Comparative Life Cycle Assessment of Traditional and Solar Water Heating in 5 U.S. Cities

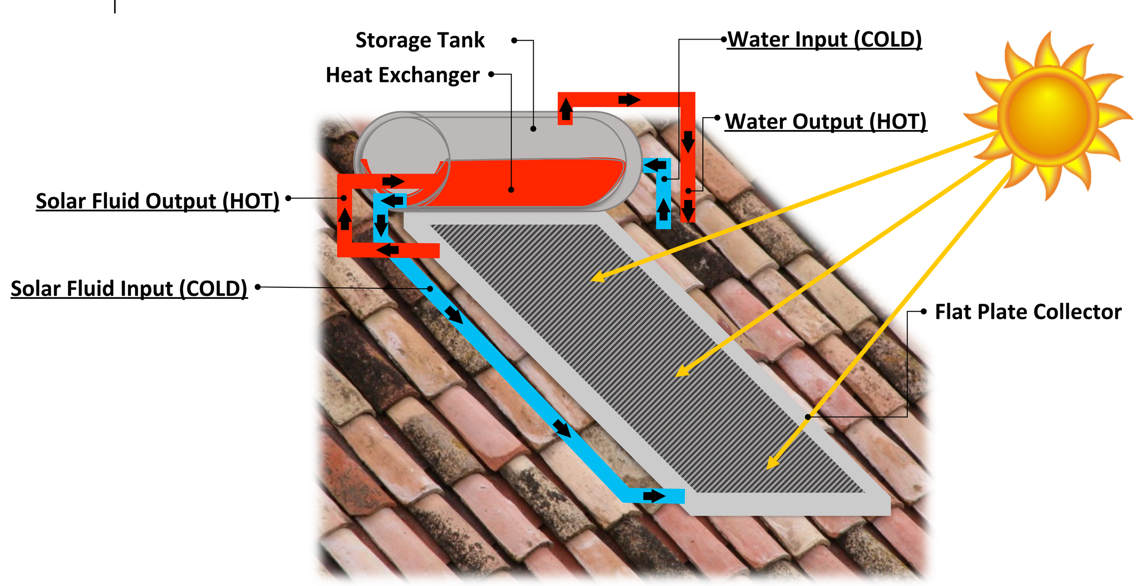
Kacie Ferraro[1], Mingcheng Ren[2], Advisor: Dr. Weiwei Mo[2]

[1]Rye Junior High School (SAU #50), [2]Department of Civil & Environmental Engineering (UNH)

Introduction:

This Life Cycle Assessment (LCA) analyzes the Cumulative Energy Demand (CED), Global Warming Potential (GWP), and Cost and Benefit of two scenarios for heating household water.

	SCENARIO 1		SCENARIO 2
HYBRID	*Thermosyphon Solar Hot Water System*	*Natural Gas Hot Water Supplement*	*100% Natural Gas Hot Water System*

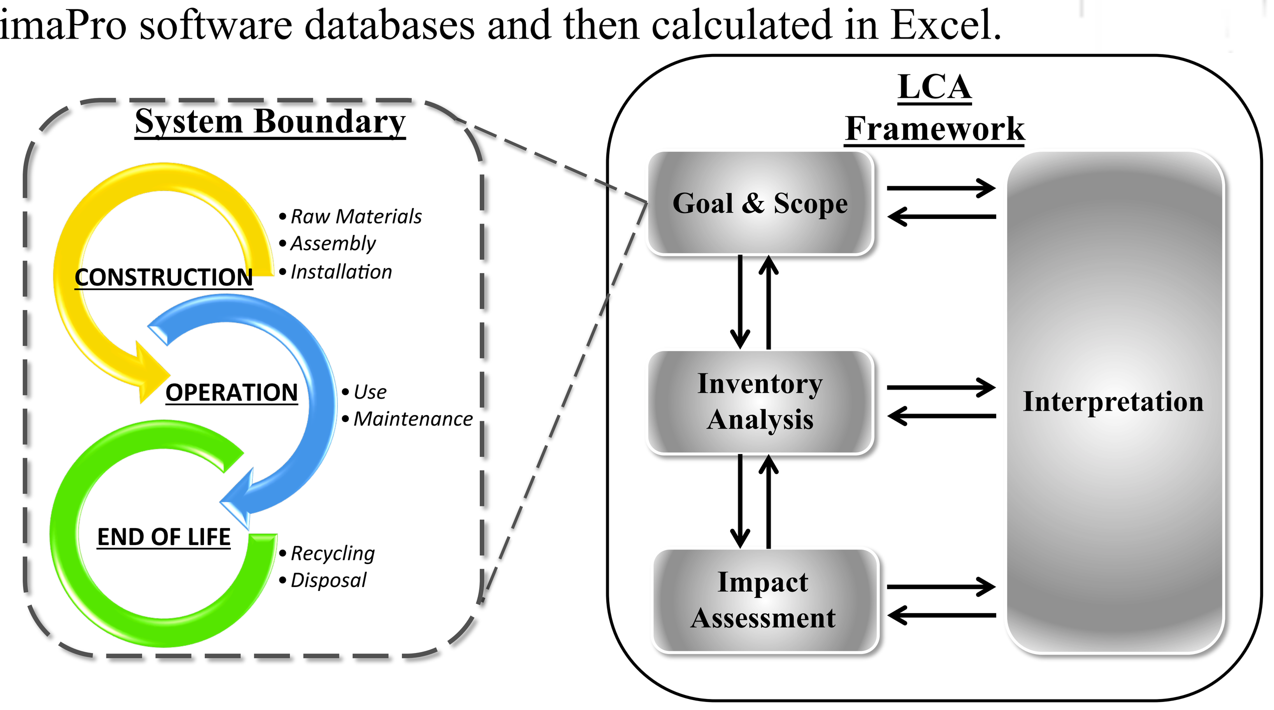


MAJOR FACTORS

Direct Normal Irradiance (DNI)	*Period of Frost*
Average Water Consumed per Person per Day	*State Tax Incentives*
Average Household Size	*Transportation Distance* • *Market=>Consumer* • *Consumer=>Landfill*
Average Cost of Water per Gallon	

Methods:

All life cycle impacts were normalized to the impact per function unit (1 gallon of hot water) produced by the system for the duration of its expected 20 year lifetime. Impacts were assessed using SimaPro software databases and then calculated in Excel.



LCA EQUATIONS

Impact Assessment

$$I_{total} = [I_{construction}/(T\times F)] + [I_{operation}/(T\times F)] + [I_{end\ of\ life}/(T\times F)];$$

I_l = impact of life stage l,
T = years of lifetime, and
F = gallons hot water per year

Cost and Benefit:

Scenario 1: (Hybrid Solar System)

$$C_{total} = C_{system} + C_{installation} + C_g + [C_{natural\ gas} \times w] - T_f - T_s$$

and

Scenario 2: (100% Natural Gas System)

$$C_{total} = C_{system} + C_{installation} + C_g + [C_{natural\ gas} \times g]$$

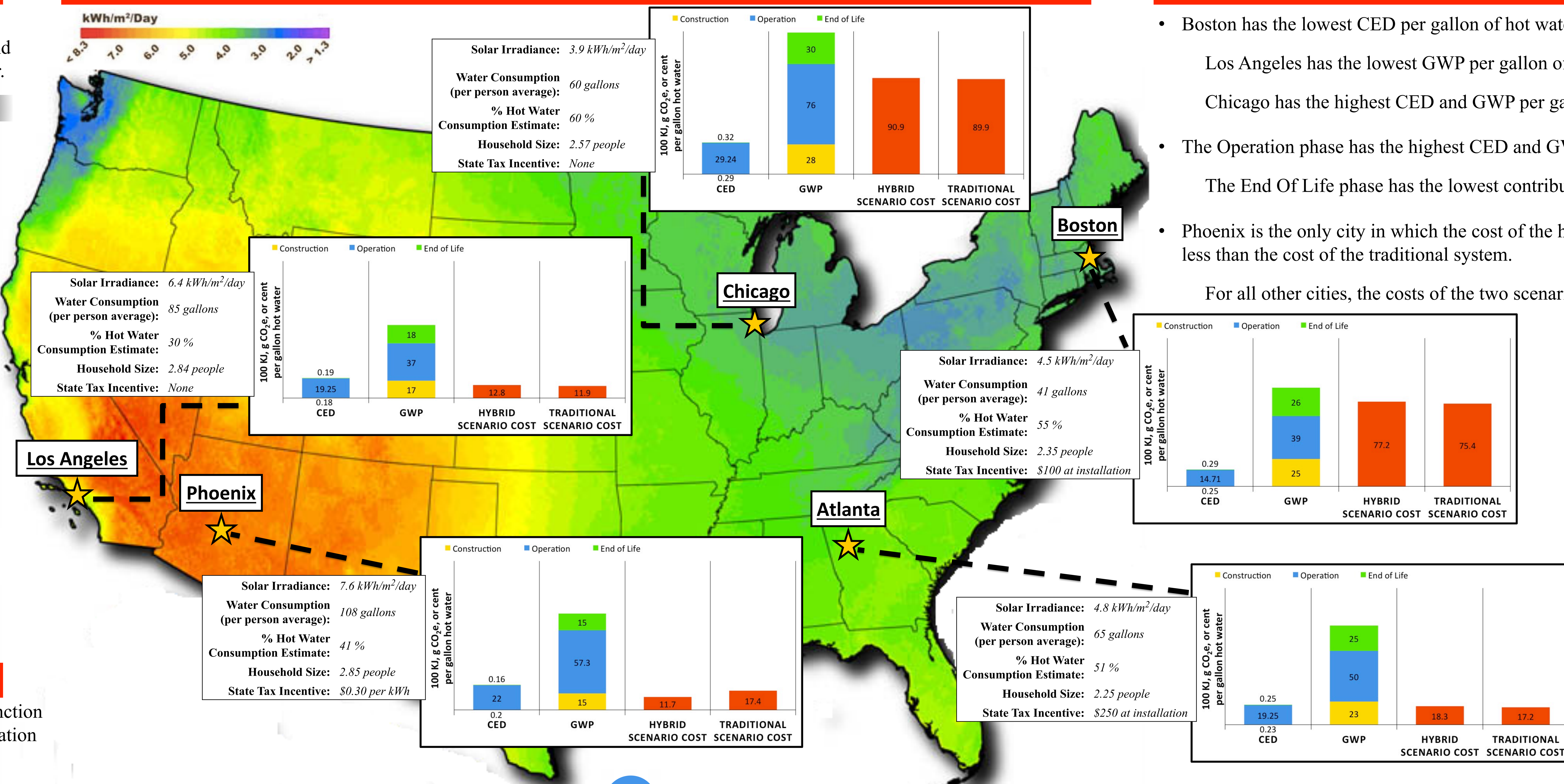
C_x = cost of factor x
g = gallons of hot water
$w = g_{consumed} - g_{solar\ produced}$
T_f = federal tax incentive
T_s = state tax incentive

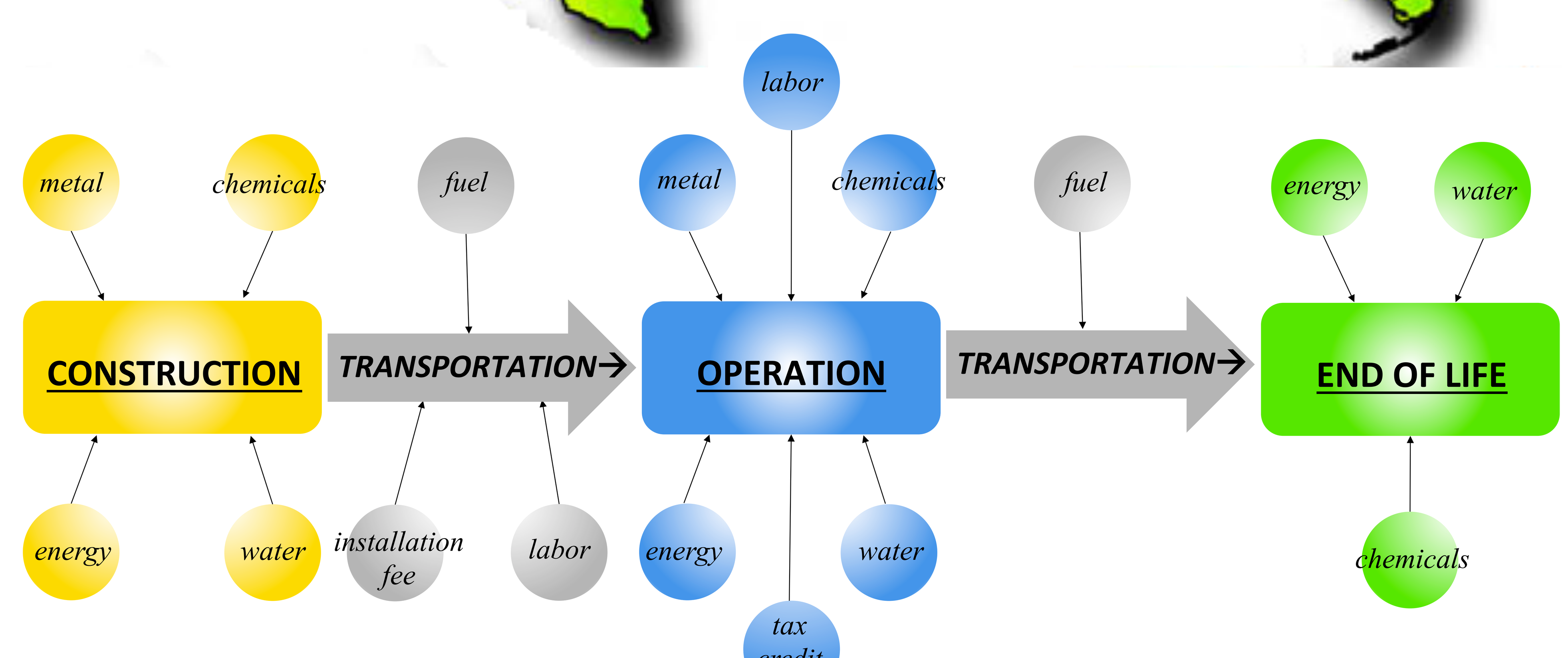
Water Production Capacity:

$$G_p = E \times J \times a \times h \div k \div d \div i$$

G_p = gallons hot water produced
E = DNI kWh/m²/day
J = 3600 KJ/kWh
a = 4 m² aperture area
h = fraction (daylight hours/day)
k = 4.2 kg°C
d = 3.79 kg/gal
I = 43°C temperature increase

Results:





INVENTORY ANALYSIS

Construction Components								Operation Components				End of Life Components			
Flat plate collector (4 m²)		Water Tank (200 L)		Support System		Other Parts		Replace Tank Anode & Element every 4 years		Refill Thermal Fluid once every year		Recycle		Disposal (Landfill)	
Material	*Mass*	*Material*	*Mass*	*Material*	*Mass*	*Material*	*Mass*	*Material*	*Mass*	*Material*	*Mass*	*Material*	*Mass*	*Material*	*Mass*
Galvanized steel	40 kg	Steel	50 kg	Galvanized Steel	5 kg	Plastic Tube	3 kg	Glass	8 kg	Propylene Glycol	36.1 kg	Galvanized Steel	45 kg	Glass Fibre	6 kg
Solar glass	10 kg	Glass	2 kg	Total	5 kg	Glass Fibre	3 kg	Aluminum	6 kg	Water	144.4 kg	Solar Glass	10 kg	Propylene Glycol	39 kg
Copper	35.83 kg	Aluminum	1.5 kg			Total	6 kg	Magnesium	0.8 kg	Total	180.5 kg	Copper	35.83 kg	Water	156 kg
Glass Fibre	3 kg	PUR	5 kg					Total	14.8 kg			Aluminum	11.5 kg	PUR	5 kg
Aluminium	4 kg	Propylene Glycol	1.9 kg									Steel	50 kg	Plastic Tube	3 kg
Propylene Glycol	1 kg	Water	7.6 kg									Glass	10 kg	Total	209 kg
Water	4 kg	Magnesium	0.2 kg									Magnesium	1 kg		
Total	97.83 kg	Total	68.2 kg									Total	163.33 kg		

Conclusions:

- Boston has the lowest CED per gallon of hot water.

  Los Angeles has the lowest GWP per gallon of hot water.

  Chicago has the highest CED and GWP per gallon of hot water.
- The Operation phase has the highest CED and GWP contributions.

  The End Of Life phase has the lowest contributions to both.
- Phoenix is the only city in which the cost of the hybrid system is less than the cost of the traditional system.

  For all other cities, the costs of the two scenarios are comparable.

Key References:

- Arnaoutakis, Nektarios, Manolis Souliotis, and Spiros Papaefthimiou. "Comparative Experimental life Cycle Assessment of Two Commercial Solar Thermal Devices for Domestic Applications." Renewable Energy 111 (2017): 187-200. Web. June 2017.
- Maltezos – Solar Hot Water Manufacturer. Maltezos SA, June 2017. www.maltezos.gr.
- SunMaxx ThermoPower & TitanPower Thermosyphon Solar Collectors." Solar Hot Water & Heating Manufacturer. SunMaxx Solar. Web. July 2017.
- Almanac, Old Farmer's. "Frost Dates Calculator." Old Farmer's Almanac. Yankee Publishing, inc., Reinvented, inc. Web. July 2017
- "Database of State Incentives for Renewables & Efficiency®." DSIRE. Web. July 2017.
- "Federal Income Tax Credits for Energy Efficiency." Federal Tax Credits for Consumer Energy Efficiency | ENERGY STAR. EPA. Web. July 2017.
- "NSRDB Data Viewer." NREL. National Renewable Energy Laboratory. Web. July 2017.

**Additional References available upon request.*

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