ADVANCED GLASS MATERIALS FOR THERMAL ENERGY STORAGE

Tim Dyer, Benjamin Elkin, and Dr. Justin Raade
Halotechnics, Inc.

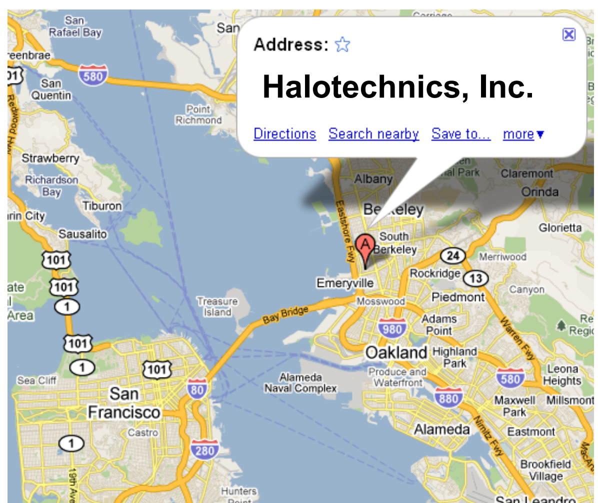
SunShot CSP Program Review
April 25, 2013

Prime Recipient	**Subcontractor**
Halotechnics, Inc.	Pratt & Whitney Rocketdyne, Inc.

Company profile of Halotechnics, Inc.

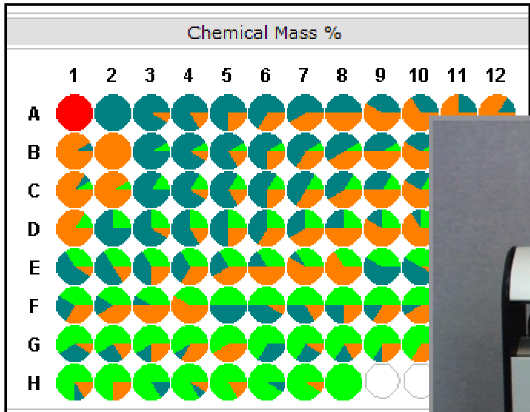
High temperature fluids are the key to abundant clean energy

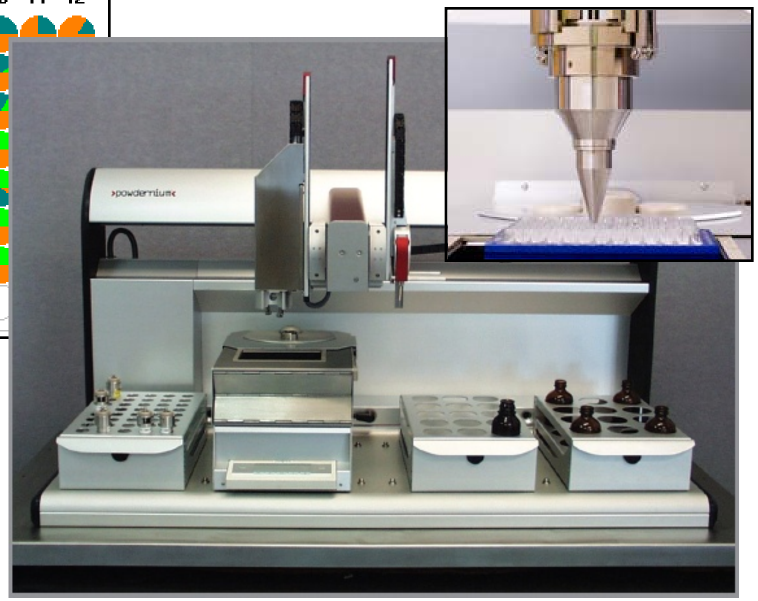
- Headquarters in Emeryville, California with fully equipped chemistry lab
- Experts in materials science, chemistry, and engineering on staff
- Board of directors made up of industry veterans



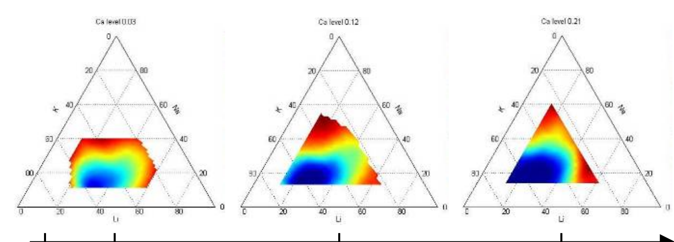
HALOTECHNICS

High throughput chemistry





- **Powerful tool for developing advanced thermal fluids**
- Proprietary software and automated lab equipment
- Can screen over 100 mixtures/day
- Screened over 22,000 mixtures to date



HALOTECHNICS

Liquid Glass Development

INNOVATION | Companies on the Cutting Edge

Energy-Storing Glass | Halotechnics

Solar power by night

Thermal solar plants use fields of mirrors to concentrate sunlight on a central receiver tower, superheating a liquid contained inside—usually molten salt. When the sun isn't shining, the stored heat is used to power steam turbines that create electricity. Molten salt can absorb only so much heat, though, which limits the plants' efficiency. Halotechnics, an Emeryville, California–based start-up, has developed a glass that remains stable at temperatures up to 1200 degrees Celsius (2192 degrees Fahrenheit) when melted—hundreds of degrees hotter than the threshold of molten salt. For ease of transport, the glass is delivered as solid beads and then melted on-site. Halotechnics recently received a $3.3 million grant from the U.S. government's ARPA-E (Advanced Research Projects Agency–Energy) agency and hopes to commercialize the product by 2015.

Mix and match

To find the perfect formula for its glass, Halotechnics used a software platform that allows the company to screen 100 chemical compounds a day.

Pump it up

At production scale, millions of the glass beads shown here would be transported to a solar power plant, melted in a large tank at 500 degrees Celsius, then pumped into a receiver tower to absorb the sun's concentrated heat.

"We're very excited about making 24/7 solar a reality."

—Justin Raade, founder and CEO, Halotechnics

Green tech

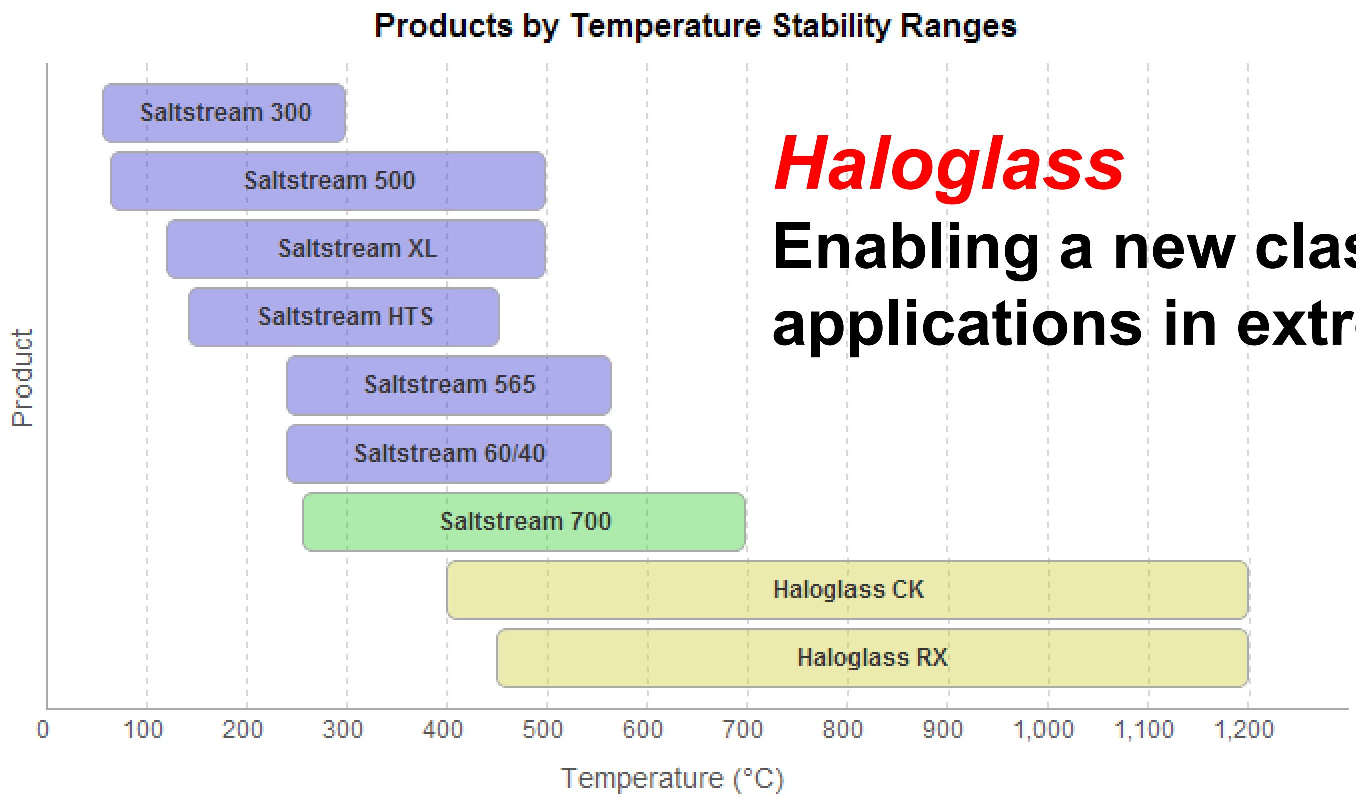
The glass gets its green color from a proprietary additive that reduces its melting point, preventing it from resolidifying when temperatures drop.

48 INC. MAY 2012

PHOTOGRAPH BY TODD TANKERSLEY | REPORTED BY J.J. MCCORVEY

HALOTECHNICS

Product announcement



Haloglass

Enabling a new class of applications in extreme heat

HALOTECHNICS

Glass Products Comparison

Haloglass RX – earth abundant, stable fluid
Haloglass CK – low viscosity, high performance

HALOTECHNICS

Glass Properties Summary Table

Product	Viscosity at 400°C (cP)	Viscosity at 1200°C (cP)	Heat Capacity (J/g·K)	Relative Cost	Safety Constraints
Haloglass RX	53,800	10	1.3 – 1.5	$	x
Haloglass CK	78	<1	1.2 – 1.3	$$$	xxx
H-G010	>500,000	53	1.8 – 1.9	$$	xx

Good heat transfer properties from 400 °C up to 1200 °C

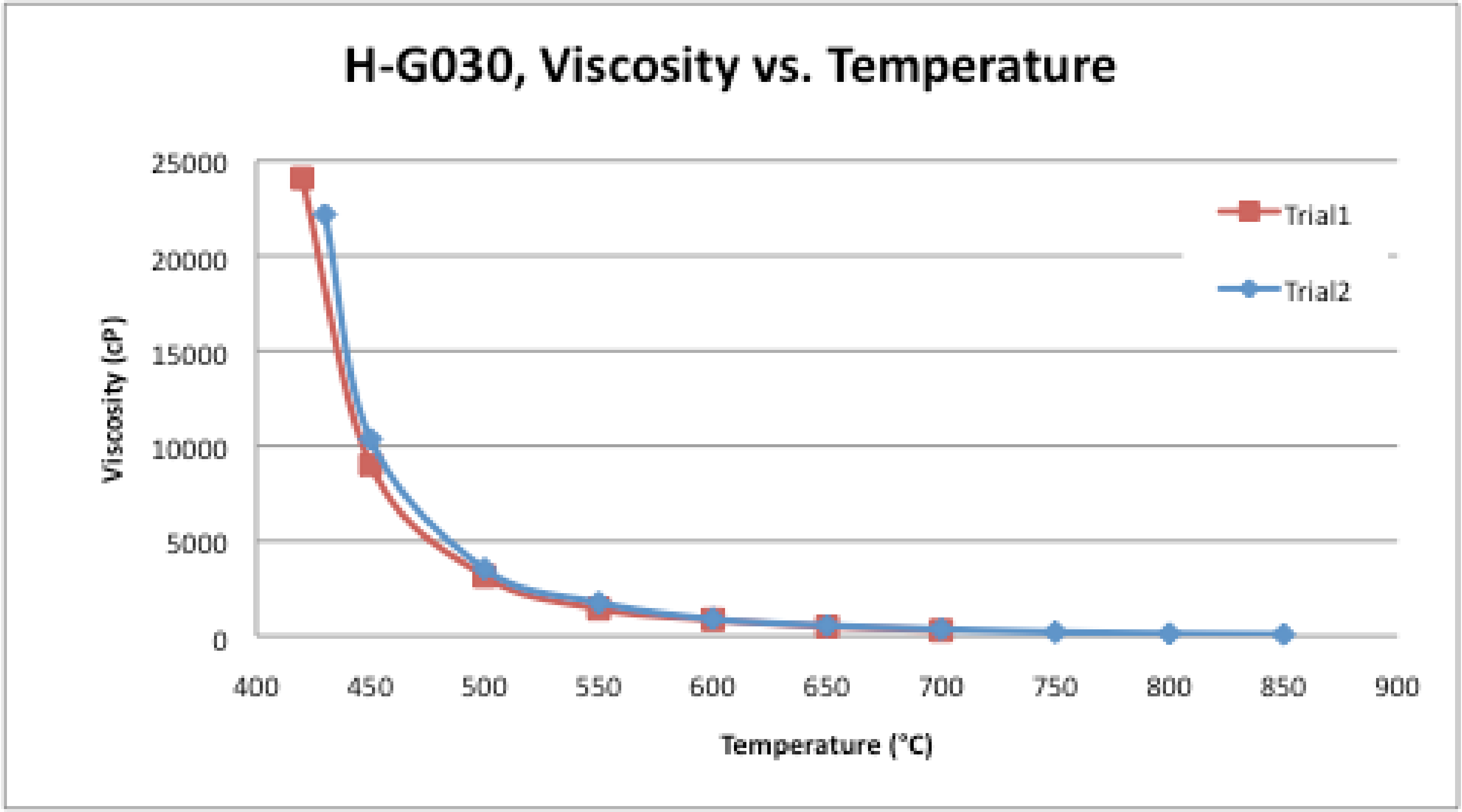
HALOTECHNICS

Haloglass RX

- Multi component, oxide based glass
- Color: Clear
- Heat capacity 1.3 -1.5 J/gK
- Viscosity at 450 °C: 10,000 cP
- Safety Constraints: Low
- Relative Cost: Low

HALOTECHNICS

Haloglass RX Viscosity Test



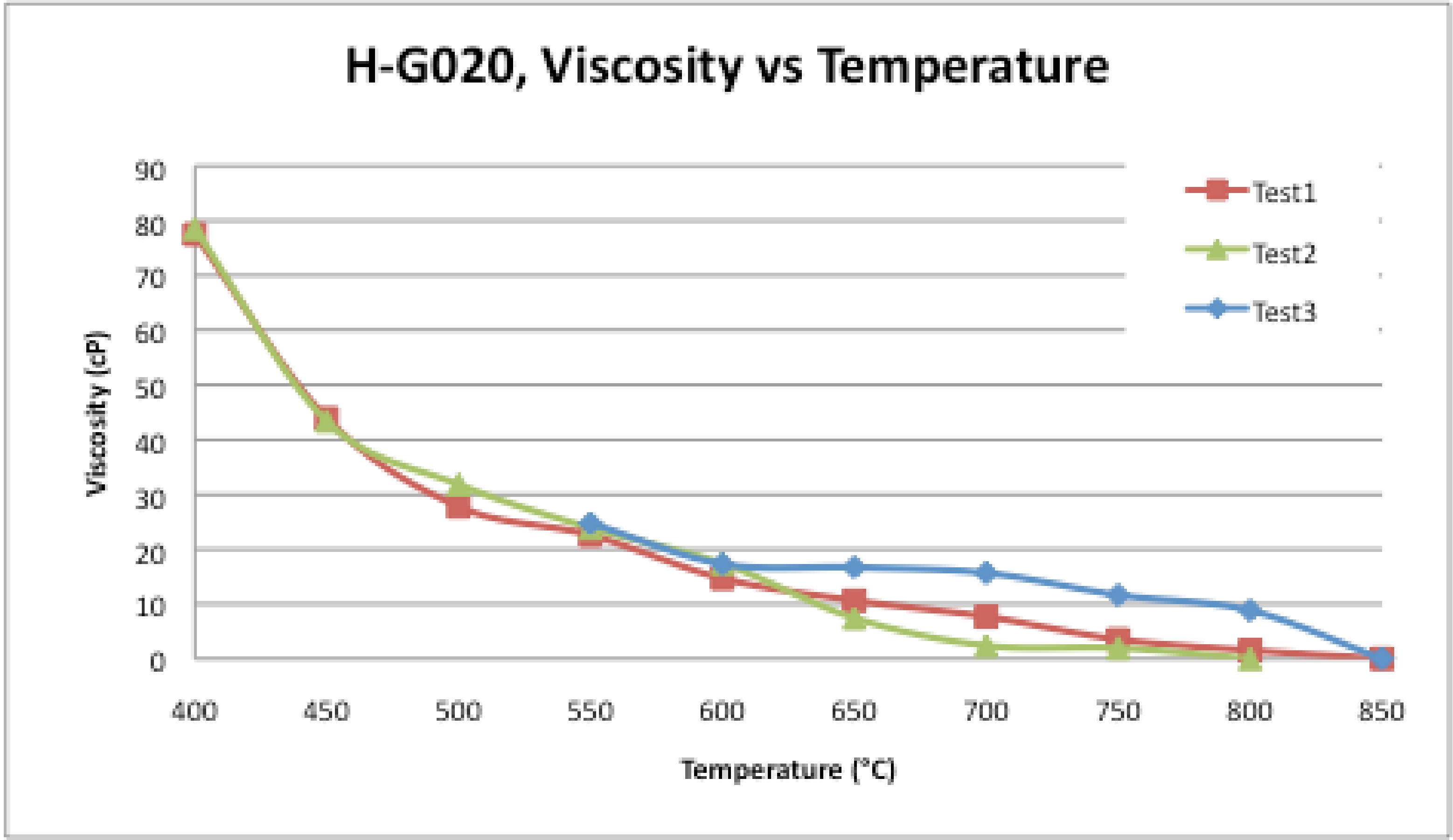
HALOTECHNICS

Haloglass CK

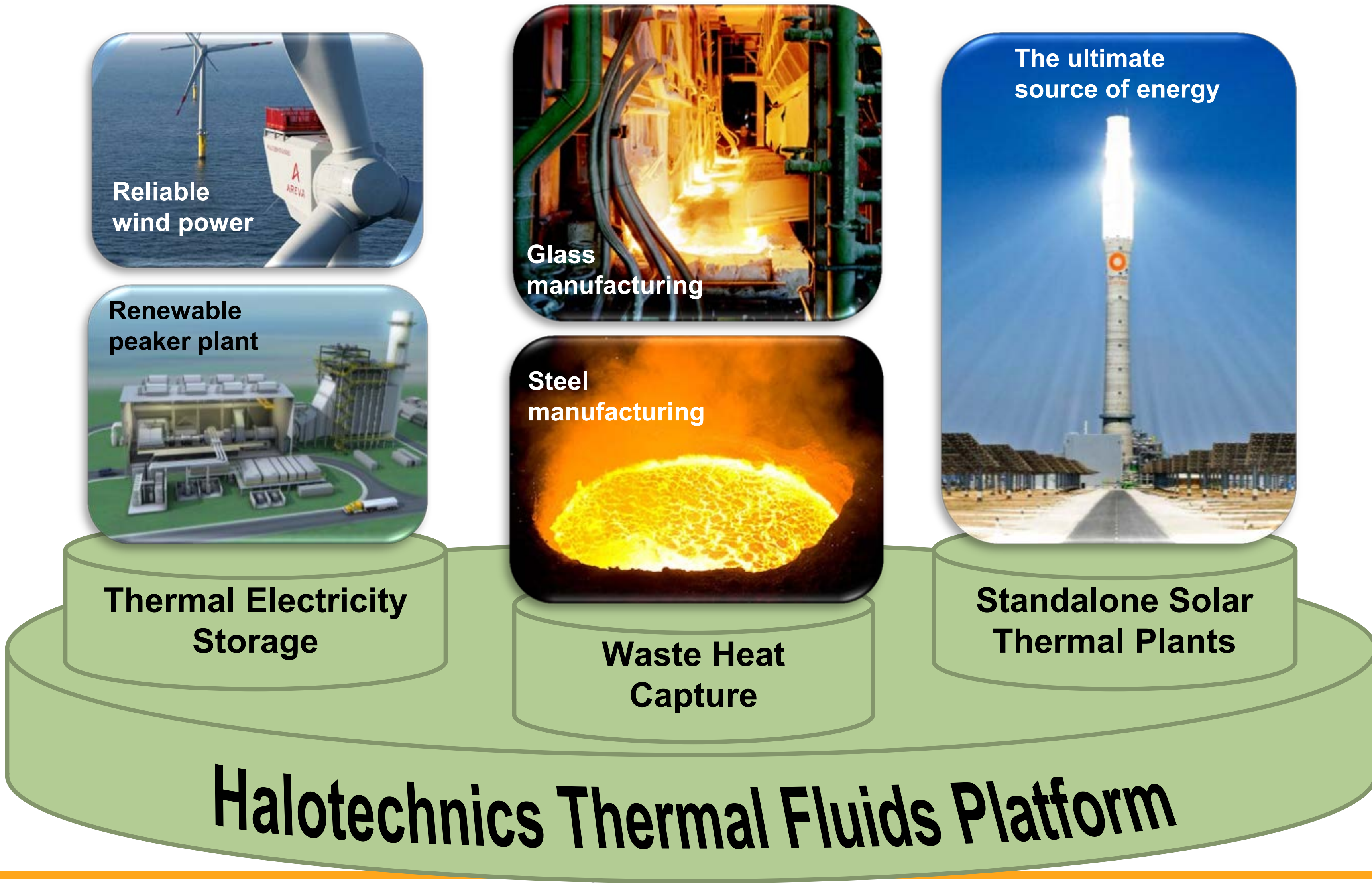
- Multi component, oxide based glass
- Color: Red/Brown
- Heat capacity 1.2 - 1.3 J/gK
- Viscosity at 400 ° C: 78 cP
- Safety Constraints: High
- Relative Cost: High

HALOTECHNICS

Haloglass CK Viscosity Test



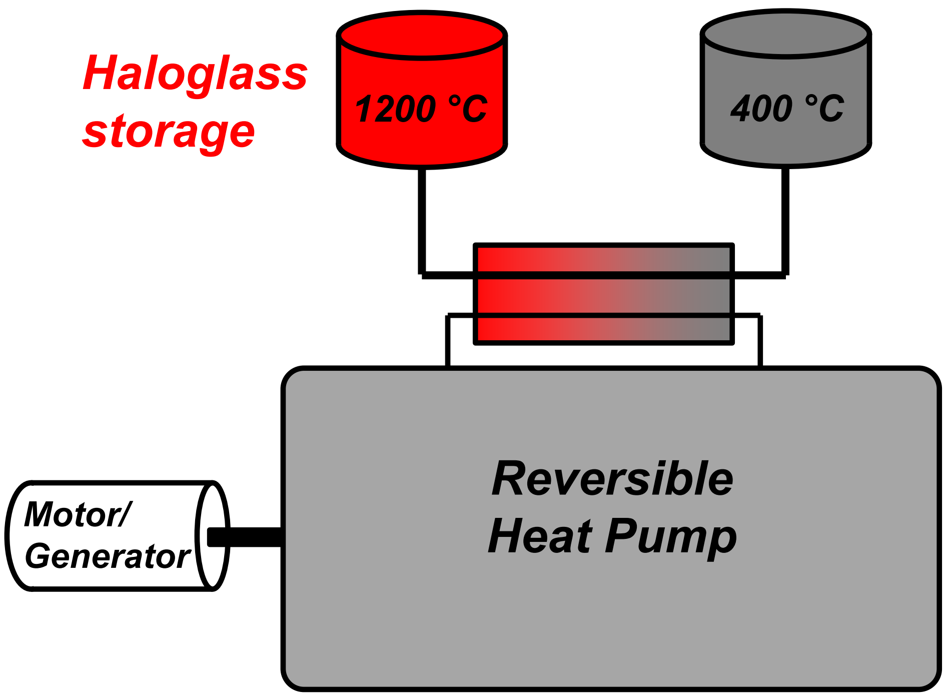
Halotechnics thermal fluids applications



HALOTECHNICS

Electricity from Thermal Energy Storage

- **Efficient *electricity storage* enabled by Halotechnics thermal storage technology**
- The efficiency of batteries at a fraction of the cost
- Scalable to hundreds of megawatts
- Grid scale storage cheaper than peaker plants



The hotter, the better…

HALOTECHNICS

Halotechnics ARPA-E Award

- $3.3 million federal award
- 36 month program, January 2012 through December 2014
- Phase 1: Critical component development (24 months)
  - Glass chemistry development
  - Glass manufacturing scale-up
  - Hot and cold pump design
  - Hot and cold tank design
  - Heat exchanger and piping
- Phase 2: System integration and testing (12 months)
- Seeking strategic partners for technology transfer and scale-up

HALOTECHNICS

Program Schedule

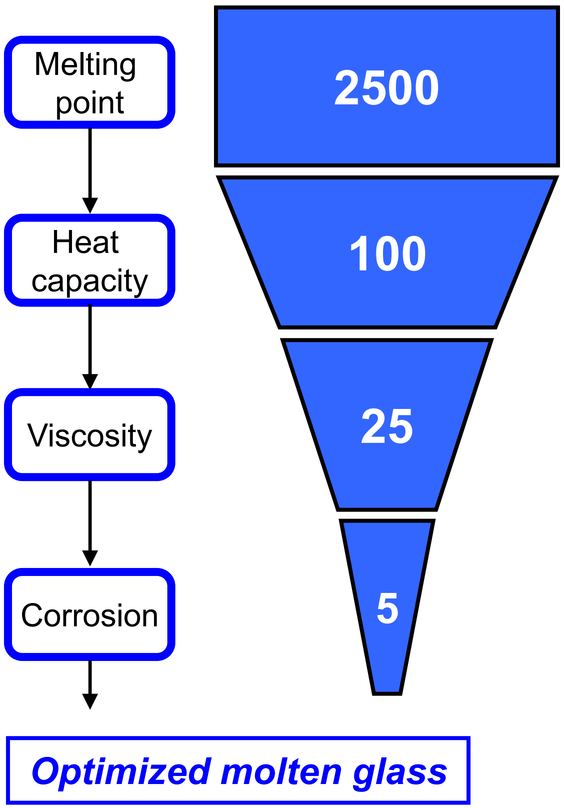
		Phase 1								Phase 2			
No.	**Task**	**Q1**	**Q2**	**Q3**	**Q4**	**Q5**	**Q6**	**Q7**	**Q8**	**Q9**	**Q10**	**Q11**	**Q12**
1	Glass screening workflow development												
2	Optimize glass material												
3	Piping material selection												
4	Corrosion testing												
5	Tank modeling												
6	Tank design and testing												
7	Pump modeling												
8	Pump design and testing												
G1	Go/No-Go 1												
9	Heat exchanger modeling												
10	Heat exchanger design and testing												
11	Furnace modeling												
12	Furnace testing												
13	Full system design and assembly												
G2	Go/No-Go 2												
14	System testing												
15	Technology transfer and outreach												
G3	Go/No-Go 3												

HALOTECHNICS

Screening workflow

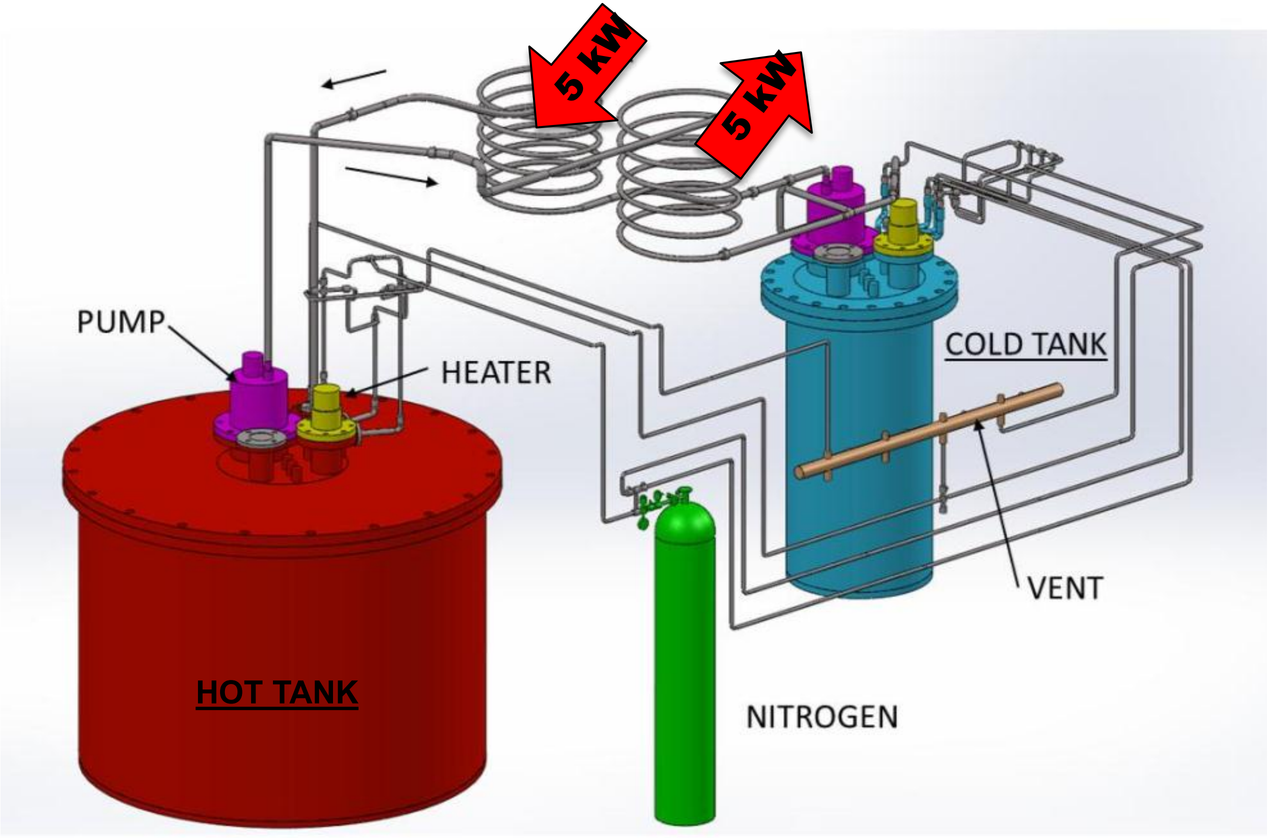
Viscometer

Corrosion



HALOTECHNICS

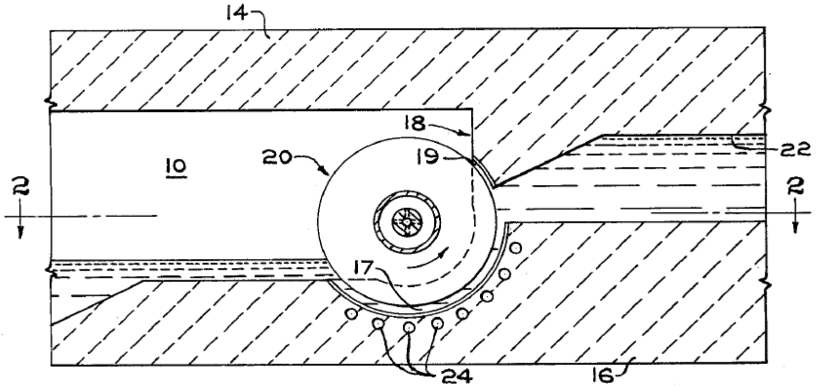
Thermal Energy Storage System

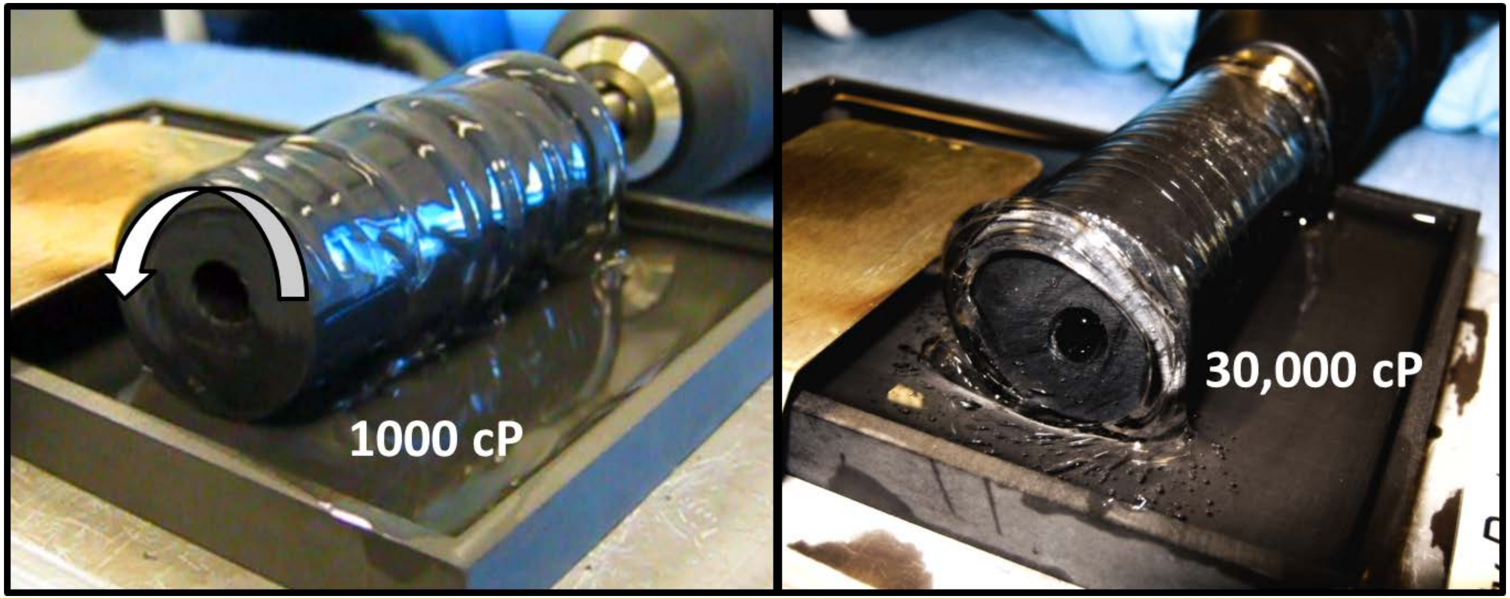


- Pilot scale thermal storage system (30 kWh, 400 kg glass)

Viscosity Pump

- Viscosity pump concept capable of pumping thick fluids
- Target 100 mL/min flow rate at 1200 °C / 400 °C

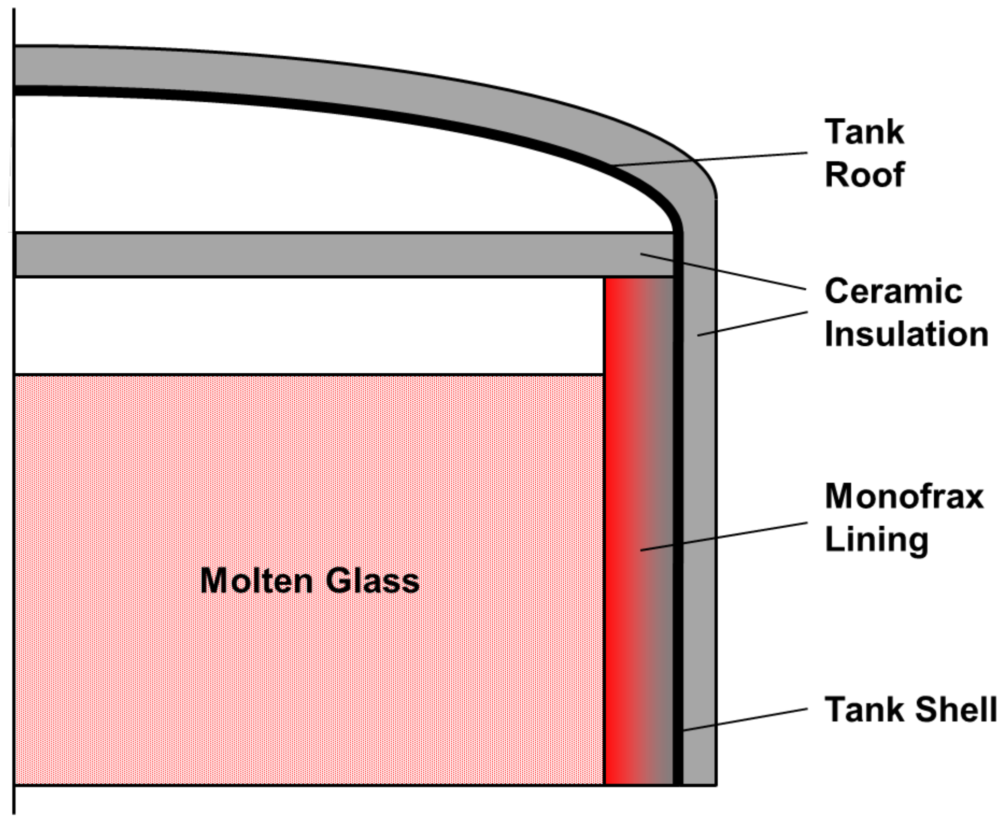




HALOTECHNICS

Thermal Storage Tank for Molten Glass

- Internally insulated design with refractory material in direct contact with molten glass
- Isolates external structural shell from hot interior
- Target low heat losses at 1200 °C / 400 °C



ADVANCED GLASS MATERIALS FOR THERMAL ENERGY STORAGE

Tim Dyer, Benjamin Elkin, and Dr. Justin Raade
Halotechnics, Inc.

SunShot CSP Program Review
April 25, 2013

Prime Recipient	**Subcontractor**
Halotechnics, Inc.	Pratt & Whitney Rocketdyne, Inc.