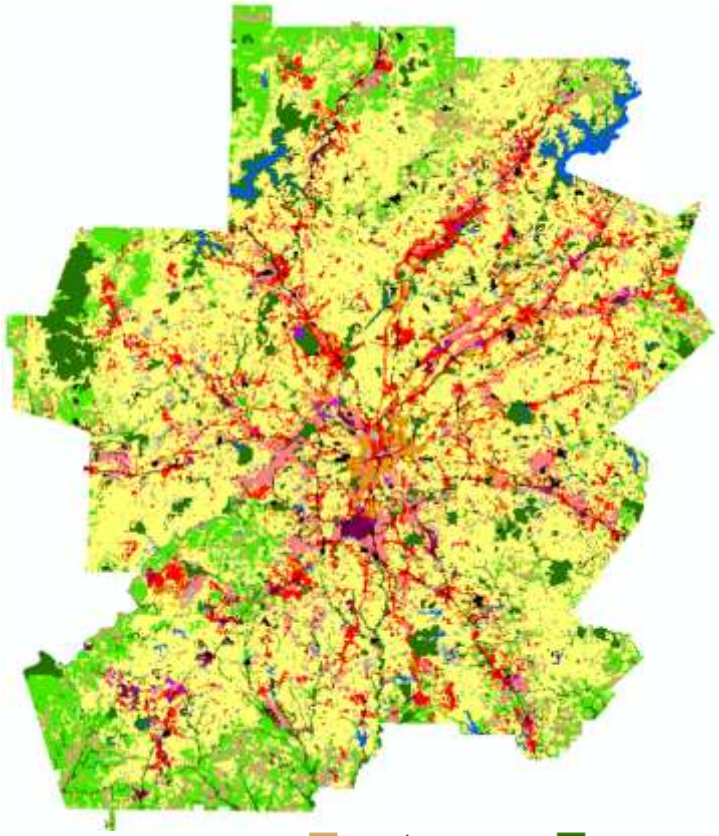
- BAU versus MSD
- Accumulation of property tax revenues for 30 years
  - *Surplus at time t = (property tax revenues at time t) – (new construction cost for stormwater management at time t) + (Surplus at time t-1)*
  - *Property tax revenues at time t = (house value at time t) × 0.4 × 0.01 × (number of households)*



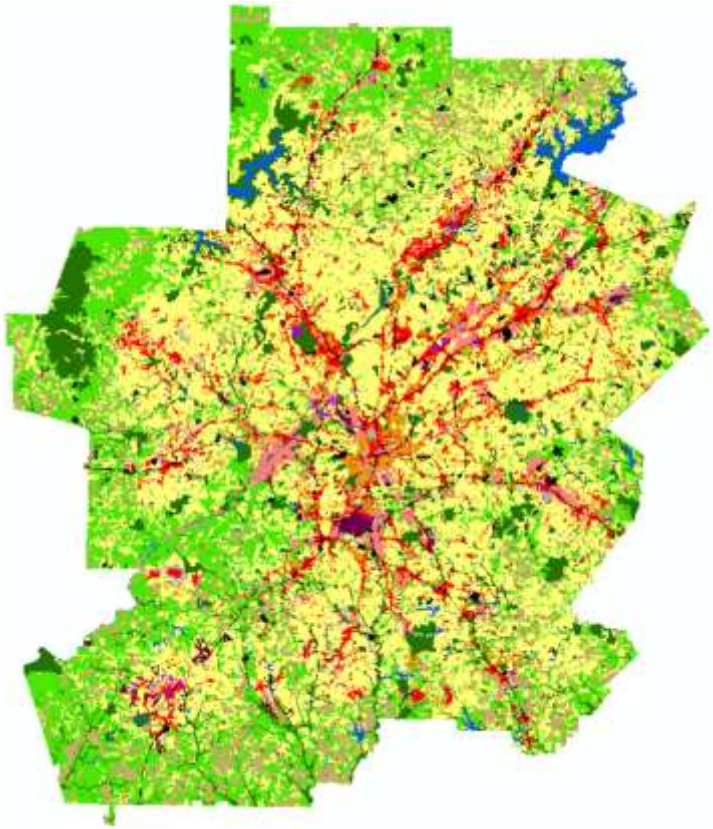
URBAN DEVELOPMENT SIMULATION AND LARGE SCALE WATER SAVINGS CARBON EMISSION REDUCTIONS FROM LID AND CHP

Projected Growth Scenarios for Atlanta

Business As Usual
Year 2030



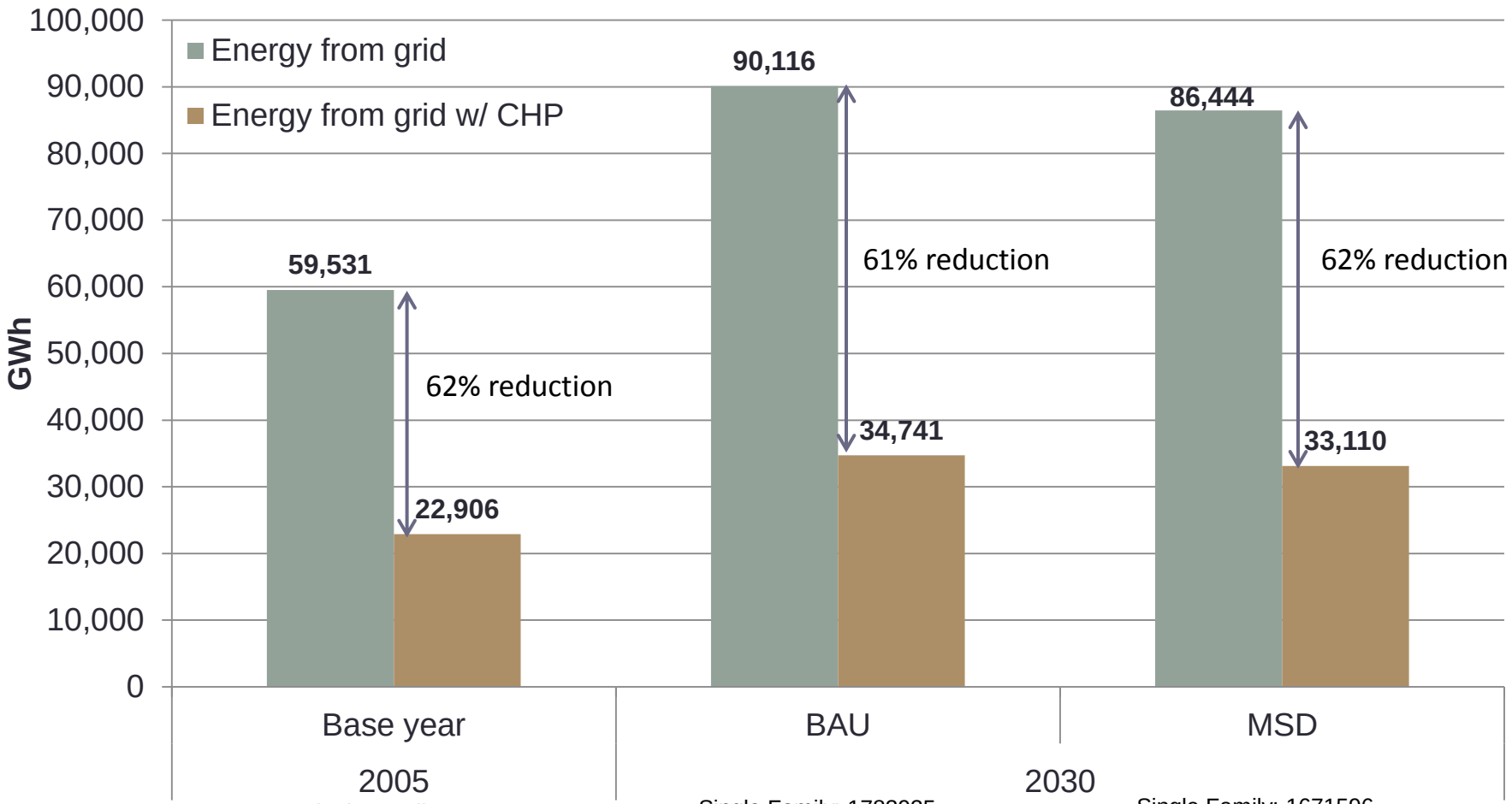
More Sustainable Development
Year 2030



Agriculture
Com_Office
Com_WholeS_Const
Conservation
Forest
HighMulti Res
Industrial
LowMed Res
Open Water
Other Developable
Parks
Pub. Institutional
TCU
Undevelopable

ATL Residential Energy Demand from Grid

(with Air Cooled Microturbines in a Decentralized CHP system)



# of Households:

Single Family: 1170283
Apartments: 458207

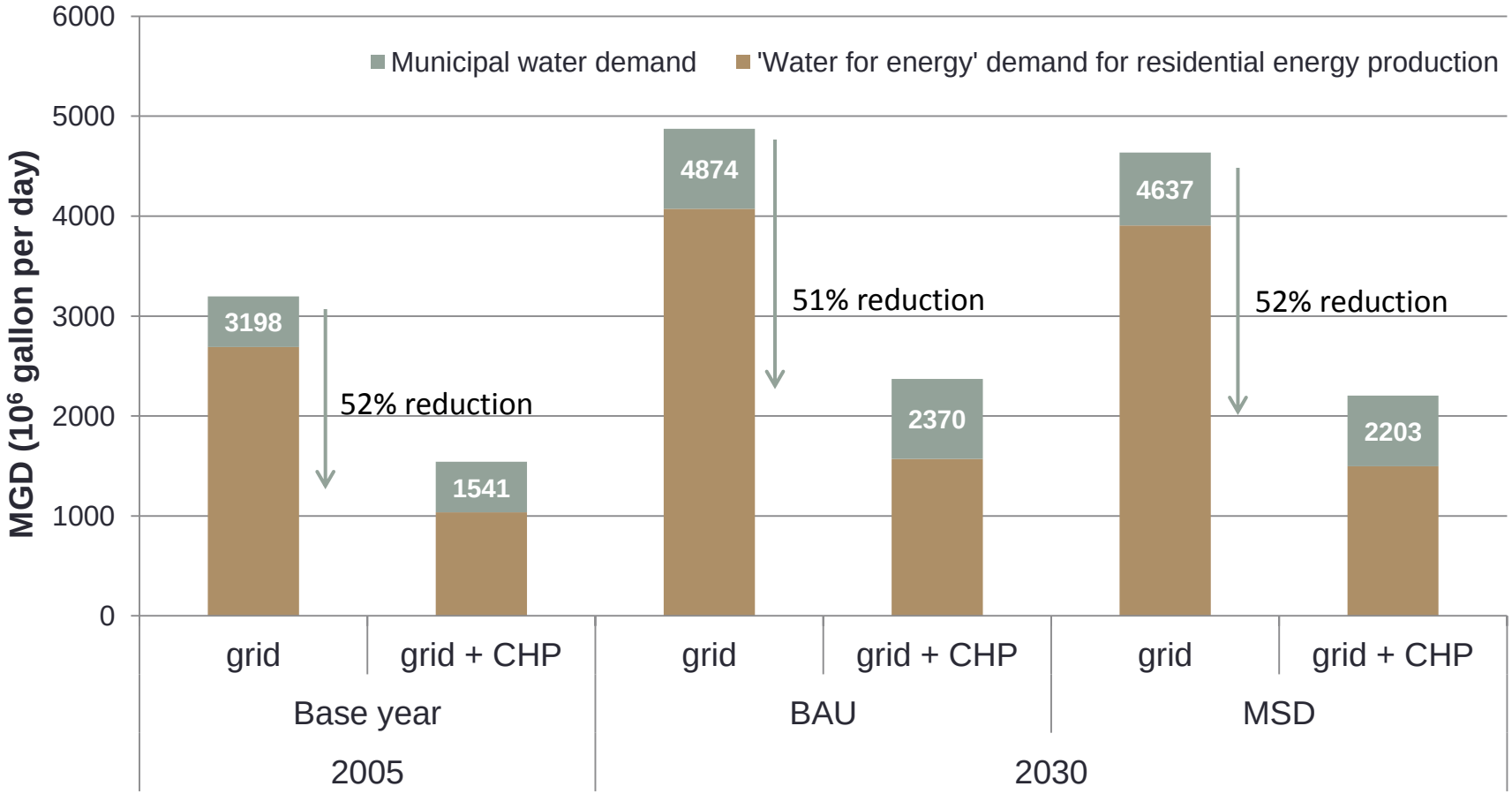
Single Family: 1783935
Apartments: 649907

Single Family: 1671596
Apartments: 763019

Note: The 2030 grid+CHP scenarios assumed all residential units in the base year were retrofitted with CHP systems

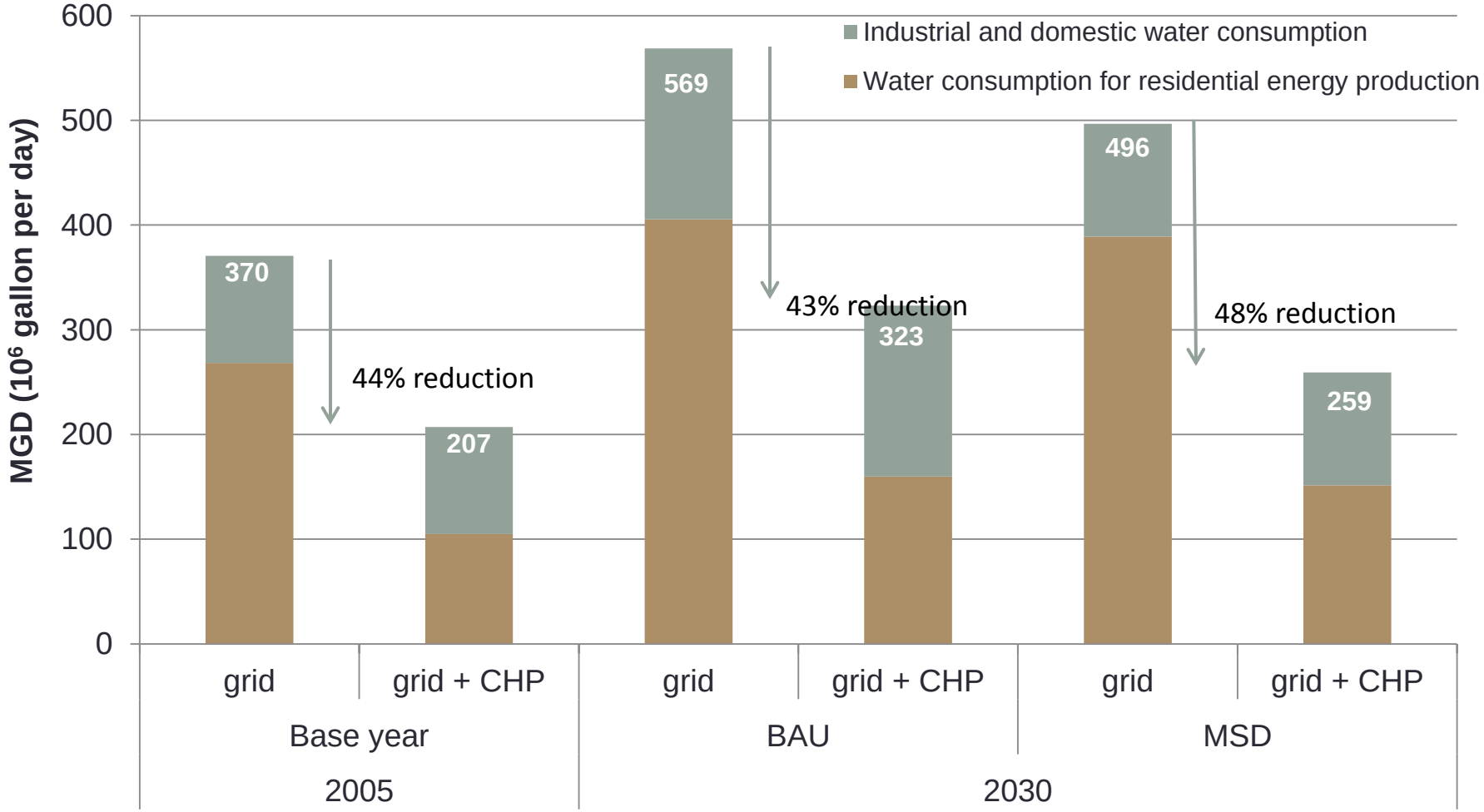
BAU= Business As Usual MSD= More Sustainable Development CHP: Combined Heat and Power

ATL Water Demand Projection (Withdrawal)
(with low flow fixtures + rooftop rainwater harvesting + CHP)



Note: The 2030 grid + CHP scenarios assumed all residential units in the base year were retrofitted with CHP systems

ATL Water Consumption Projection (Evaporation)
(with low flow fixtures + rooftop rainwater harvesting + CHP)



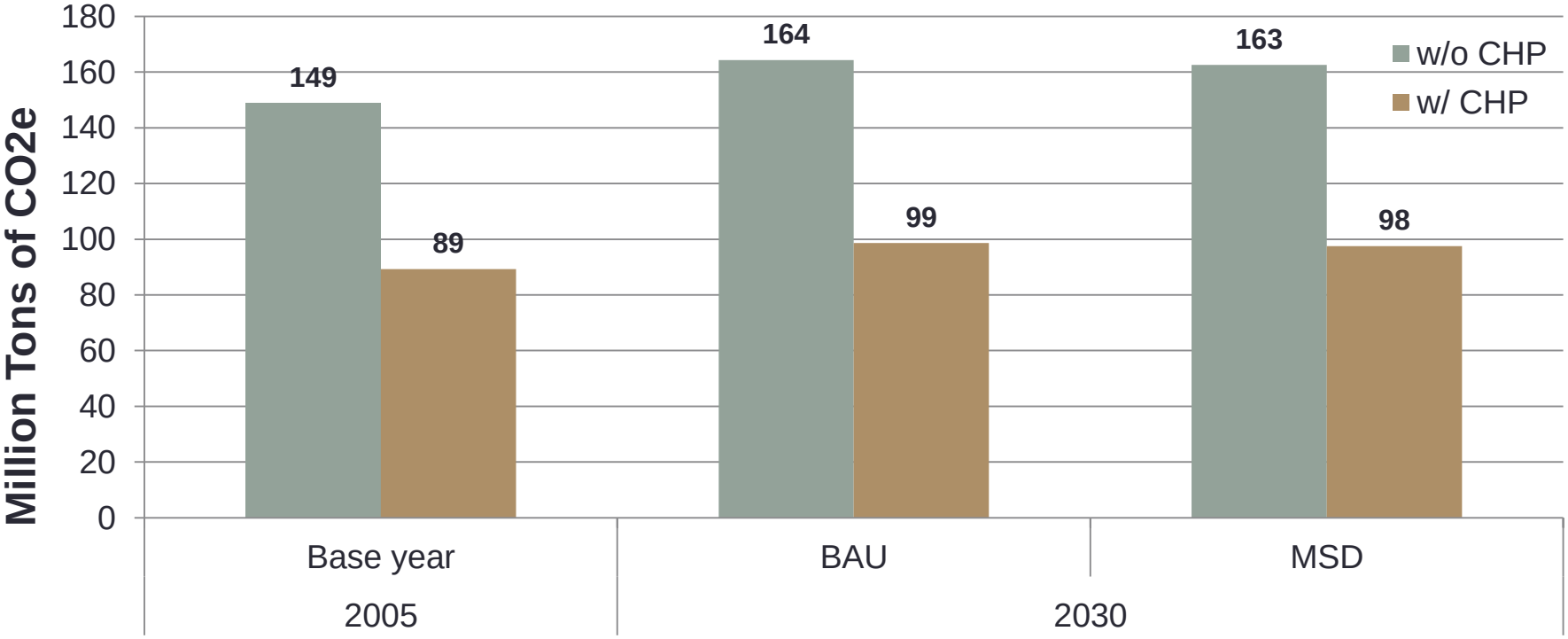
Note: The 2030 grid + CHP scenarios assumed all residential units in the base year were retrofitted with CHP systems

(Courtesy: Crittenden et al., Georgia Tech)

Potential GHG reductions in 2030

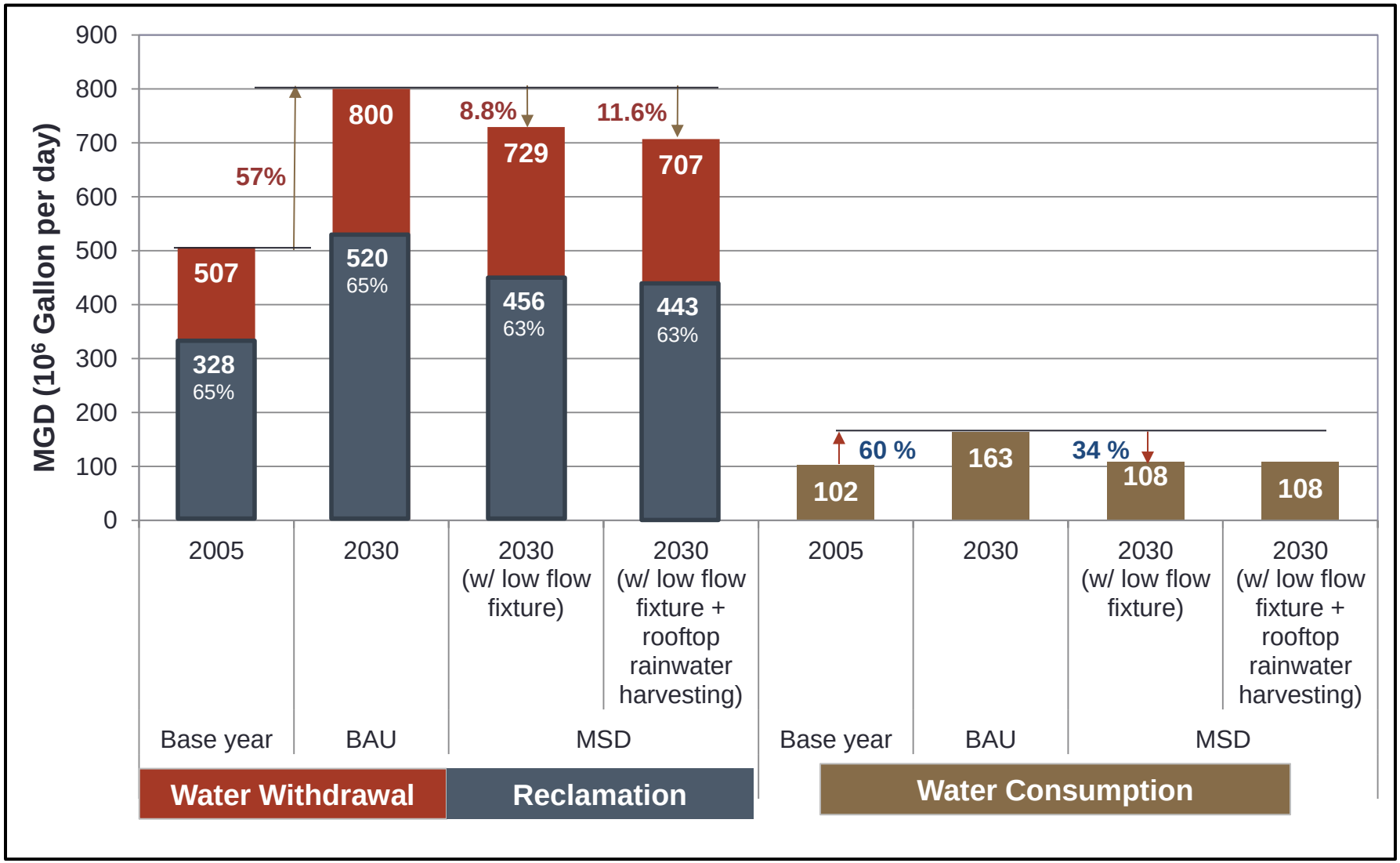
- The reduction is based on the electricity produced by CHP replacing that from the centralized power plant.
- Base year case assumes that all existing homes are retrofitted to facilitate a CHP system.
- The 2030 grid+CHP scenarios assumed residential units in the base year were also retrofitted with CHP systems
- For MSD implementation the CO_2e Savings is 0.065 Gt

~ 40% Reduction in all cases



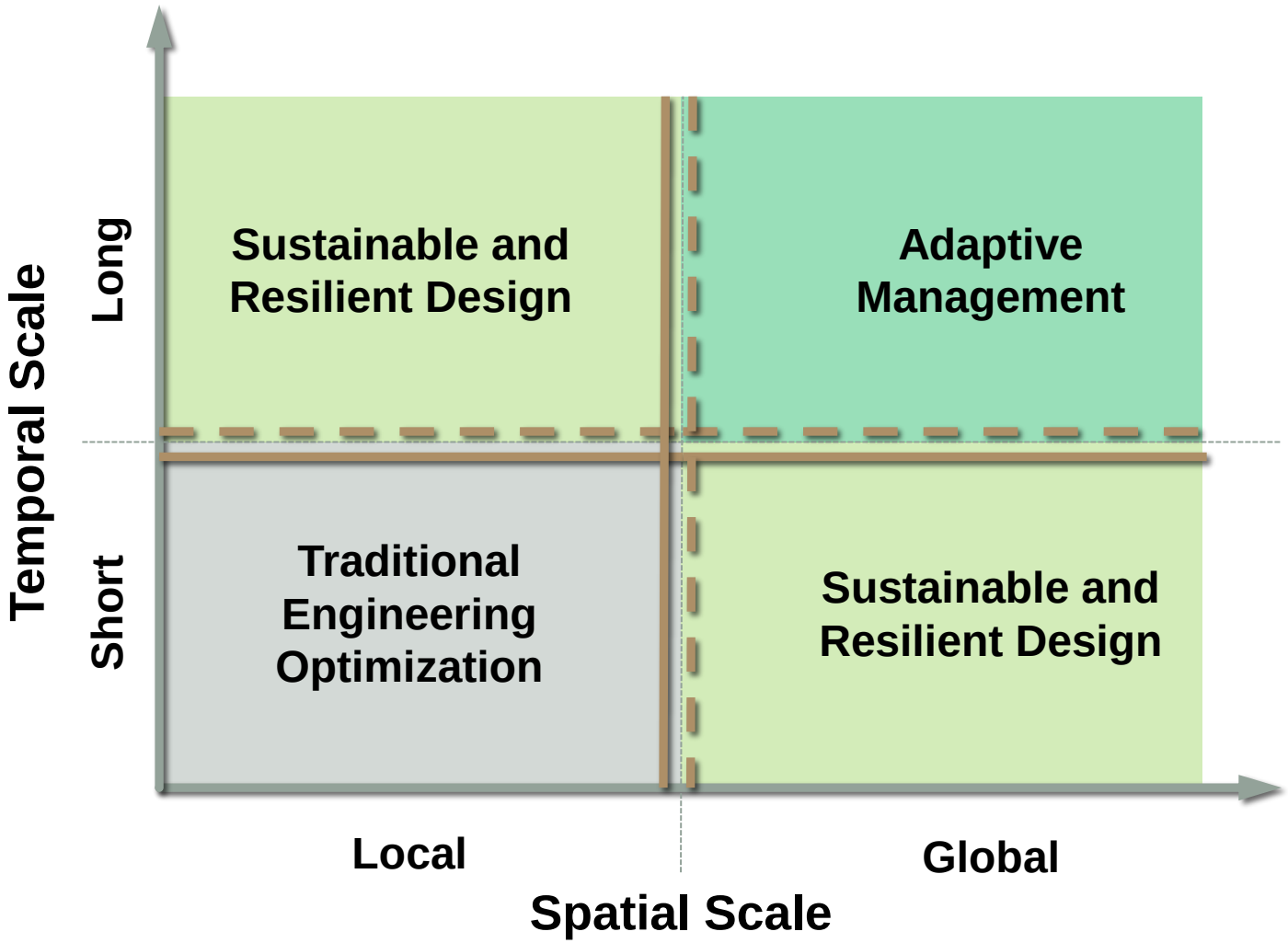
Projected Domestic Water Demand

(with low flow fixture + rooftop rainwater harvesting + reclamation)



IMPLICATIONS FOR DECISION MAKING

Dimensions of Decision Making



Sustainable and Resilient Design and Adaptive Management

Sustainable and Resilient Design

- Technological Intervention
  - Increase the capacity of the system to absorb shocks from a perturbation and minimize the damage.
  - Decrease the response time in the aftermath of a perturbation
    - ***Smart infrastructure:*** wireless sensors to communicate failure events

Adaptive Management

- Policy Intervention
  - To make the Urban Infrastructure Systems more flexible and adaptable to changing scenarios.
  - To increase and promote adoption of more *"sustainable and resilient"* alternatives (both technological and behavioral) across the urban System through policy tools.

SUMMARY

Summary

- Urban Systems Are All Connected and More Efficiency Can be Achieved by Looking at Their Interactions
- Decentralized Energy and Combined Heat and Power Can Save Energy and Water
- Decentralized Water / Low Impact Development Can Save Water, Energy and Money
- Land Use/ Planning Is Vital in Reducing the Impact Of Urban Systems and Examining Their Interactions
- Agent Based Models May Be Useful to Examine the Adoption Rate of Policy Instruments

THANK YOU!!