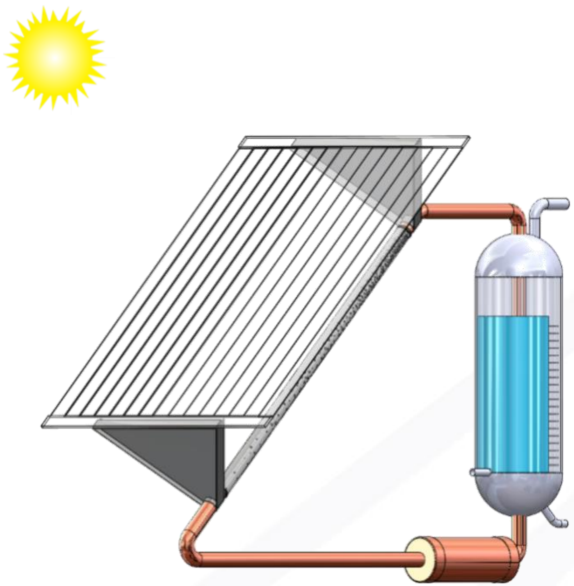
U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

SOLAR ENERGY TECHNOLOGIES OFFICE

SETO CSP Program Summit 2019



Loop Thermosyphon Enhanced Solar Collector

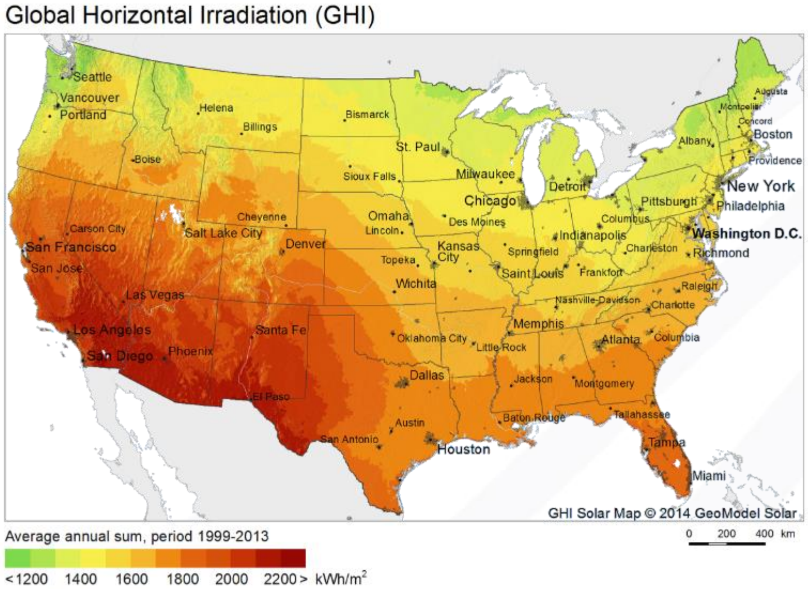
Advanced Cooling Technologies, Inc.

University of Maryland, College Park

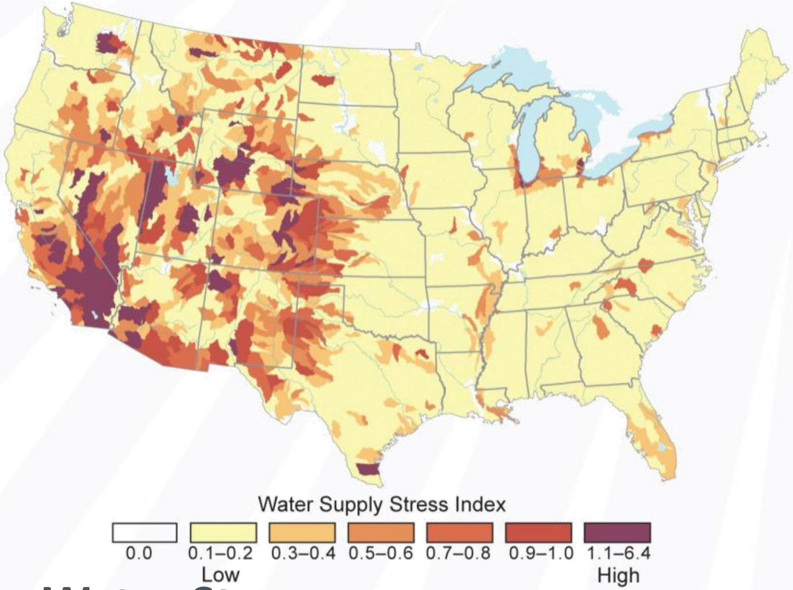
Fangyu Cao, Ph.D.

Background

Solar availability for desalination



Solar Irradiation



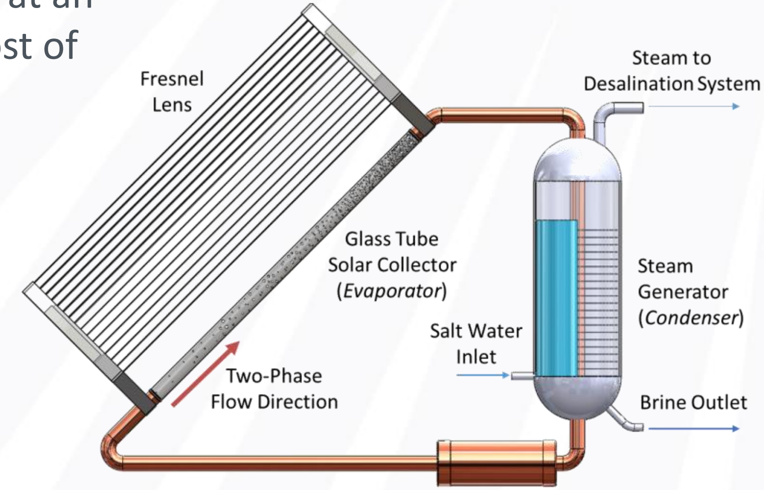
Water Stress

Project Objective

TOPIC AREA 2:
Low-cost solar thermal heat

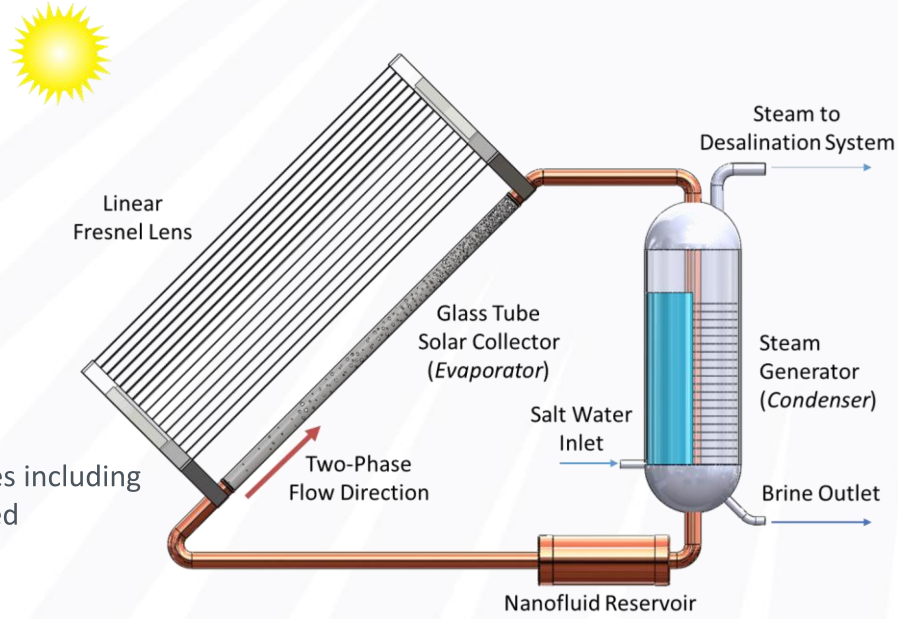
- ACT, collaborating with UMD, is developing an innovative, low-cost Loop Thermosyphon Solar Collection (LTSC) system.
- The overall project goal: to develop a LTSC system that efficiently collect and convert up to 1.5 kW/m^2 solar radiation to generate steam from brackish water at an overall efficiency of >80%, with an installation cost of less than $\$30/m^2$.
- System components:
  - Solar concentrator
  - Evacuated glass tube
  - Volumetric absorbing nanofluid
  - Loop thermosyphon
  - Steam generator

DE-EE0008398
Budget period: 10/01/2018 – 09/30/2021
$1.5M federal funding + $375k cost share

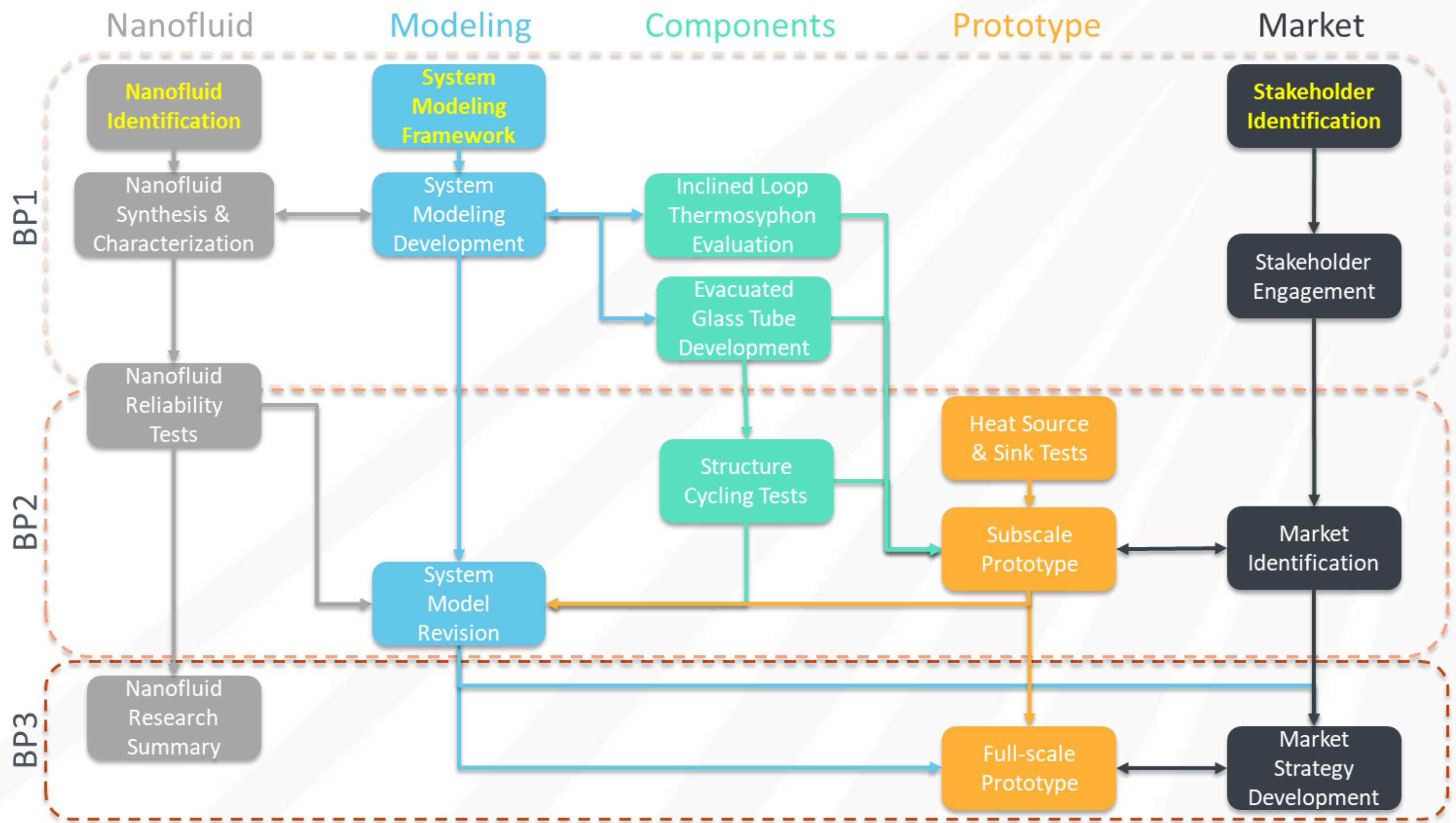


Technical Innovation

- Graphene-oxide based nanofluid
  - Volumetric solar absorbing
  - Local heating of working fluid
  - Reliable two-phase durability with no surfactant
- Transparent evacuated glass tube
  - No back surface absorbing coating
  - Decreased surface radiation and coating cost
  - No risk of coating degradation
  - No risk of nanofluid degradation at hot surface
  - Current low-cost evacuated tube and coating technologies including anti-reflection and low emission coatings will be leveraged
- High performance loop thermosyphon system
  - High heat flux limit
  - Stable two-phase nanofluid circulation
  - Passive operation with no solid moving parts
  - Low maintenance with no operation cost
- Overall high solar-to-thermal energy conversion rate with low



Technical Approach



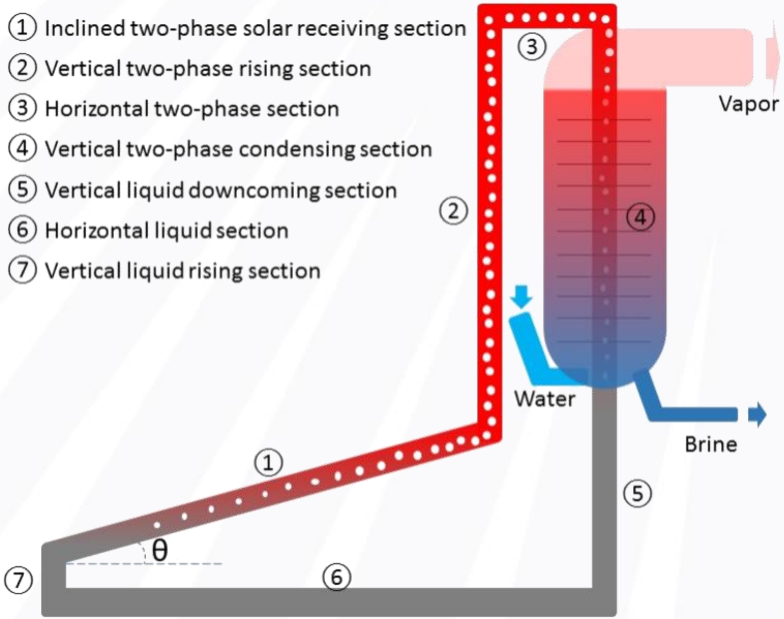
Loop thermosyphon modeling

Pressure balance: $\sum \Delta P_{friction} + \sum \Delta P_{gravitational} = 0$

Mass balance: $\dot{m}_{tot} = \sum \dot{m}_{vapor} + \sum \dot{m}_{liquid}$

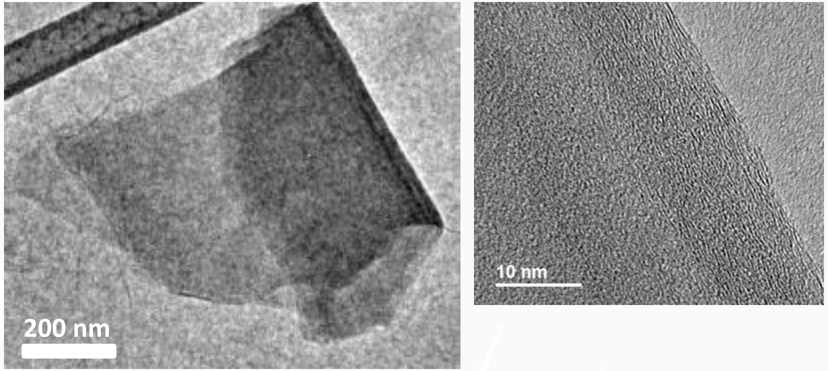
Input Power: $Power = \dot{m}_{tot}\, h_{fg}\, (x_7 - x_2)$

$\Delta P_{friction}$	Rising 2ϕ tube (evap. outlet -> cond. Inlet)	Horiz. 2ϕ tube (evap. outlet -> condenser Inlet)	Fall 1ϕ vertical tube (condenser out -> evap. Inlet)	Fall 1ϕ horizontal tube (condenser outlet -> evap. Inlet)
Density (ρ_i)	$\bar{\rho}_{2\phi}(T) = \left[\frac{x}{\rho_V(T)} + \frac{1-x}{\rho_L(T)}\right]^{-1}$	$\bar{\rho}_{2\phi}(T) = \left[\frac{x}{\rho_V(T)} + \frac{1-x}{\rho_L(T)}\right]^{-1}$	$\rho_L(T)$	$\rho_L(T)$
Viscosity (μ_i)	$\bar{\mu}_{2\phi}(T) = \left[\frac{x}{\mu_V(T)} + \frac{1-x}{\mu_L(T)}\right]^{-1}$	$\bar{\mu}_{2\phi}(T) = \left[\frac{x}{\mu_V(T)} + \frac{1-x}{\mu_L(T)}\right]^{-1}$	$\mu_L(T)$	$\mu_L(T)$
Length (L_i)	$L_{2\phi,v}$	$L_{2\phi,H}$	$L_{1\phi,v}$	$L_{1\phi,H}$
Diameter (D_i)	$D_{2\phi,v}$	$D_{2\phi,H}$	$D_{1\phi,v}$	$D_{1\phi,H}$
Velocity (V_i)	$\frac{\dot{m}_{total}}{\bar{\rho}_{2\phi}(T)\left(\frac{\pi}{4}(D_{2\phi,v})^2\right)}$	$\frac{\dot{m}_{total}}{\bar{\rho}_{2\phi}(T)\left(\frac{\pi}{4}(D_{2\phi,H})^2\right)}$	$\frac{\dot{m}_{total}}{\rho_L(T)\left(\frac{\pi}{4}(D_{1\phi,v})^2\right)}$	$\frac{\dot{m}_{total}}{\rho_L(T)\left(\frac{\pi}{4}(D_{1\phi,H})^2\right)}$
Reynolds Number (Re_i)	*Homogeneous model; S=1, Avg. 2ϕ properties* $Re_{2\phi} = \frac{(\bar{\rho}_{2\phi}(T)) V_i D_{2\phi,v}}{\bar{\mu}_{2\phi}(T)}$	$Re_{2\phi} = \frac{(\bar{\rho}_{2\phi}(T)) V_i D_{2\phi,H}}{\bar{\mu}_{2\phi}(T)}$	$\frac{(\rho_L(T)) V_i D_{1\phi,v}}{\mu_L(T)}$	$\frac{(\rho_L(T)) V_i D_{1\phi,H}}{\mu_L(T)}$
Friction Factor (f_i)	$Re_{2\phi} < 2300,\ f_{2\phi} = 64/Re_{tp}$, else $f_{2\phi} = 0.316\ Re_{2\phi}^{-0.25}$		$Re_{1\phi} < 2300,\ f_{1\phi} = 64/Re_{1\phi}$, else $f_{1\phi} = 0.316\ Re_{2\phi}^{-0.25}$	
Pressure gradient (dP/dz_i)	$\frac{dP}{dz}_{2\phi} = (\Phi_{LO}^2)\frac{dP}{dz_{LO}};\ \frac{dP}{dz_{LO}} = \frac{f_i \rho_L(T) V_i^2}{2D_{2\phi,v}}$ $\Phi_{LO}^2 = \left[1 + x\frac{(\rho_L - \rho_V)}{\rho_V}\right]\left[1 + x\frac{(\mu_L - \mu_V)}{\mu_V}\right]$		$\frac{dP}{dz}_{Liq.} = \frac{f_i \rho_L(T) V_i^2}{2D_{1\phi,v}}$	$\frac{dP}{dz}_{Liq.} = \frac{f_i \rho_L(T) V_i^2}{2D_{1\phi,H}}$

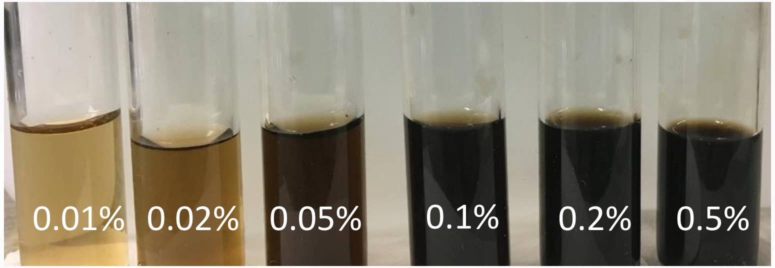


Nanofluid synthesis

- Literature review: graphene/GO nanofluids are suitable working fluids in the loop thermosyphon system
  - Metal/ceramic nanofluids are instable without surfactant
  - Graphene/GO nanofluids have high thermal conductivity, high solar absorbance, high stability, and moderate viscosity increase
- Partially-reduced graphene oxide aqueous nanofluids will be used as the bulk solar absorbing working fluid
  - Absorbing efficiency near 100% over solar wavelength
  - Non-surfactant nanofluid for two-phase stability
- Volumetric boiling of the working fluids
  - Preventing nanoparticle precipitation and agglomeration on a hot surface
  - In-situ boiling of working fluid on the graphene oxide – water interface minimizes thermal resistance (large heat transfer area)



Typical size of graphene/GO particles



Samples of GO aqueous nanofluids

Summary

- ACT and UMD are developing a Thermosyphon Solar Collection system to provide low-cost solar thermal energy for desalination.
  - Low-cost, reliable passive loop thermosyphon operation
  - Volumetric solar conversion by nanofluid
  - High solar-to-thermal efficiency with low thermal resistance and exergy loss
- Budget: $1.5M federal + $375k cost share
  - 10/01/2018 – 09/30/2021
- Impact
  - Reduced cost of solar heat for desalination etc.
  - Broader freshwater resources from brackish water at acceptable cost
  - Passive loop thermosyphon technology for other heat transfer applications

Questions?