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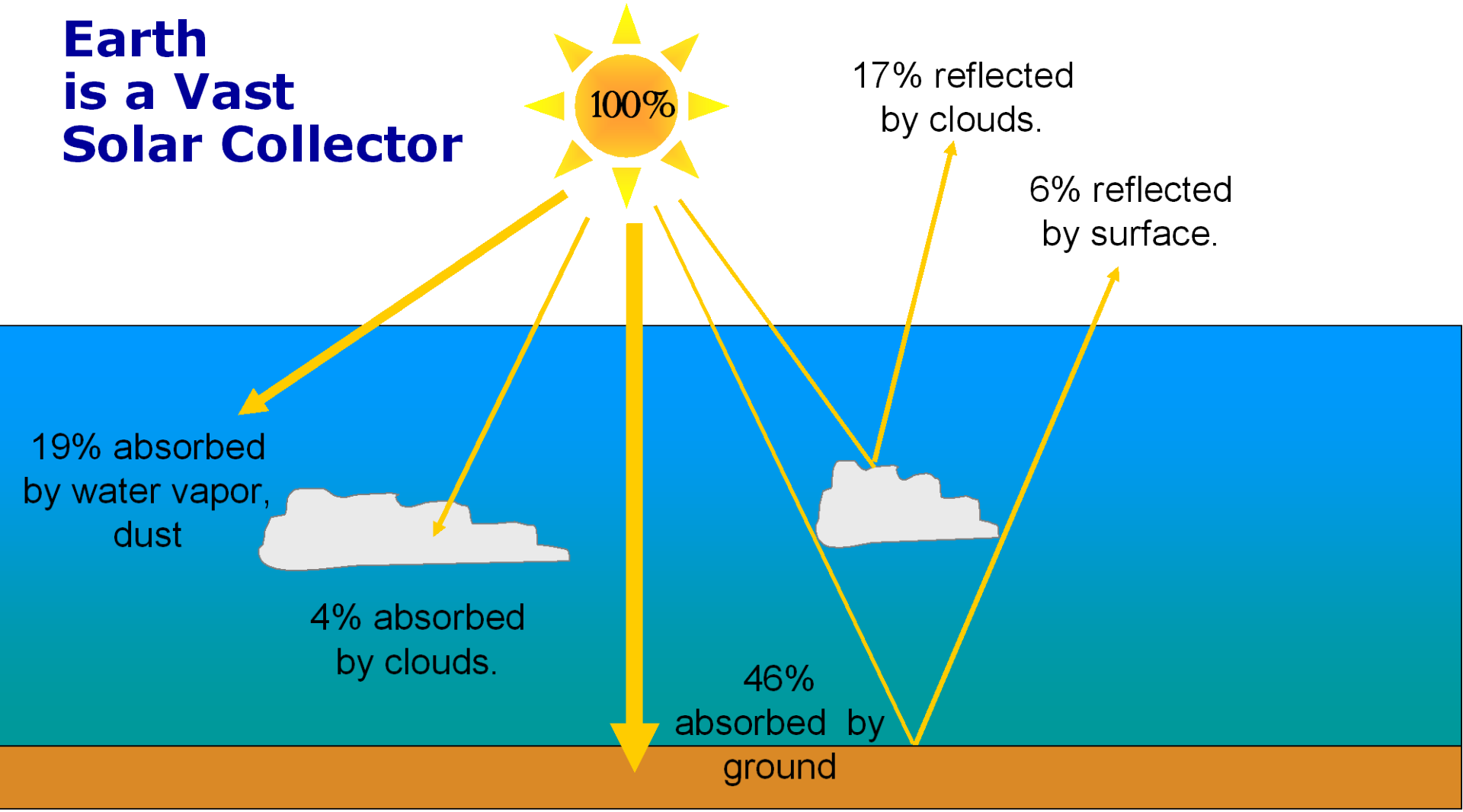
Assessment of National Benefits from Retrofitting Existing Single-Family Homes with Ground Source Heat Pump Systems

Agenda

- Overview of ground source heat pump (GSHP)
- Rationale of this study
- Assessment methodology
- Results
  - Estimated benefits
  - Economic analysis
- Conclusions

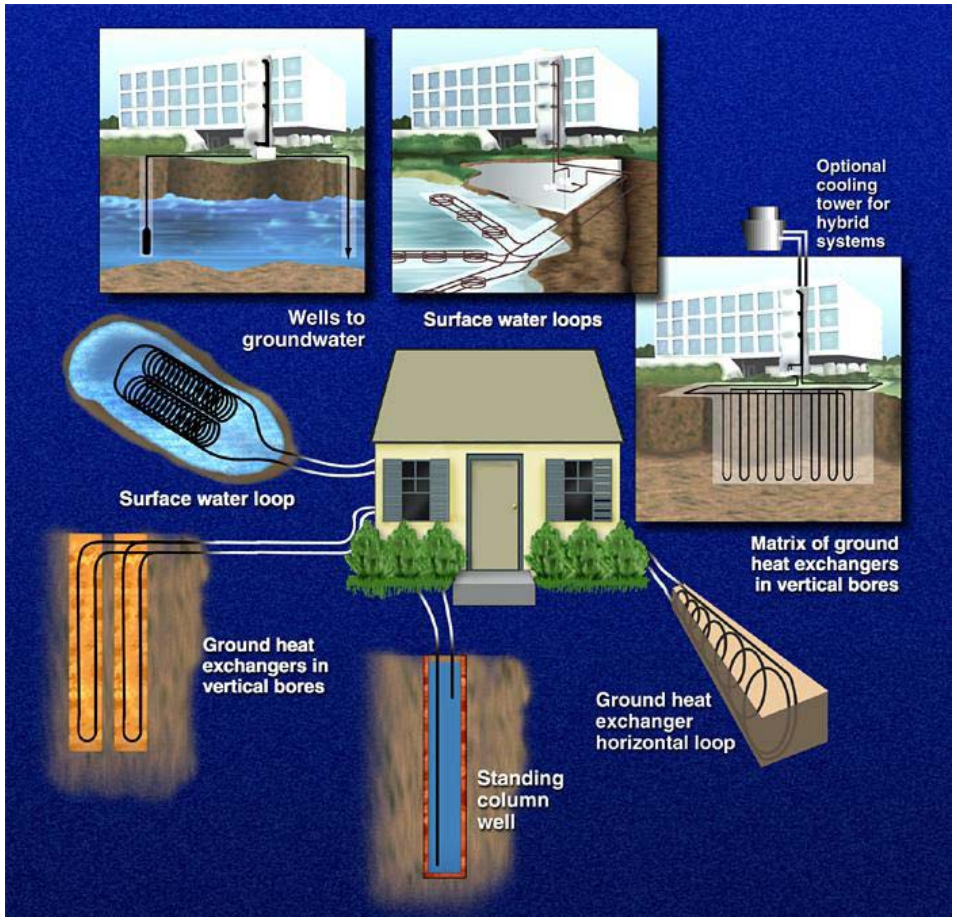
Earth is a Vast Solar Collector



Solar energy maintains a nearly constant temperature throughout the year just below ground

Characteristics of GSHP

- Use renewable low-grade energy in
  - Earth, ground water, river, and etc.
- Move heat at high energy efficiency
  - With 3-5 COP today
- Reduce peak electrical demand
- Labor intensive installation (create jobs)
- Widely applicable
  - New
  - Retrofit
  - Commercial and residential



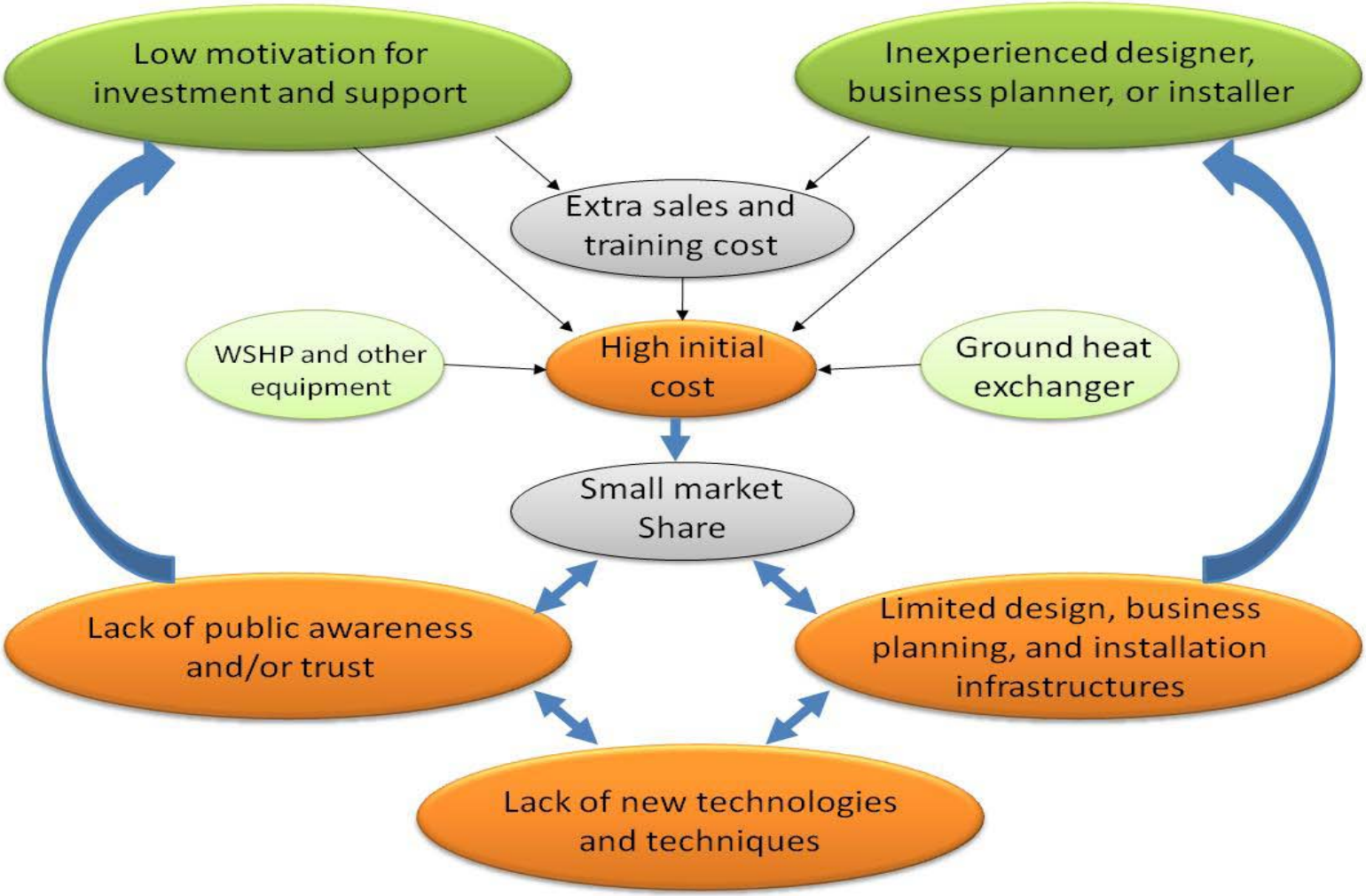
Best candidates for GSHP: Single-family Homes

- 79.8 million single-family homes (SFH) in U.S. (Census Bureau 2005)
- On average, 73% of the energy consumed in SFH is for space conditioning and WH (DOE 2009)
- Many of existing conventional space conditioning and WH equipments in SFH are approaching the end of their service life and thus need to be replaced
- Many SFHs have adequate space and accessibility for installing ground heat exchanger

Market Status of GSHP in U.S.

- Totally 600,000 GSHP systems installed in U.S. by 2005, which is less than 1% of total SFHs in U.S.
- Approximately 100,000 GSHP units are manufactured and shipped in 2009
- Economics of GSHP systems
  - Retrofits: 8.6 to 12 year simple payback
  - New constructions: PB better but >5 yr still common

Barriers to Rapid Deployment of GSHP



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Why Assessing National Benefits of Residential GSHP Retrofits?

- Provides technical input for evaluating various major national energy policy options with key metrics, including:
  - Savings in primary energy
  - Reduced carbon dioxide (CO2) emissions
  - Reduced summer electrical peak demand
  - Savings in consumer energy expenditures
  - Cost

Assessment Methodology

- Rely heavily on energy consumption and other data obtained from the latest Residential Energy Consumption Survey conducted by EIA (2005)
- Determine relative differences in energy consumption between state-of-the-art GSHP system and existing residential space-heating, space-cooling, and water-heating (SH–SC–WH) systems with a well-established energy analysis program
- Accounts for various climate and geological conditions, energy costs, as well as source energy factors and emissions factors for electricity and fossil fuels

Types and Efficiencies of Existing SH-SC-WH Systems in SFHs

Energy services	Existing systems and equipment	Rated efficiencies
Space heating	ASHP	3.2 COP
	Electric heater	100 EF
	Natural gas–fired furnace/boiler	80 AFUE
	Propane- or LPG-fired furnace/boiler	80 AFUE
	Heating oil–fired furnace/boiler	80 AFUE
Space cooling	CAC/ASHP	10 SEER
	RAC	7.7 SEER
	Combination of CAC and RAC	7.7–10 SEER
Water heating	Electric heater	88 EF
	Natural gas heater	58 EF
	Propane or LPG heater	58 EF
	Heating oil heater	58 EF

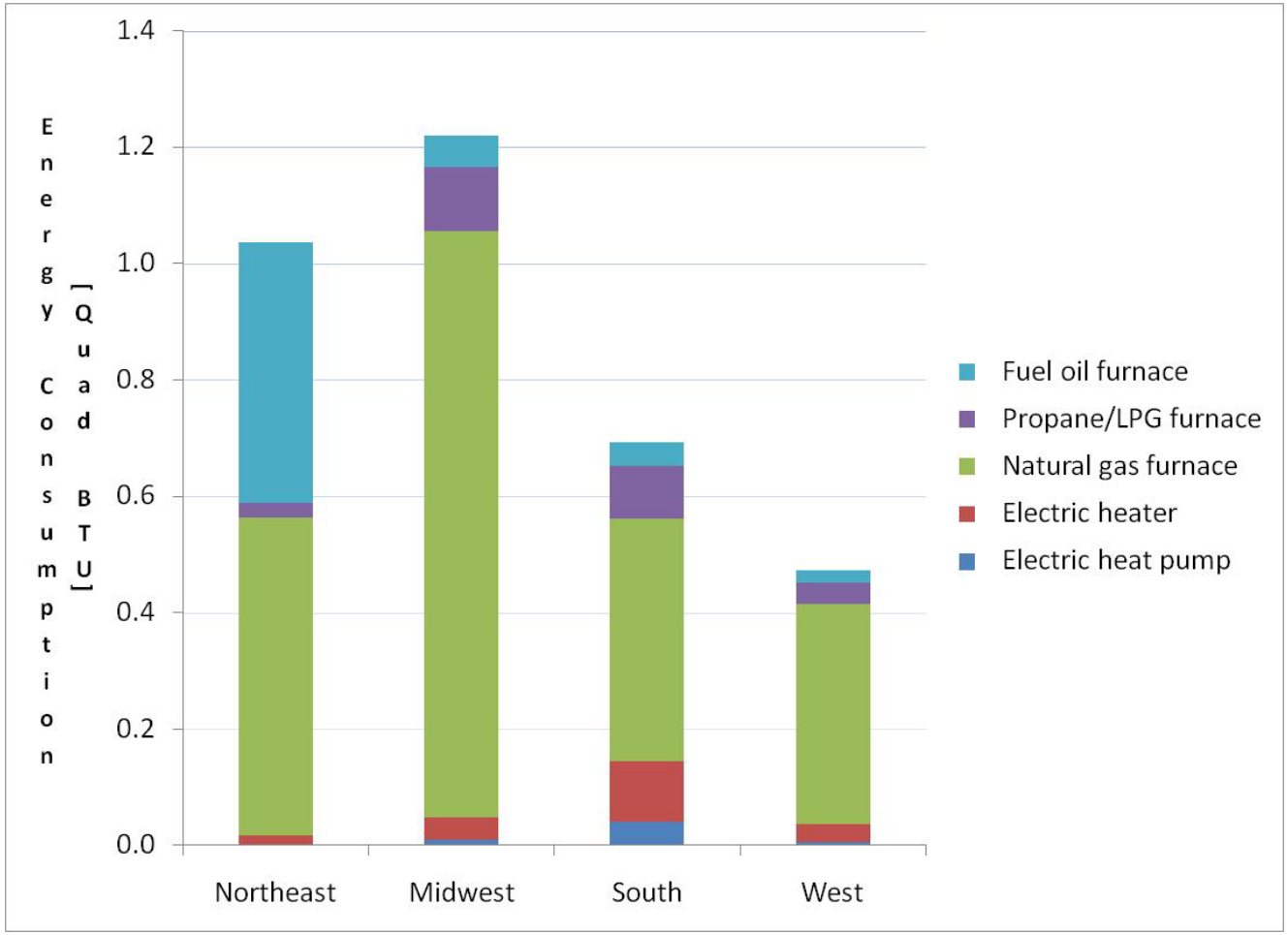
(EIA 2000; DOE 2005)

State-of-the-Art GSHP System

Consists of :

- a packaged water-to-air GSHP unit with a two-stage scroll compressor, variable-speed fan
  - Cooling: 18.2 EER (full load) & 27 EER (part load)
  - Heating: 4.0 COP (full load) & 4.5 EER (part load)
- a vertical close loop ground heat exchanger sized for maintaining 30°F–95°F entering fluid temperature to the GSHP unit
- a storage-type electric water heater assisted with the desuperheater of the GSHP unit
- a highly energy-efficient circulation pump

Energy Consumption of Existing Space Heating Systems by Census Region



Obtained from 2005 RECS Public Use Microdata Files

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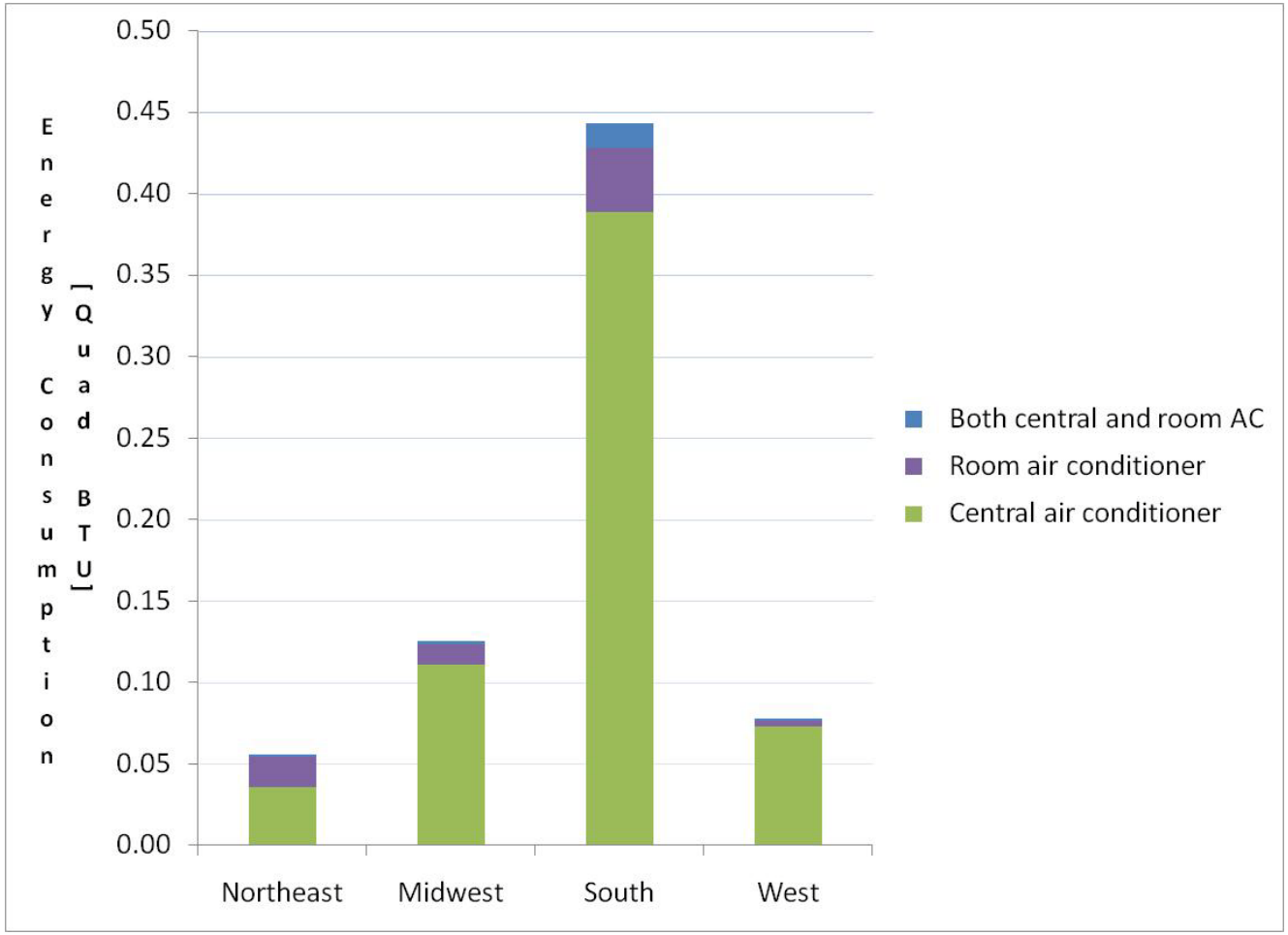
Energy Consumption of Existing Space Cooling Systems by Census Region



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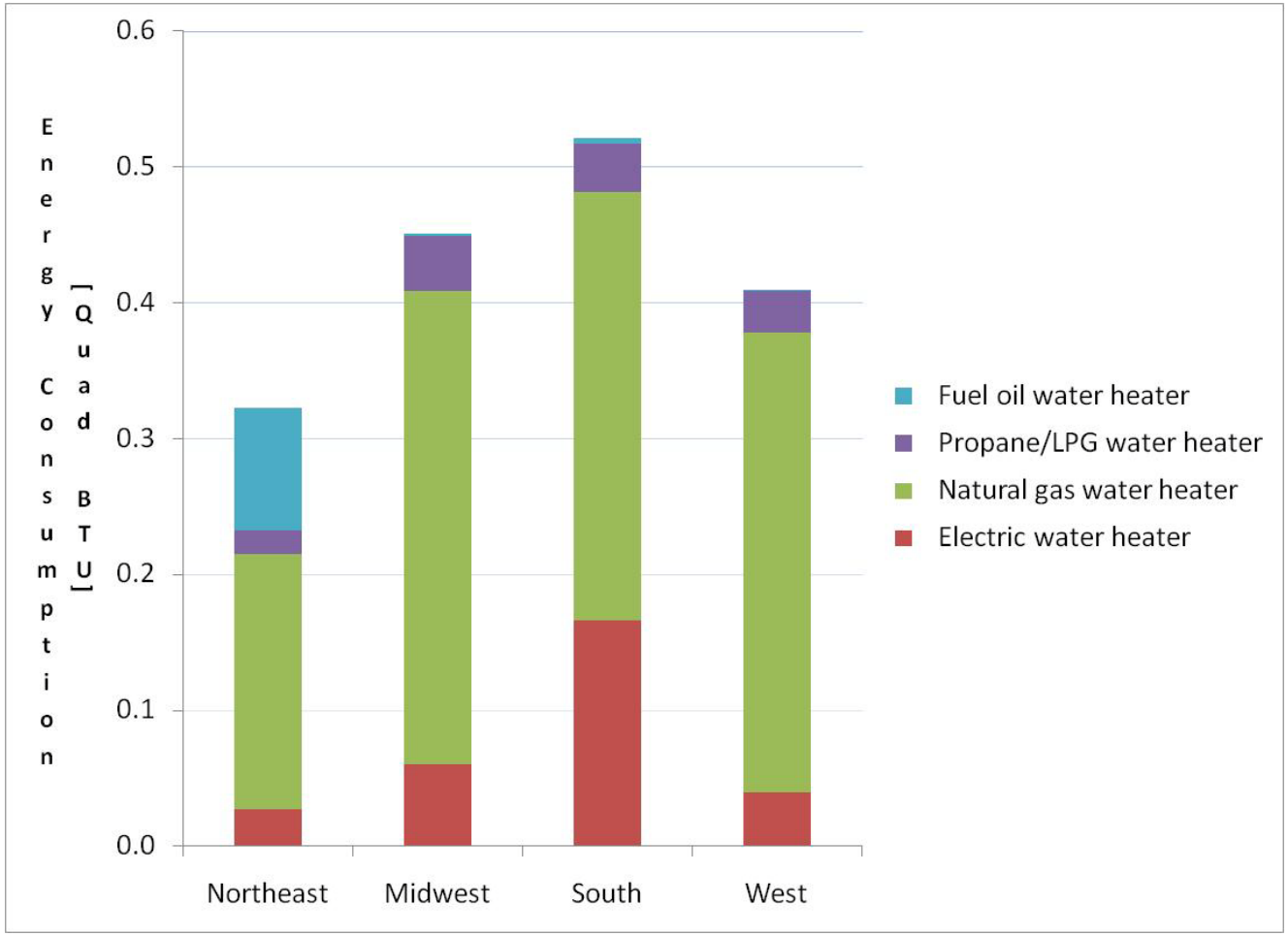
Energy Consumption of Existing Water Heating Systems by Census Region



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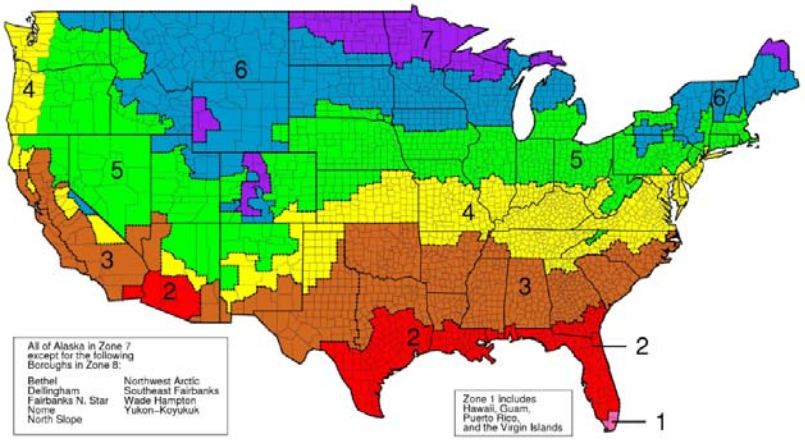
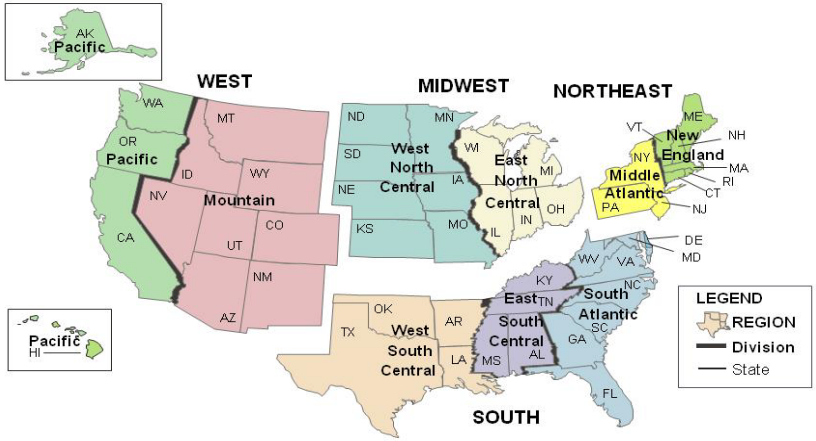
Various Climate and Geology



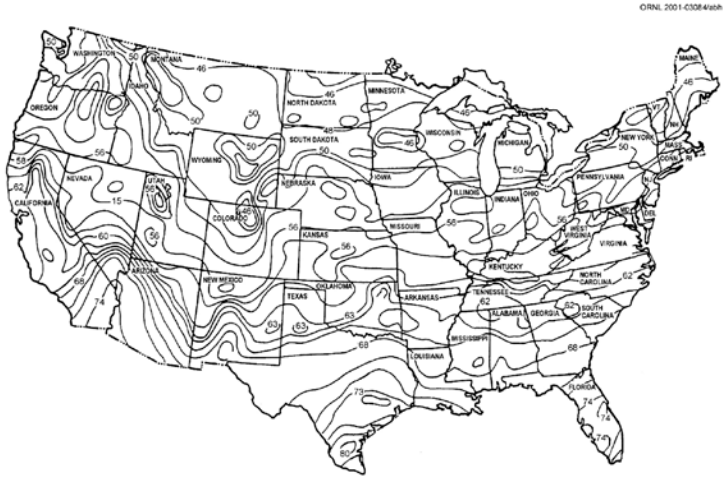
2004 IECC climate zones of the U.S.

Efficiencies of ASHP and AC are affected by local weather conditions

Efficiency of GSHP is affected by local geological conditions (e.g., ground temperature)



U.S. census regions and divisions



Ground or groundwater temperatures in the U.S.

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Annual National Benefits:
Maximum Potential

- a savings of **4.2 quad Btu in primary energy**, a **45.1%** reduction in primary energy consumption associated with SH–SC–WH in existing U.S. SFHs
- a reduction of **271.9 million metric tons of CO_2 emissions**, a **45.3%** reduction in CO_2 emissions associated with SH–SC–WH in existing U.S. SFHs
- a savings of **$52.2 billion in energy expenditures**, a **48.2%** reduction in energy expenditures for SH–SC–WH in existing U.S. SFHs
- a reduction of **202.1 gigawatts (GW) in summer peak electrical demand**, a **55.2%** reduction in summer peak electrical demand in existing U.S. SFHs

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Annual National Benefits:
at Various Market Penetration Rates

Market Penetration Rate of GHP Retrofit	20%	40%	60%	80%	100%
Primary Energy Savings [Quad BTU]	0.8	1.7	2.5	3.3	**4.2**
Percentage Savings	9.0%	18.0%	27.1%	36.1%	**45.1%**
CO2 Emissions Reduction [MM ton]	54.3	108.7	163.0	217.3	**271.7**
Percentage Savings	9.1%	18.1%	27.2%	36.2%	**45.3%**
Summer Peak Electrical Demand Reduction [GW]	40.4	80.8	121.3	161.7	**202.1**
Percentage Savings	11.0%	22.1%	33.1%	44.2%	**55.2%**
Energy Expenditures Savings [Billion $]	10.4	20.9	31.3	41.7	**52.2**
Percentage Savings	9.6%	19.3%	28.9%	38.5%	**48.1%**

There is wide variability in SFH characteristics, installed equipment, and other geographic considerations not specifically addressed in this analysis that can influence the suitability of individual housing units for GHP retrofit. For that reason, this table presents a wide range of market penetration rates with the associated annual national benefits. These factors include items such as high density SFH in urban settings that may not have adequate space and/or accessibility to install a ground heat exchanger, added cost to retrofit a GHP in SFH that currently use high temperature hydronic or steam heating, extremely hot climate that results in very large cooling need but little, or no, heating need, etc.

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Economic Analysis of Investments in Residential GSHP Retrofits

- Alternative retrofit solutions
- Installed and operating costs of GSHP and alternative retrofits
- Net present value (NPV) of GSHP investment

$$NPV = \sum_{j=1}^{m} (E_j \cdot CEC_j) \times \sum_{i=1}^{n} \frac{(1+e)^{i-1}}{(1+d)^i} - CP$$

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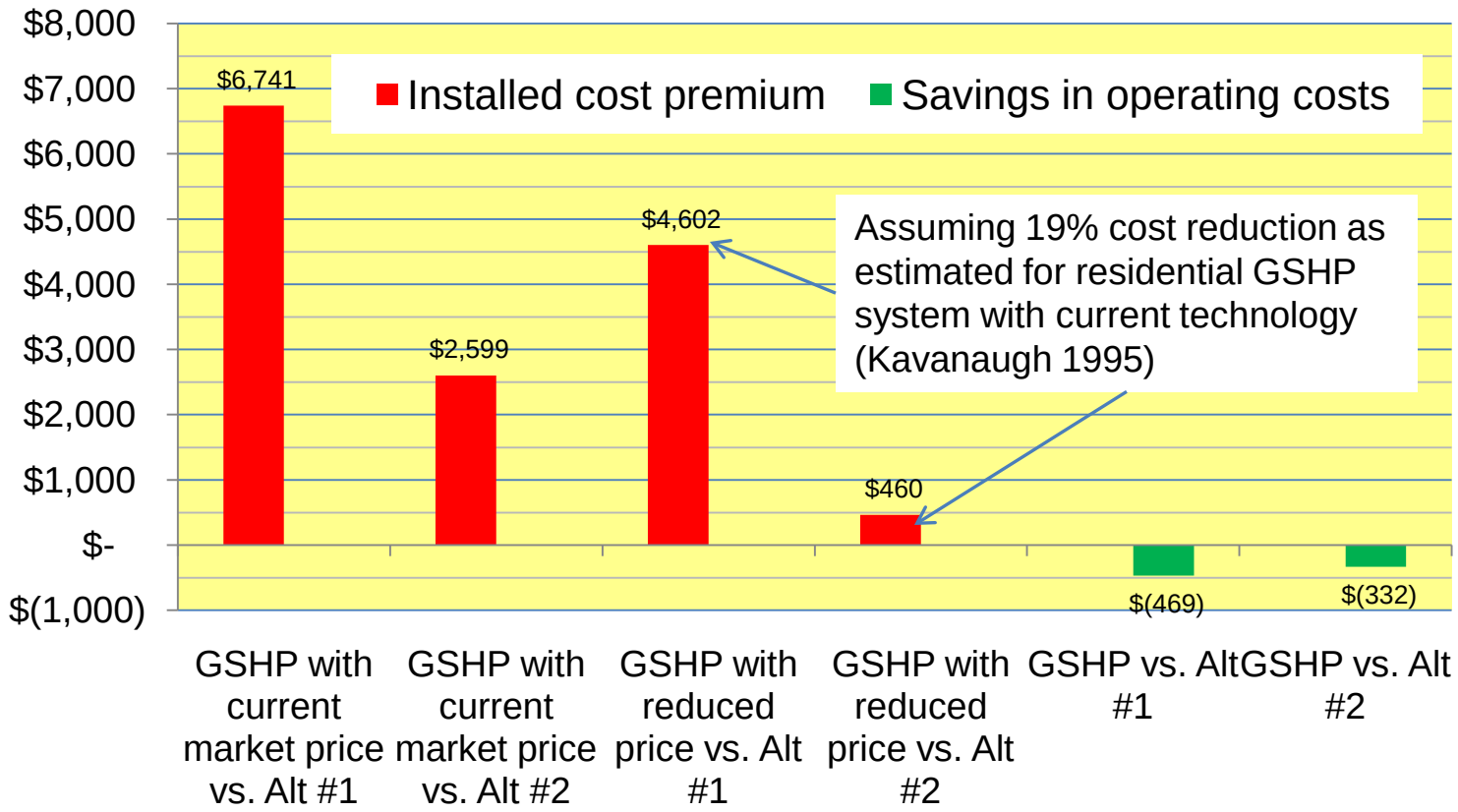
Alternatives

Name	Description	Note
Alt #1	SEER 13 AC and 80 AFUE natural gas furnace	Minimum allowed
Alt #2	SEER 21 AC and 93 AFUE natural gas furnace	State-of-the-art

Installed Cost Premium and Savings in Operating Cost of a 3-ton GSHP System



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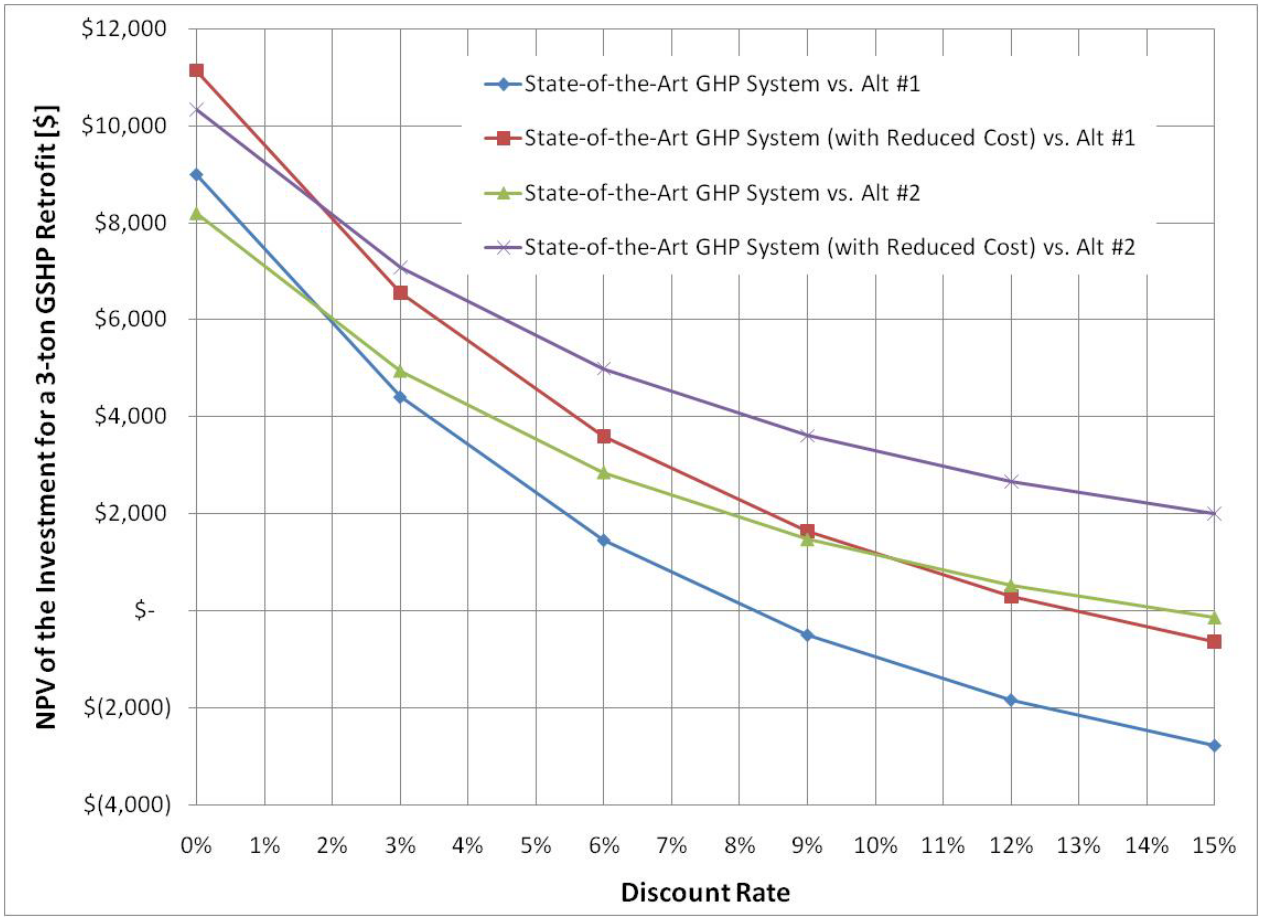
NPV of Investments for a 3-ton GSHP System Retrofit



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More Favorable Should Following Values be Accounted for

- Reduced CO_2 emissions
  - 1.6-2.5 metric ton per SFH per year
- Reduced summer peak electrical demand
  - 0.2-1 kW/ton
- Vertical ground loop heat exchanger
  - Outlive several generations of the heat pump units

Conclusions

- Large-scale retrofit of U.S. single-family homes with the state-of-the-art GSHP system has tremendous potential in reducing primary energy consumption, CO2 emissions, and electrical peak demand
- Without any tax incentive, GSHP retrofit at current cost is shown to be favorable over 20 year life cycle for many single-family homes when the discount rate is lower than 8%
- GSHP retrofit would be more favorable should its cost be reduced/subsidized and/or the residual value of the ground loop heat exchanger and the value of reduced CO_2 emissions and peak electrical demand be accounted for in the purchase and operating cost of the GSHP system

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