Technical Assessment of Micro-Generation Technologies within the United States

Mark Davis, NIST

Building Integration of
Micro-Generation Technologies

October 27, 2010

Purpose

Demonstrate the potential primary energy savings, carbon dioxide emission savings, and annual energy cost savings that result from the integration of micro combined heat and power within a typical house in six representative US cities using *predictive performance models*

Outline

- Micro-CHP Devices
- Predictive Performance Models
- Residential Micro-CHP System Equipment
- "Typical" US Residence
- Modeling Assumptions
- Results
- Conclusions

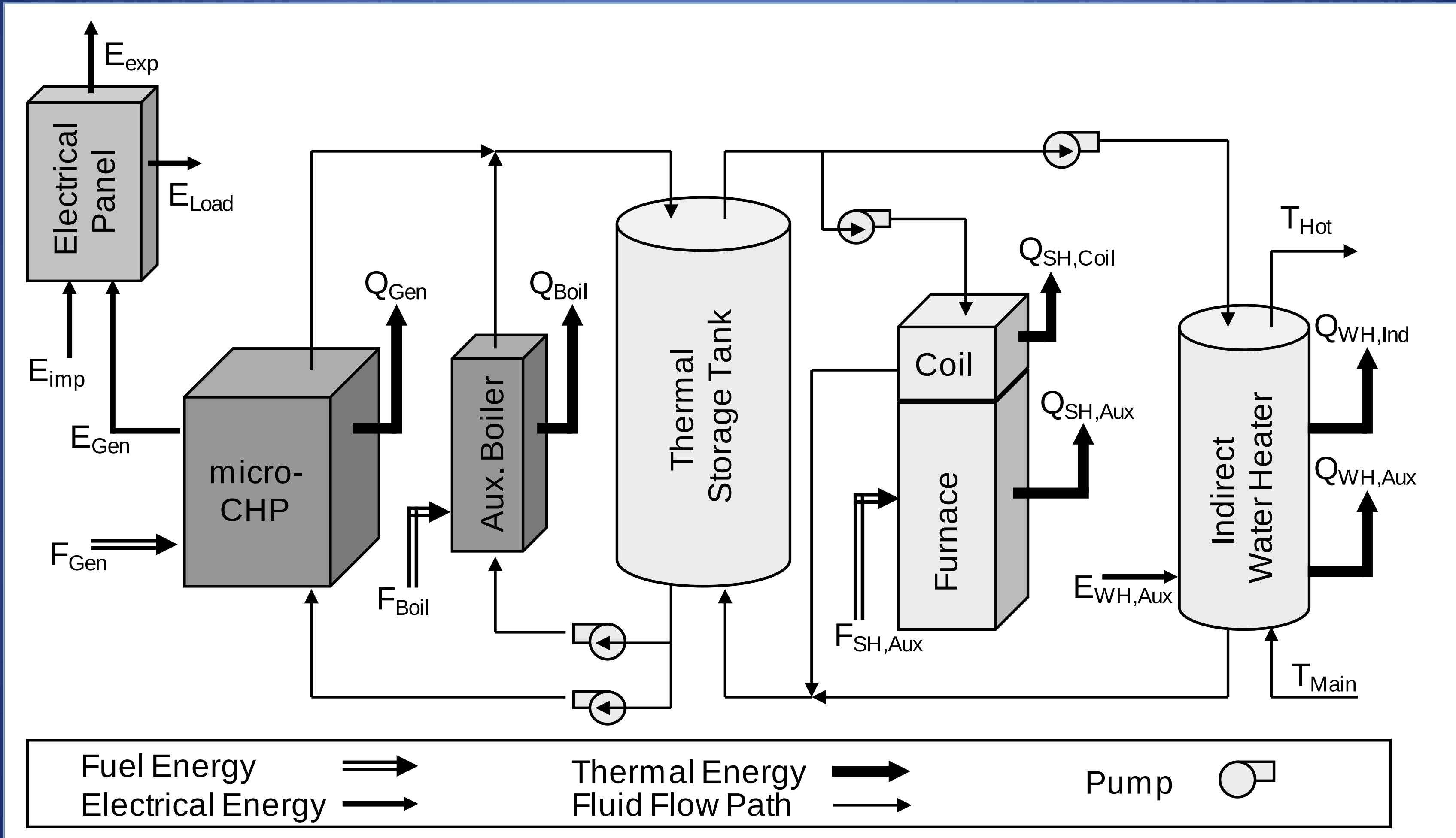
Representative Micro-CHP Devices

Parameter	Small ICE	Medium ICE	Large ICE	Small SE	Medium SE	Large SE
Fuel Consumption (kW)	4	12	20	4	12	20
Electrical Output (kW)	1	3	5	0.35	1	1.7
Electrical Efficiency	25 %	25 %	25 %	8.5 %	8.5 %	8.5 %
Recovered Heat (kW)	2.6	7.8	13.0	3.4	10.3	17.2
Heat Recovery Efficiency	65 %	65 %	65 %	86 %	86 %	86 %

Predictive Performance Model

- Developed by IEA/ECBCS Annex 42
- Implemented in TRNSYS
  - Transient building energy simulation platform
- Steady state efficiency affected by
  - Electrical power
  - Circulating fluid temperature
- Transient performance accounts for
  - Startup/shutdown
  - Changes in electrical power and fluid temperature

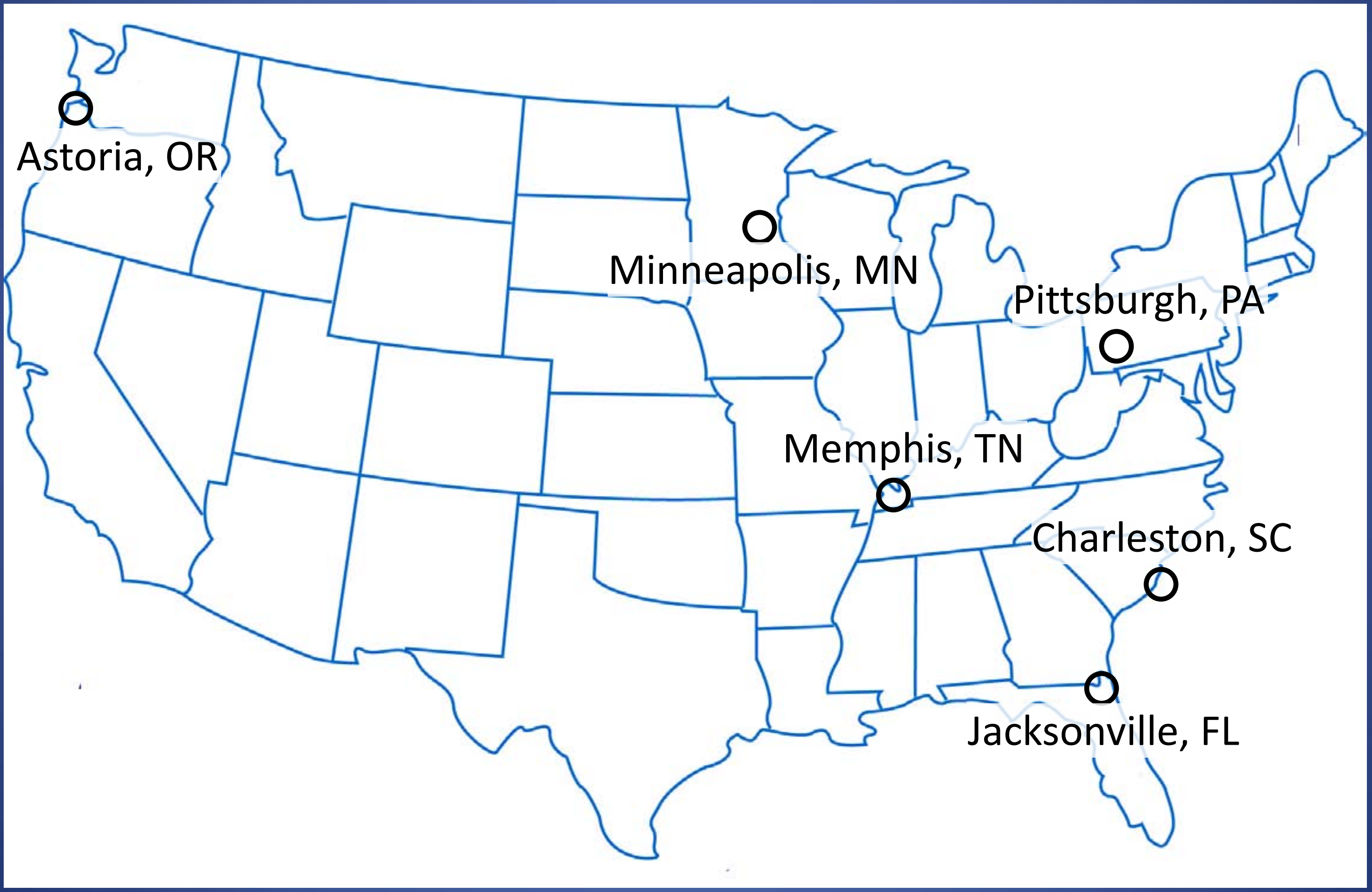
Residential Micro-CHP System



"Typical" US Single-Family House

- Modeled in Energy Plus
- Based on DOE/Energy Info. Admin. Statistics
  - Conditioned floor area: 210 m^2 (2260 ft^2)
  - Rooms: 3 bedrooms, 2 bathrooms, basement, garage
  - Windows: 14 Low-e, double glazed / 20 m^2 (215 ft^2)
  - Appliance/Lighting load: 9400 kWh
- Hourly annual space heating load determined
  - 6 cities representing US climate zones

Cities Representing US Climate Zones



Assessment of Micro-CHP

"Do I replace my existing heating system with micro-CHP or a high-efficiency conventional system?"

- Conventional equipment varies between climate zones
  - Minneapolis, Pittsburgh, and Memphis
    - 90 % AFUE furnace
    - Gas water heater with Energy Factor = 0.62
  - Astoria, Charleston, and Jacksonville
    - Heat pump with HSPF = 8.2
    - Electric water heater with Energy Factor = 0.92
- Examine primary energy, CO_2, and energy $$$

ENERGY STAR

Primary Energy Savings

- Electricity generated at the central plant requires fuel
  - Range from 35% (Minneapolis) to 69% (Astoria)
  - Efficiency varies by region
- Electricity produced on-site by micro-CHP reduces required output of central plant
- Heat rate – ratio of fuel energy to net electrical output of central plant

Primary Energy Savings Calculation

- Natural gas reference system
  - – Minneapolis, Pittsburgh, Memphis

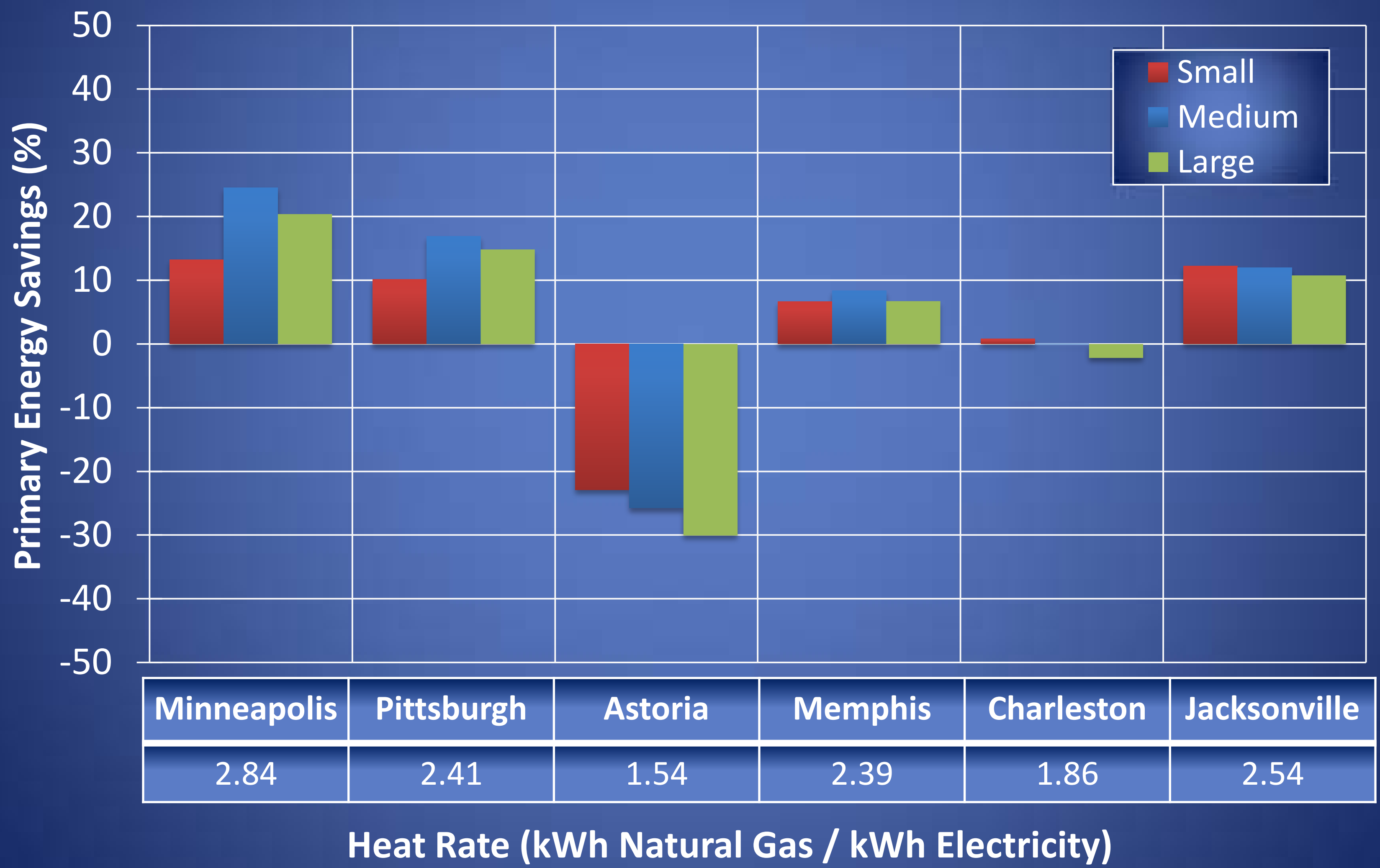
$$PESav = 1 - \frac{Fuel_{CHP} + Fuel_{Aux} + HeatRate \cdot \left(Elec_{import} - Elec_{export}\right)}{Fuel_{Furnace} + Fuel_{WH} + HeatRate \cdot \left(E_{Load} + E_{A/C}\right)}$$

- Electrical reference system
  - – Astoria, Charleston, Jacksonville

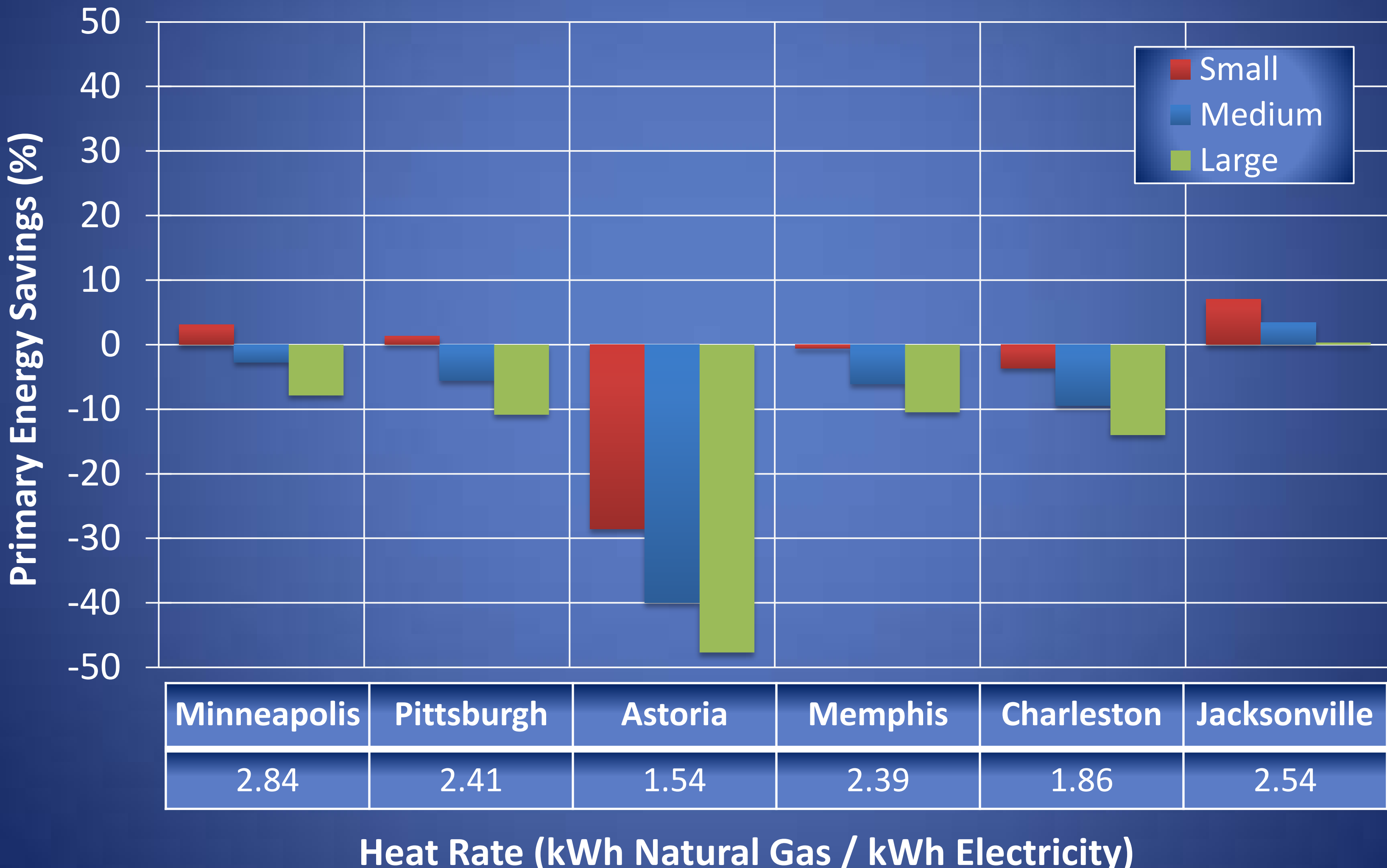
$$PESav = 1 - \frac{Fuel_{CHP} + Fuel_{Aux} + HeatRate \cdot \left(Elec_{import} - Elec_{export}\right)}{HeatRate \cdot \left(E_{HP} + E_{WH} + E_{Load} + E_{A/C}\right)}$$

Heat Rate and CO2 Vary by Region

Primary Energy Savings - ICE



Primary Energy Savings - SE



CO_2 Emissions Savings

- CO_2 emissions vary by source of electricity
  - Coal releases much CO_2
  - Natural gas contributes much less
  - Generating stations that meet non-baseload demand often contribute more CO_2
- Micro-CHP can be advantageous because
  - Efficiency
  - CO_2 content

CO_2 Emissions Savings Calculation

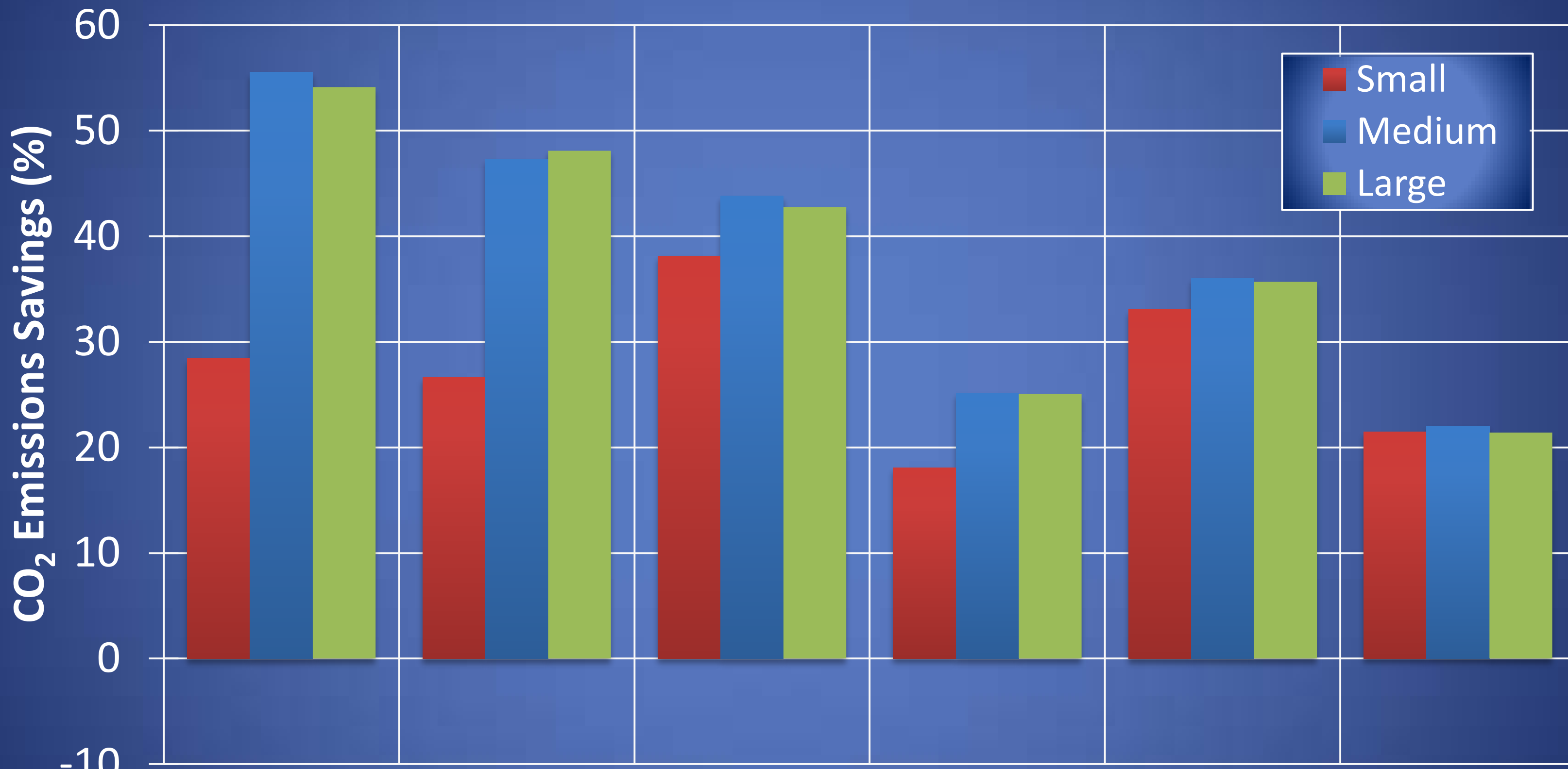
- Natural gas reference system
  - Minneapolis, Pittsburgh, Memphis

$$CO_2Sav = 1 - \frac{CO_2Rate_{NG} \cdot (Fuel_{CHP} + Fuel_{Aux}) + CO_2Rate_{Plant} \cdot (Elec_{import} - Elec_{export})}{CO_2Rate_{NG} \cdot (Fuel_{Furnace} + Fuel_{WH}) + CO_2Rate_{Plant} \cdot (E_{Load} + E_{A/C})}$$

- Electrical reference system
  - Astoria, Charleston, Jacksonville

$$CO_2Sav = 1 - \frac{CO_2Rate_{NG} \cdot (Fuel_{CHP} + Fuel_{Aux}) + CO_2Rate_{Plant} \cdot (Elec_{import} - Elec_{export})}{CO_2Rate_{Plant} \cdot (E_{HP} + E_{WH} + E_{Load} + E_{A/C})}$$

CO_2 Emissions Savings - ICE

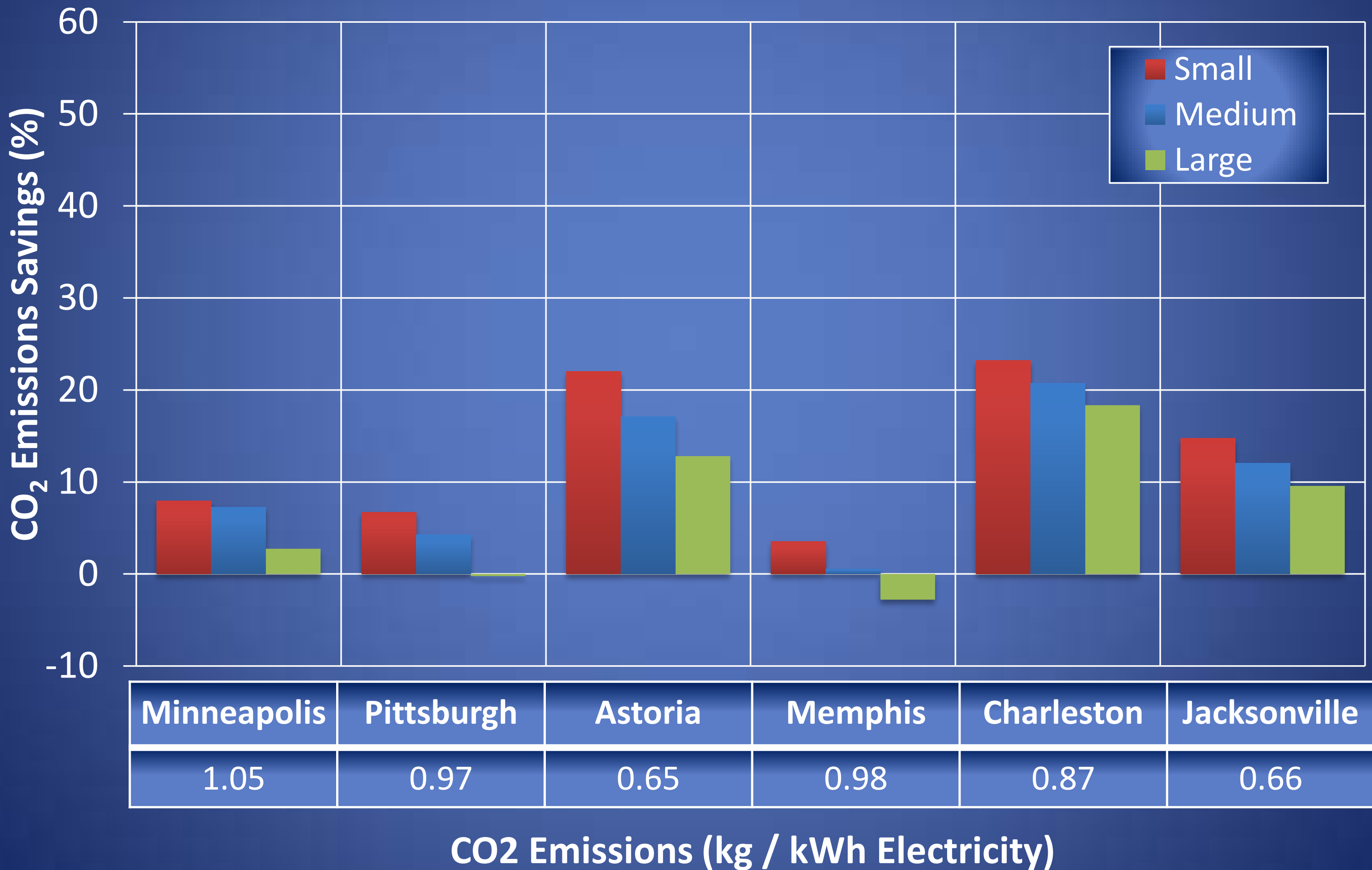


Nat. Gas	Minneapolis	Pittsburgh	Astoria	Memphis	Charleston	Jacksonville
0.18	1.05	0.97	0.65	0.98	0.87	0.66

(kg / kWh NG)

CO2 Emissions (kg / kWh Electricity)

CO_2 Emissions Savings - SE



Energy Cost Savings

- Electricity and gas prices vary by utility and region
  - Gas prices are lower than electricity
  - Difference is referred to as “spark spread”
  - Larger spread is advantageous to on-site generation
- Some states allow micro-CHP devices to sell power to utility
- Investigation assumes home owner sells electricity for same prices as they buy it

Energy Cost Savings Calculation

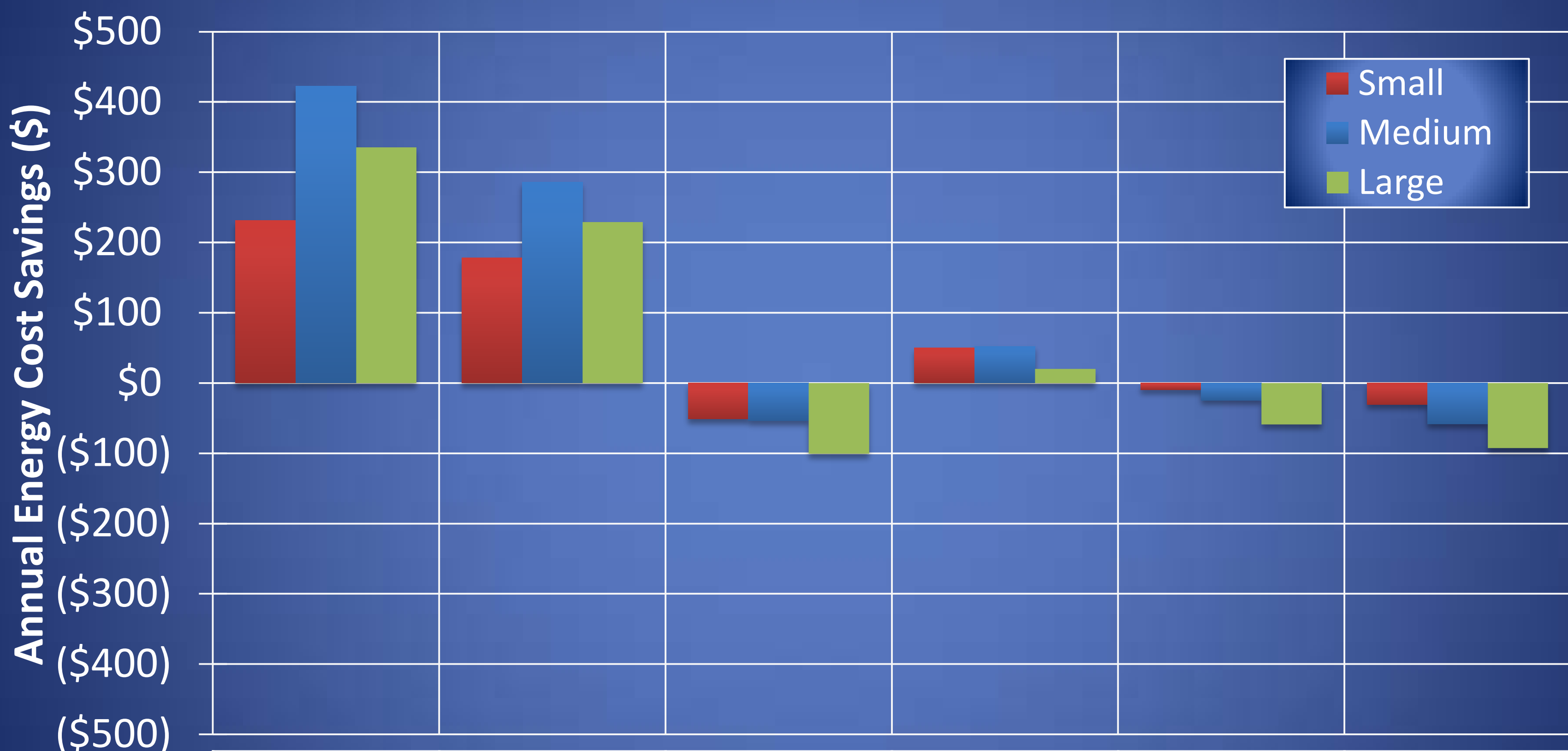
- Natural gas reference system
  - Minneapolis, Pittsburgh, Memphis

$$\mathrm{CostSav} = \left[\$_{NG} \cdot \left(\mathrm{Fuel}_{CHP} + \mathrm{Fuel}_{Aux}\right) + \$_{Plant} \cdot \left(\mathrm{Elec}_{import} - \mathrm{Elec}_{export}\right)\right] - \left[\$_{NG} \cdot \left(\mathrm{Fuel}_{Furnace} + \mathrm{Fuel}_{WH}\right) + \$_{Plant} \cdot \left(E_{Load} + E_{A/C}\right)\right]$$

- Electrical reference system
  - Astoria, Charleston, Jacksonville

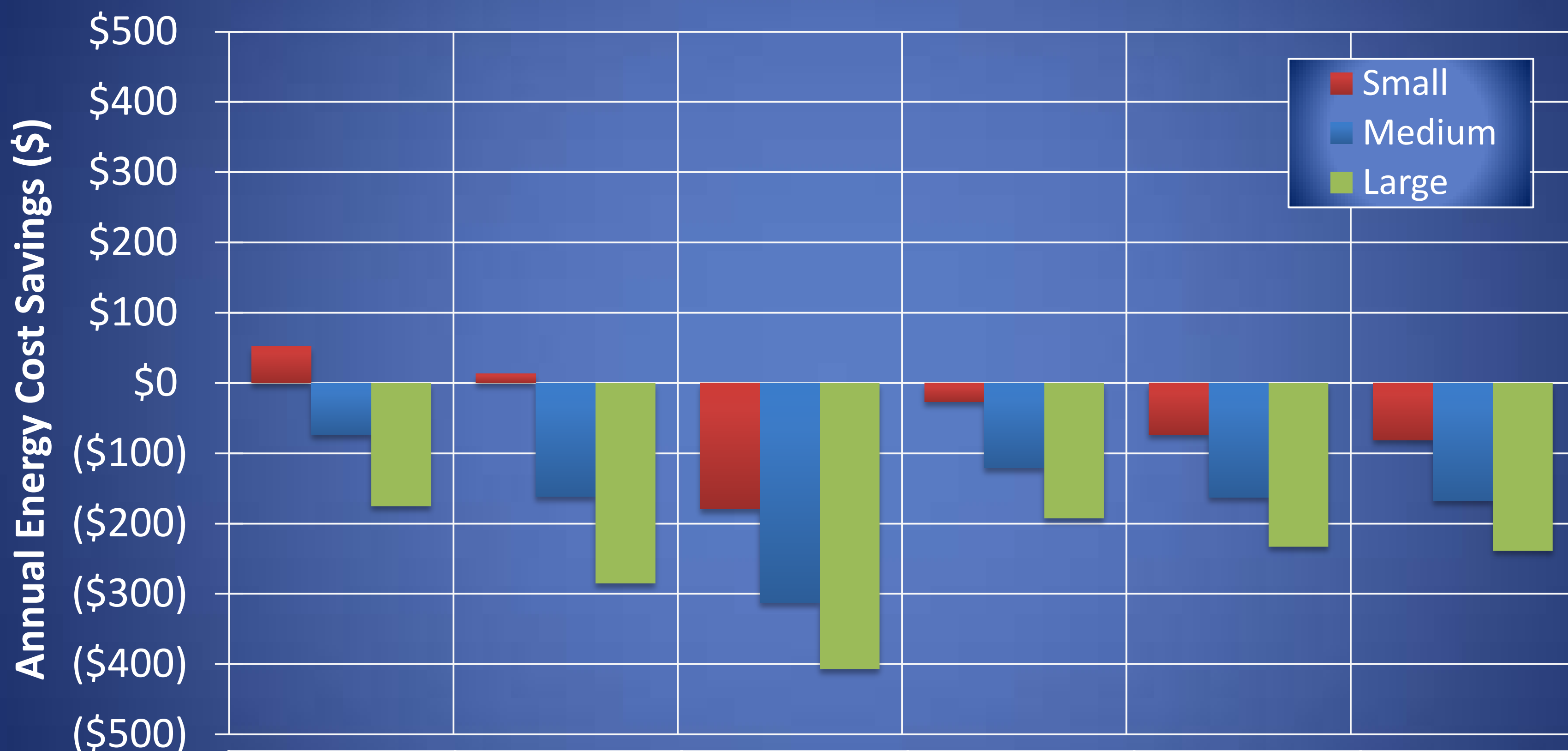
$$\mathrm{CostSav} = \left[\$_{NG} \cdot \left(\mathrm{Fuel}_{CHP} + \mathrm{Fuel}_{Aux}\right) + \$_{Plant} \cdot \left(\mathrm{Elec}_{import} - \mathrm{Elec}_{export}\right)\right] - \left[\$_{Plant} \cdot \left(E_{HP} + E_{WH} + E_{Load} + E_{A/C}\right)\right]$$

Energy Cost Savings - ICE



	Minneapolis	Pittsburgh	Astoria	Memphis	Charleston	Jacksonville
Elec ($/kWh)	0.100	0.117	0.088	0.093	0.102	0.123
Gas ($/kWh)	0.038	0.054	0.047	0.048	0.056	0.071

Energy Cost Savings - SE



	Minneapolis	Pittsburgh	Astoria	Memphis	Charleston	Jacksonville
Elec ($/kWh)	0.100	0.117	0.088	0.093	0.102	0.123
Gas ($/kWh)	0.038	0.054	0.047	0.048	0.056	0.071

Conclusions

- Micro-CHP shows potential to provide benefits
  - Society
    - Primary energy savings as much as 25%
    - CO_2 emission savings as much as 55%
  - Home owner
    - Energy cost savings up to $400 per year
- Benefits are maximized in regions
  - High spark spread
  - Large heating loads
  - High electrical efficiency