The SLIC Primer

The Guide to Full Immersion Cooling of Electronics

with Single-phase, Liquid Immersion Coolants

Gary Testa, President & CEO
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Purpose

• This document is intended to provide a general understanding of the concepts, architectures, system parameters, and components used in Single-phase, Liquid Immersion Cooling ("SLIC") solutions for cooling electronics.

• We will focus on use of open tanks for the purpose of cooling crypto miners and similar types devices; however the same techniques can be applied for cooling of most any electronic devices including CPUs, FPGAs, GPUs, and entire servers.

• Note that because tanks and electronics come in a wide variety of shapes and sizes, it is not possible to provide exact measurements, flow rates, and power usage in this presentation. Each system is a calculated balance between waste heat of the devices, tank volumes, coolant flow rates, heat rejection, climate, location and other aspects of the system.

• All information in this presentation should be considered as guidelines only. All systems should be thoroughly tested and verified for use with your equipment. If you need design, flow, or general SLIC consulting assistance for your application : Please contact us: sales@engineeredfluids.com
We want your feedback and input to improve this resource

• Send any suggestions, questions or recommendations for improving this guide to:
  • sales@engineeredfluids.com

• Need design or technical support?
  • support@engineeredfluids.com

• You can purchase all the Engineered Fluids’ products online in quantities of <180L at:
  • www.engineeredfluids.store

• Need a quote for quantities greater than 180L or for ocean shipping quotations:
  • https://www.engineeredfluids.com/request-a-quote

• Have a great SLIC cooling rig you are willing to share with the immersion cooling community?
  • Send us your pictures or short videos and we’ll post them on our website in our SLIC System Gallery
  • Please include your name, email address, city and country, and coolant type and a URL link if applicable
  • You can find the SLIC System Gallery here: https://www.engineeredfluids.com/slic-design-gallery
About Engineered Fluids

**Specialized developer of Single-phase Liquid Immersion Cooling Solutions**

**High-Performance Biodegradable, Non-Toxic, Non-Corrosive Dielectric Coolants**

**BitCool®** - Dielectric Immersion Coolants designed specifically for ASIC based miners
- Supports all ASIC Crypto-mining devices

**ElectroCool®** - Dielectric Immersion Coolants for Semiconductors and Servers
- Server / CPU / GPU / SSD / DRAM
- Lasers / LEDs / RF Amplifiers / Tubes / Processors / RADAR
- Battery / Fuel Cell cooling for Power Generation (Solar / Wind / Conventional) in stationary electrical storage applications

**AmpCool®** - Dielectric Immersion Coolants for Batteries, Electric Motors and Hydraulics
- Electric motors & motor controllers
- Hydraulic power transmission and actuator systems
- Aquatic applications for pressure compensating, insulating, and lubrication
- Battery and Fuel Cell cooling in hybrid and electric vehicles

**VoltCool®** - High Voltage Dielectric Heat Transfer Fluids for use Power and Distribution
- Power & Distribution Transformers, Switch Gear, AC & DC feeder lines
- High Voltage Battery / Fuel Cell cooling in specialty and stationary electrical storage applications

**Products for protecting and cleaning electronic equipment during and after immersion**

**VoltCool® Additives** - Highly Concentrated Transformer Oil Protection
- Power & Distribution Transformers, Switch Gear, AC & DC feeder lines
- Anti-oxidation and Corrosive Sulfur Stop Additives for use with hydrocarbon transformer oils

**Dielectric Solvents** – Safe and Effective Removal of Dielectric Fluids and Mineral Oils
- Fully dielectric solvents for use with all electronics and immersion cooling systems
## Engineered Fluids vs. Other Dielectrics

*ElectroCool & BitCool are simply the better dielectric coolants*

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>ElectroCool &amp; BitCool</th>
<th>Mineral Oil &amp; White Oil</th>
<th>Fluorinated Fluids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dielectric Strength (ASTM 1816)</td>
<td>60kV</td>
<td>25kV</td>
<td>40kV</td>
</tr>
<tr>
<td>Relative Heat Capacity ((\text{Air} = 1))</td>
<td>1610</td>
<td>1170</td>
<td>1360</td>
</tr>
<tr>
<td>Environmental Impacts (GWP)</td>
<td>0</td>
<td>0</td>
<td>&gt;9000</td>
</tr>
<tr>
<td>Products Intended Use (Design Criteria)</td>
<td>Dielectric Coolant</td>
<td>Lubrication</td>
<td>Solvent</td>
</tr>
<tr>
<td>Worker Health and Safety</td>
<td>+++</td>
<td>-</td>
<td>---</td>
</tr>
<tr>
<td>Biodegradable and Nontoxic</td>
<td>+++</td>
<td>--</td>
<td>---</td>
</tr>
<tr>
<td>Non-corrosive to Electronics</td>
<td>+++</td>
<td>Corrosive Sulfur</td>
<td>Micro-cavitation</td>
</tr>
<tr>
<td>Characteristics are Standardized, Tested and Guaranteed</td>
<td>+++</td>
<td>x</td>
<td>++</td>
</tr>
<tr>
<td>Material Compatibility Guarantee</td>
<td>+++</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Cooling Systems are Simple, Quiet, and Clean</td>
<td>+++</td>
<td>+</td>
<td>--</td>
</tr>
</tbody>
</table>
BitCool® Dielectric Coolants for ASIC Miners

BitCool Dielectric Coolants are the highest performance biodegradable, non-toxic dielectric thermal management fluids available for specifically for ASIC Based mining devices

**BitCool BC-888 - Compatible ASIC-based Miners**

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Miners</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beloit Miner</td>
<td>BK-R/Nx0, N+ X</td>
</tr>
<tr>
<td>BitMain ANTMINER™</td>
<td>A3, B3, D3, E3, G2, L3+, R3, S2, g1, T9v, V9, X3, Z9</td>
</tr>
<tr>
<td>Canaan Creative</td>
<td>Avalon 6, 741, 821, 841</td>
</tr>
<tr>
<td>Ebang</td>
<td>E9.2, E9.3, E10</td>
</tr>
<tr>
<td>GMO Miner</td>
<td>Rx (Pending Release and Testing)</td>
</tr>
<tr>
<td>Halong Mining</td>
<td>i1T, D2a, D5a, T1</td>
</tr>
<tr>
<td>Innosilicon</td>
<td>A1S, A5+, A6, A5, A8+, ABC, A9, D9, S11-12</td>
</tr>
<tr>
<td>Penguin Miner</td>
<td>M3, Mx3</td>
</tr>
</tbody>
</table>

**Key Characteristics of BitCool Dielectric Coolant**

<table>
<thead>
<tr>
<th>Product ID</th>
<th>BC-888</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application</td>
<td>Single-phase, Liquid Immersion Cooling of ASIC-based Cryptocurrency Mining Devices</td>
</tr>
<tr>
<td>Key Characteristic</td>
<td>Compatibility with ASIC Mining Devices</td>
</tr>
<tr>
<td>Appearance</td>
<td>Light Green Tint</td>
</tr>
<tr>
<td>Pour Point (°C)</td>
<td>&lt; 0</td>
</tr>
<tr>
<td>Flash Point (°C)</td>
<td>&gt; 130</td>
</tr>
<tr>
<td>Density, g/cc @ 25°C</td>
<td>0.82</td>
</tr>
<tr>
<td>Coefficient of Thermal Expansion, volume/°C</td>
<td>0.00068</td>
</tr>
<tr>
<td>Viscosity (cSt) @ 40°C</td>
<td>&lt; 10</td>
</tr>
<tr>
<td>Viscosity (cSt) @ 100°C</td>
<td>&lt; 2</td>
</tr>
<tr>
<td>Thermal Conductivity (W/m·K) @ 40°C</td>
<td>0.1373</td>
</tr>
<tr>
<td>Thermal Conductivity (W/m·K) @ 100°C</td>
<td>0.1333</td>
</tr>
<tr>
<td>Specific Heat 0°C</td>
<td>2034 JgK-1</td>
</tr>
<tr>
<td>Specific Heat 40°C</td>
<td>2203 JgK-1</td>
</tr>
</tbody>
</table>

Updated: 20180608 10
**ElectroCool® Dielectric Coolants for GPUs**

ElectroCool Dielectric Coolants are the highest performance biodegradable, non-toxic dielectric thermal management fluids available.

ElectroCool Coolants feature the broadest material compatibility, highest safety, and widest useful temperature range.

<table>
<thead>
<tr>
<th>Product ID</th>
<th>EC-100</th>
<th>EC-110</th>
<th>EC-120</th>
<th>EC-130</th>
<th>EC-140</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Typical Application</strong></td>
<td>General electronics cooling with excellent material compatibility</td>
<td>Outdoor and sealed system electronics cooling and insulation</td>
<td>Enterprise grade cooling of servers, semiconductors, and electronics</td>
<td>Data center cooling of servers, GPUs, semiconductors, and electronics</td>
<td>High temperature semiconductor &amp; electronics cooling and insulation</td>
</tr>
<tr>
<td><strong>Fluid Behavior</strong></td>
<td>Non-Compressible, Incompressible, Newtonian</td>
<td>Non-Compressible, Incompressible, Newtonian</td>
<td>Non-Compressible, Incompressible, Newtonian</td>
<td>Non-Compressible, Incompressible, Newtonian</td>
<td>Non-Compressible, Incompressible, Newtonian</td>
</tr>
<tr>
<td><strong>Appearance</strong></td>
<td>Clear</td>
<td>Clear</td>
<td>Clear</td>
<td>Clear</td>
<td>Clear</td>
</tr>
<tr>
<td><strong>Dielectric Strength</strong></td>
<td>&gt;50 kV</td>
<td>&gt;50 kV</td>
<td>&gt;50 kV</td>
<td>&gt;50 kV</td>
<td>&gt;50 kV</td>
</tr>
<tr>
<td><strong>Dielectric Constant</strong></td>
<td>2.3</td>
<td>2.3</td>
<td>2.3</td>
<td>2.3</td>
<td>2.3</td>
</tr>
<tr>
<td><strong>Refractive Index @20°C</strong></td>
<td>1.462</td>
<td>1.440</td>
<td>1.442</td>
<td>1.453</td>
<td>1.465</td>
</tr>
<tr>
<td><strong>Pour Point (°C)</strong></td>
<td>-55</td>
<td>-57</td>
<td>-66</td>
<td>-57</td>
<td>-54</td>
</tr>
<tr>
<td><strong>Flash Point (°C)</strong></td>
<td>185</td>
<td>150</td>
<td>157</td>
<td>135</td>
<td>280</td>
</tr>
<tr>
<td><strong>Density, g/cc @ 15 °C</strong></td>
<td>0.8133</td>
<td>0.7980</td>
<td>0.7980</td>
<td>0.9244</td>
<td>0.9300</td>
</tr>
<tr>
<td><strong>Coefficient of Thermal Expansion, μm/°C</strong></td>
<td>0.00076</td>
<td>0.00097</td>
<td>0.00076</td>
<td>0.00065</td>
<td>0.00070</td>
</tr>
<tr>
<td><strong>Kinematic Viscosity @0°C</strong></td>
<td>47.12</td>
<td>27.43</td>
<td>18.99</td>
<td>12.12</td>
<td>75.61</td>
</tr>
<tr>
<td><strong>Viscosity @40°C</strong></td>
<td>3.58</td>
<td>5.63</td>
<td>5.02</td>
<td>3.72</td>
<td>64.46</td>
</tr>
<tr>
<td><strong>Viscosity @100°C</strong></td>
<td>2.68</td>
<td>2.00</td>
<td>1.70</td>
<td>1.41</td>
<td>5.53</td>
</tr>
<tr>
<td><strong>Thermal Conductivity @0°C</strong></td>
<td>0.1396</td>
<td>0.1382</td>
<td>0.1383</td>
<td>0.1404</td>
<td>0.1801</td>
</tr>
<tr>
<td><strong>Thermal Conductivity @100°C</strong></td>
<td>0.1373</td>
<td>0.1359</td>
<td>0.1359</td>
<td>0.1374</td>
<td>0.1804</td>
</tr>
<tr>
<td><strong>Specific Heat @0°C</strong></td>
<td>2.0540</td>
<td>2.0608</td>
<td>2.0608</td>
<td>2.0577</td>
<td>2.0460</td>
</tr>
<tr>
<td><strong>Specific Heat @100°C</strong></td>
<td>2.2032</td>
<td>2.2121</td>
<td>2.2121</td>
<td>2.2030</td>
<td>2.1912</td>
</tr>
<tr>
<td><strong>Global Warming Potential</strong></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Biodegradability (28 Days)</strong></td>
<td>&gt;93%</td>
<td>&gt;96%</td>
<td>&gt;96%</td>
<td>&gt;93%</td>
<td>&gt;50%</td>
</tr>
<tr>
<td><strong>Material’s Compatibility Warranty</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Product Operational Warranties (Yrs)</strong></td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td><strong>Shelf Life (Yrs)</strong></td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>
The Challenge of Thermal Management

Heat dissipation is the limiting factor in data centers and crypto-mining

New multi-core CPUs / GPUs / FPGAs / ASICs waste heat can now exceed >2000W per device.

Air cooling is extremely power inefficient – consuming 40% to 50% of total facility energy usage:

- 30 - 40% of power is consumed by air-conditioning, fans, and associated air-cooling and handlers
- 5% – 20% of the power used by the devices onboard fans alone!

Air-cooling is space inefficient and severely limits the facilities compute density

- More than 1/3 the space in data centers / mines are dedicated to or dictated by air cooling requirements
- Fans, Filters, Air Conditioners, Chillers, Duct Work, Compressors, etc.

The Air-cooling infrastructure can represent 50% or more of capital infrastructure costs

Air-cooling represents up to 50% of total operational costs (power, maintenance & operational costs)

Noise Levels often exceed 89db with facility hot alise temperatures exceeding 100F are not uncommon.

Not to mention all the operational issues related to maintaining air filters, humidity control, corrosive air-borne contaminants, and mechanical air-handling equipment, etc.
Comparing PUEs of Air and SLIC solutions

Be sure to remove the device fans out of the denominator!

- PUE = Power Usage Effectiveness
- Device fans consume between 10-20% of the total device power
- To accurately compare a SLIC PUE with air cooling PUE you must recalculate your air-cooled PUE to account for removing the device fans out of IT load.

**Typical Air-Cooled PUE Calculation**

\[
PUE = \frac{\text{Total Facility Energy}}{\text{IT Equipment Energy}}
\]

- \(2.0 = \frac{1,000\text{ kW}}{500\text{ kW}}\)
- \(1.5 = \frac{750\text{ kW}}{500\text{ kW}}\)
- \(1.2 = \frac{600\text{ kW}}{500\text{ kW}}\)
- \(1.1 = \frac{550\text{ kW}}{500\text{ kW}}\)

**True Air-Cooled PUE Calculation**

Assuming only 10% of IT Equipment power is consumed by Server Fans

\[
PUE = \frac{\text{Total Facility Energy}}{\text{IT Equipment Energy}}
\]

- \(2.22 = \frac{1,000\text{ kW}}{450\text{ kW}}\)
- \(1.66 = \frac{750\text{ kW}}{450\text{ kW}}\)
- \(1.33 = \frac{600\text{ kW}}{450\text{ kW}}\)
- \(1.22 = \frac{650\text{ kW}}{450\text{ kW}}\)

Actual PUE is at Least 11% Higher!
Important SLIC Concepts

- Your electronics generate *as much heat (measured in KWs) as they consume in electricity.*
  - Effectively your devices are just expensive and highly efficient heating elements. All the power they consume is exhausted as heat to the outside environment, typically through noisy and power-hungry fans.

- *Air is not a good conductor of heat; in fact, it is an excellent insulator.*
  - Think of your down jacket, it is filled with air which is what traps your body heat inside the jacket thereby insulating the warm you from the cold outside. The down in the jacket is actually only there to create the air gaps that maintain the volume of insulating air between you and the outside environment.

- *Liquids can be excellent conductors of heat because of their density*
  - Unfortunately, while water is one of the very best heat transfer fluids, it has one very significant draw back for use electronics cooling – it is highly conductive of electricity!
  - Therefore, in order to use water to cool electronics you must spend a lot of time and money engineering the complex plumbing and interface systems, as well as the protective failure modes, to keep water and electronics separate.
  - In addition, water has a low boiling and high freezing point. Thus to be effective, you must add glycol, biocides, and other chemicals to water to stop it from boiling, freezing and to stop the constant growth of organic matter in the system that clogs the pipes, cold-plates, and radiators.

- *Dielectric Coolants from Engineered Fluids* are biodegradable, non-toxic, non-corrosive and are both excellent conductors of heat and fully non-conductive (Dielectric = non-conductive of electricity) up to 60KV.
Cooling Solutions used with Electronics

A quick review of various cooling systems and their operational characteristics
Typical air-cooled Infrastructure

A/C & Water chilling units, compressors, and associated fans use about 40% of power in the typical mine or Data Center.

Air-Cooling requires multiple systems and multiple redundancies all delivered at great cost of capital and maintenance.

These cooling fans can use up to 30% of the all the power consumed by miners.

Hot and cold aisles and cooling infrastructure take up more than ½ of available floorspace!
Cold Plates


Indirect cooling of devices using chip-specific, fluid-cooled heat exchangers mounted on each chip. Cools the chips through closed loop circulation of high-pressure water through cold plates, dumping waste heat using fluid-to-fluid, fluid-to-air heat exchangers. Requires water cooling infrastructure to the rack, internal server plumbing, CRAC units, and fans.

Cold plates are micro-filters and fail due to fouling from bio slime other contaminants.

Incoming water manifold pressures can exceed 200psi, requiring water plumbing rated at 1000psi per ASHRE.

Requires very expensive dripless connectors to prevent high-pressure water failure and intrusion.

Every board & chip layout requires a custom plumbing and cold plate design.
Back of Rack Water Cooled Radiators

Adds water filled air-cooling radiators to the back of the rack. Cools the miners through closed loop circulation of chilled water through radiators, dumping waste heat using fluid-to-fluid or fluid-to-air heat exchangers. Requires water cooling infrastructure to each rack and fans are required on both the servers and the back of rack radiator. This is in addition to the air-cooling infrastructure already in place.

- Requires chilled water plumbed into each individual rack.
- Servers still have all their fans operating.
- Add even more fans at the back every rack.
- Still need the same air-cooling infrastructure.
Two-phase Immersion Cooling (2PIC)

Miners are fully immersed in low-temp boiling fluoroketone (halogenated fluids). Cools the server through vaporization of fluid by hot electronics. Heat is removed by recondensing the vaporized coolant with gas-to-water heat exchangers, dumping waste heat using fluid-to-fluid or fluid-to-air heat exchangers. Requires water cooling infrastructure to the rack, vapor containment, and pressurized sealed system.

- Requires chilled water plumbed into each tank for the vapor to be cooled through a gas to fluid condenser.
- Fluid is vaporized by the heat of the electronics. Closed system is required to prevent the coolant from dispersing and evaporating.
- The boiling action of the coolant creates micro-cavitation which actually erodes the heated metals in the device destroying it and contaminating the coolant with metallic particles making the coolant conductive.
Single-phase Fluid Immersion Cooling (SLIC)

Electronics are fully immersed in dielectric liquid coolant. Cools the server through low pressure circulation of coolant around servers, dumping waste heat using fluid-to-fluid or fluid-to-air heat exchangers. Requires coolant infrastructure to the rack and can use an open or sealed containment system.

No fans are required! Just a low pressure (2-5psi) flow of BitCool through off the shelf air-cooled miners is more than enough to cool them without fans.

Very high miner density up to 144 miners in a single SLIC Tank.

Open bath cooling with no vapors, no smell, and no problems!

With the fans gone there is no noise!
Single-phase, Liquid Immersion Cooling Large Scale Tank Design
Immersion Tank Design Basics – Flow is the Key

- Cool Dielectric flow
- Hot Dielectric out

Target an input coolant flow of 2-4L/min/kW as a starting point.

Coolant Level in Tank
No less than 3cm above devices

Coolant Level in Tank
(No less than 5cm above Coolant Level)

Top Level of Tank
(No less than 5cm above Coolant Level)

Leave adequate space for power wiring.

Coolant Recovery
Pipe level dictates level of coolant in tank.

Target a minimum of a delta-T of 10°C

Dielectric Coolant Flow

Perforated plate

Device

Coolant Level in Tank
No less than 3cm above devices

Coolant Level in Tank
(No less than 5cm above Coolant Level)

Top Level of Tank
(No less than 5cm above Coolant Level)

Leave adequate space for power wiring.
Immersion Tank Materials

• 12ga Cold Rolled Steel - The cheapest and easiest material
  • Easy to form, bend, weld, long lasting, and impervious to heat
  • You don’t have to paint the inside of the tank, but we do recommend painting the outside with two part epoxy paint or have it high temperature powder coated

• Stainless Steel – Long-lasting, but expensive
  • Great look, no need to paint or finish
  • Materials can be expensive and difficult to weld without experience.

• Aluminum – easy to form and cut, but increasingly expensive
  • Easy to form and cut out parts, long lasting
  • Difficult to weld unless you have experience

• Polycarbonate and Acrylic are great clear tank materials, but the chemical welds are not strong enough given a high heat load and high volume in large scale tanks
  • We recommend using acrylic for small test tanks and display tanks
  • It is easy to work with and chemically weld.
  • Do not use bonding glue with polycarbonate, it is porous to ElectroCool and BitCool
Use of Non-metallic Materials

*Grounding is critically important when using non-metallic materials!*

When using any type of non-metallic materials in your system like:

- cPVC Pipe, cPVC Fittings, Acryilic, Polycarbonate Tanks, etc.

Static electricity will build up due to the passage of the BitCool and ElectroCool Dielectric Coolants flowing through and over the other non-metallic dielectric materials.

- As the Dielectric Coolant flows over a non-metallic dielectric material electrons are stripped away from the stationary materials and a static charge will build up in the flowing dielectric coolant.

If the system is not properly grounded a very large static charge will build up. This charge can easily damage electronics and/or shock the people working on the system. With metallic tanks the easy way to avoid any issue is to ground the tank.

When using a non-metallic tank the simplest way to ground the system is to use a copper or steel plate or strip on the bottom of your tank and ground it well. What is important is that your coolant flows over the grounded plate. The larger the surface area the better the grounding effect.
Crypto Immersion Tank Design – Front View

- **12ga Steel Tank Walls**
- **Sled Mounting Rail**
- **Sled Mounting Rails**
- **Coolant Dispersion Plate**
- **Cold Coolant Insertion Pipes (4x)**
- **Cable Management**
- **Coolant Level is 3-6cm above Miners**
- **PSUs can be air or liquid cooled**
- **2 - 12 Sled capacity Tank**
- **3cm clearance between server and tank walls**
- **Depth: dependent on length of number of miners (3 miners deep is typical)**
- **Bottom clearance is 2cm from coolant dispersion plate**
Crypto Immersion Tank – Side View - PSUs in Air

- 12 ga Steel Tank Walls
- Coolant Level is 3-6 cm above Miners
- 3 cm clearance between server and tank walls
- Sled Rail
- Sled Rail (make sure coolant can flow past)
- Sled Rail (make sure coolant can flow past)
- Depth: dependent on Sled Design
- Bottom clearance of miner is 2 cm from coolant dispersion plate

In operation maintain FRC at 50-75% full

FRC overflow wall sets height of Coolant in Tank

FCR width 7-10 cm

Coolant Dispersion Plate

Cold Coolant Insertion Pipes (4x)
Crypto Immersion Tank – Side View – PSUs Immersed

- 12 ga Steel Tank Walls
- Coolant Level is 3-6 cm above Miners
- 3 cm clearance between Sled and tank walls
- FRC overflow wall sets height of Coolant in Tank
- In operation maintain FRC at 50-75% full
- FCR width 7-10 cm
- Coolant Dispersion Plate
- Cold Coolant Insertion Pipes (4x)
- Sled Rail
- Sled Rail (make sure coolant can flow past)
- Depth: dependent on Sled Design and type of miners supported
- Bottom clearance of miner is 2 cm from miner

In operation maintain FRC at 50-75% full.
Crypto Tank - Miner Sled Designs

PSUs Not Immersed

PSUs Immersed in Coolant

Fluid Level
SLIC Crypto Tank – Design Considerations

Things to consider in your tank design:

• For ASIC Miners use BitCool BC-888 Dielectric Coolant.
• For GPUs, FPGAs use ElectroCool Dielectric Coolant.
• Check your miner physical dimensions as they change often and incorporate some growth volume in your tank design.
• Position a lifting mechanism about the tanks (engine lift, or a rail crane assembly) to raise and lower heavy devices and sleds in and out of tanks.
• Leave enough empty volume in the fluid recovery channel to allow the displaced fluid to not overflow the tank due to insertion of new devices.
• Ensure you have adequate flow across all devices, this is dictated by design of your dispersion plate and the overall pressure of the incoming coolant.
• Keep in mind that cabling, especially power cabling on board the miners takes up a lot of space, and you must plan for this volume in your design.
• To prevent capillary action in ethernet cables drawing up coolant you can create a capillary break by striping off 5-6mm of the cover a few cm above the fluid and separating the wires by at least 2mm from each other.
Single-phase, Liquid Immersion Cooling System Component Selection

Materials that work and what to avoid
Fluid Circulation Considerations

Fluid Volume per Min per KW
- Plan to circulate the Dielectric Coolant at a flow rate of roughly 2 - 4L/min per 1000W.
- The calculated optimum flow rate for BC-888 is 1.2L/min per 1000W, however because no tank is perfectly efficient you should always leave at least 50% margin for larger miners and tank flow constraints.
- This rate of circulation should provide plenty of safety margin to take into account varying tank designs, overall volume, and ambient operating temperatures. You can fine tune the flow rate and dry cooler fan speeds based on your systems actual performance measurements.

Fluid Circulation in Tank and Dry Coolers
- Your tank should be designed with the coolant being injected into bottom of the tank and removed from the top. This allows for natural convection of the coolant to assist in the fluid flow.
- If you are using a non-sealed tank and a Single Loop SLIC Configuration you must ensure the coolant level in the dry cooler never exceeds the height of the coolant in the tank. If the level of the coolant in the dry cooler exceeds the level in the tank you are at risk of the coolant in the dry cooler flooding back into the tank should a vacuum break occur in the dry cooler.
- Keep in mind that Centrifugal pumps are not sealed systems and will allow coolant to flow through them in either direction in an uncontrolled manner when they are not operating.
Heat Rejection Sizing Calculation

\[ W_M = \text{Power use per Miner in Watts} \]
\[ W_{PS} = \text{Power use per Power Supply Watts} \]

\[ Q_M = \text{Quantity of Miners in Tank} \]
\[ Q_{PS} = \text{Quantity of Power Supplies in Tank} \]

\[ X_{\text{SafetyFactor}} = \text{A percentage between 20\% to provide a safety factor to oversize the cooler} \]

\[ (W_M \times Q_M) + (W_{PS} \times Q_{PS}) = W_{\text{TOTAL}} \text{ (Total Watts of Heat to be Dissipated in the Tank)} \]

\[ W_{\text{TOTAL}} \times 100\% + 20\%_{\text{SafetyFactor}} / 1000W = W_{\text{DryCooler}} \text{ (KW size of Dry Cooler)} \]
Pump Selection for SLIC

For circulating our Dielectric Coolants through a cooling system, we recommend the use of an appropriately sized centrifugal pump with Viton® seals (also called FKM). The pump motor should be sized so that the desired flow rate and head is well within the efficiency curve of the pump/motor combination. Explosion-proof equipment is not required.

The systems that offer the most control and variety tend to be made for hydronic heating and in-floor hydronic systems. Many manufactures offer pumps together with control systems that will monitor and maintain a temperature range as well as provide backup controls as well.

Here are a few of manufactures that we have had success with:

**Grundfos Pumps** – We always use the CR line of inline pumps, very simple and efficient:  
http://lp.us.grundfos.com/newcr

**March Pumps** - They make a wide variety of small to large pumps:  
http://www.marchpump.com/pumps/series-mdx/

**Hayward / Webster** - Maker of excellent small and medium pumps:  

**Bell and Gosset** - They offer a massive line-up of pumps and great system-syzer tools to add in flow and pump curve selection:  
http://bellgossett.com/pumps-circulators/end-suction-pumps/  

FOUND A GREAT PUMP? Let us know at sales@engineeredfluids.com, and we'll add it to the list!
Pump Selection for SLIC

You can consider any centrifugal pump with Viton (FKM) seals for your system. If you are going to use a pump made out of a resin or plastic material just make sure to check the material compatibility guide for the product you are considering (Look under our Support Tab on the website for the MGCs) and be sure to check out the materials used for the seals, impeller, and the pump chamber itself as most pumps will use a mix of materials in construction. Our coolants also provide lubrication so ceramic bearings are fully compatible.

Many smaller 12v and 24v pumps used for biodiesel and fuel oil will also work well with our Coolants.

Here is the link to the Grundfos pump sizing tool:

Here is a link to the Bell and Gosset pump sizing tool

When using any pump sizing tool, make sure to pay close attention to fluid characteristics that the tool is set for as most use water as the base fluid. You can use water to get a close approximation, however, our Coolants have a higher viscosity which can result in the pump operating above its optimal efficiency range.
Selecting Pipe & Hoses for SLIC

• When selecting rigid pipe for use with our coolants, its straightforward:
  • Iron, Steel, Stainless, Copper, and Aluminum pipe all work great
  • Schedule 40 and Schedule 80 Chlornated PVC (cPVC) is the best piping to use given the temperatures and pressures, we use this all the time in all our builds. You must de-rate the pipe’s maximum pressure by 30% at 50C.

• For flexible hose you are looking for hoses that are generally compatible with bio-diesel fuels, diesel fuel, and hydraulic fluids. Here are some good sources for hoses that are compatible with our coolants:
  • We use this tubing in most of our large-scale builds:
    Series OV200X100, Oil Vac™ - Heavy Duty Oil Resistant Polyurethane Suction Hose
    https://products.kuriyama.com/item/kuriyama-of-america/-oil-resistant-polyurethane-suction-hose-1/ov200x100
  • VITON (FKM) hoses are great for smaller systems. Watch their pressure rating:
    https://www.customadvanced.com/viton-extruded-tubing.html
    https://www.customadvanced.com/viton-tubing.html
Small Diameter Hoses for SLIC

• A great product for hose connections of up to 1”/25mm I.D. diameter are the Parker Push-Lok Plus hoses.
  • These are hydraulic hoses and they come in a range sizes (1/4”/6.3mm to 1”/25mm) and colors (red, blue, black, green, gray, yellow).
  • What is great about this product is that the connectors are field installable without tools! You can literally just press in the barbed fittings that are designed for this product into the hose and they are ready to go, no need for a crimping machine or trip to the shop.

• We recommend Parker Push-lok Plus Multipurpose Hose Model 801

• For the connectors you must use either:
What about Filters…

• Filters are big question with many of our customers, since most systems are open tanks they can be susceptible to dust and dirt incursion. However, if you keep your mine clean that can eliminate a lot of the problem.

• The biggest problem that most mines have with dust is their use of open vents for cooling air, this allows dirt, dust and pollution into your mine. So with the use of SLIC you should be able to eliminate entirely the source of dust as you no longer need the open vents for cooling.

• That said there is always the possibility of dust in the air, but you also need to consider the impact that installing a filter will have on your system and then choosing the right approach.

• In small tanks we advise skipping a dedicated filter and once a year simply reroute the input hose system through a funnel filled with a couple of layers of paper towels they are good down to 20-30 microns. Keep in mind you need to shut down your miners or they will overheat!

• For large systems we recommend installation of a bypass filter. This would be a 30 micron screw on diesel oil filter in which only a small amount (1-3%) of the total flow is actually filtered this eliminates the back pressure on the system and therefore reduces the size of the pumps needed and increases the efficiency of the system overall.

• [https://www.amazon.com/iFJF-Automotive-Separator-Fitting-4-19-Complete/dp/B072X8CSHL/ref=pd_sbs_263_4?_encoding=UTF8&pd_rd_i=B072X8CSHL&pd_rd_r=WY23SHAXWZ71KX3T546&pd_rd_w=6MNNf&pd_rd_wg=xAJMQ&psc=1&refRID=WY23SHAXWZ71KX3T546](https://www.amazon.com/iFJF-Automotive-Separator-Fitting-4-19-Complete/dp/B072X8CSHL/ref=pd_sbs_263_4?_encoding=UTF8&pd_rd_i=B072X8CSHL&pd_rd_r=WY23SHAXWZ71KX3T546&pd_rd_w=6MNNf&pd_rd_wg=xAJMQ&psc=1&refRID=WY23SHAXWZ71KX3T546)
Single-phase, Liquid Immersion System Architectures

Design Principles
Air-Cooled vs Liquid Immersion Cooling

**Air-Cooled**
- 25 kW
- 15 kW
- 10 kW
- 5 kW
- Below 5 kW

**ElectroCool**
- 800-4,000 CFM @ ΔT=20°F
- Intake Air 65-85°F

**Liquid Cooled**
- 100 + kW
- 100 kW
- 75 kW
- 50 kW
- 25 kW
- 20 kW

**Exhaust**
- 85-125°F

**Return**
- 56-160°F

*Figure 2. Comparison of heat transfer air versus liquid volumes at 11°C (20°F) ΔT*

Source: The Green Grid – Whitewater #70 – Liquid Cooling Technology Update (2016), pg 9, ElectroCool Details added by Engineered Fluids.
Effective Cooling Range is 5kW – 25kW per Rack

Typical PUE is 1.5 - 2.3
Typical Liquid Immersion Cooling Infrastructure

What goes away...
- No Cold Plates
- No Server Fans
- No high pressure water in Data Room
- No CRAC units
- No Air Handlers
- No Air Ducts

What is required:
- Immersion Container
- Coolant Distribution
- Coolant Pumps

Effective Cooling Range is 10kW – 200kW per Rack

*Typical PUE is 1.03 – 1.07*
The basic open tank configuration is composed of a tank in which the cold coolant is pumped into the bottom of the tank and as it flows up through the miners it absorbs the heat generated by the miners.

Once the heated fluid reaches the top of the tank it is recovered pumped through to the dry coolers.

Depending on the duty level of the dry cooler design a fan assists in moving cool ambient air through the liquid to air heat exchanger (radiators).

Redundant pumps are used to circulate the fluid. Because the Dry Coolers require pressure to operate it is typically best to have the fluid pumps on the heat recovery side to provide the operating pressure and flow rate back to the tank.

In this configuration ElectroCool Dielectric Coolant is flowing through the entire coolant loop because the dry coolers are kept at the same height as the tank. This prevents the static head of the coolant to flow everything in the tank.
Double Loop SLIC Configuration

- In this configuration there are two loops.
- One is a coolant loop from the tank to the plate heat exchanger.
- And one water/glycol mix loop from the heat exchanger to the dry coolers.
- This configuration is used where there is a large vertical distance between the tank and the dry coolers.
Double Loop SLIC with Water Chiller

- In this configuration there are two loops.
- One is a coolant loop from the tank to the plate heat exchanger.
- And one water/glycol mix loop from the heat exchanger to the water chiller system.
- This configuration is used where there is availability of chilled water systems in a building or installed as part of the plant.
In this configuration there are two loops.
- One is a coolant loop from the tank to the plate heat exchanger.
- And one water/glycol mix loop from the heat exchanger to the Cooling Tower
- This configuration requires a source of make up water to replace the water lost to evaporation during operation of the tower.
SLIC Technical Solutions for Immersion

Solutions for common challenges of developing SLIC systems
Upgrading a Koolance ERM-3K3UA

The Koolance ERMs are a great tool for use in the Lab or for small installations, this how to shows you what components you need to replace to use them with Engineered Fluids Dielectric Coolants.
www.koolance.com makes small integrated dry coolers and radiator systems for use with water cooled PCs for the gaming industry. We often use their CDUs and some of their flow components for testing and demonstration systems. Because their products are designed for use with water they have EPDM or Buna gaskets which are not compatible with dielectric coolants.

The ERM-3K3UA is a small dry cooler unit with an integrated radiator, fans, pump, and tank all in a single package. It retails for about $1040.00.

The rated capacity is 2,700W with water, but our measurements indicate it can only support about 2,000W when used with BitCool due to its viscosity.

Before using the ERM-3K3UA with Engineered Fluids Dielectric Coolants two hoses and two O-rings must be upgraded to ensure compatibility.

Note that when you open the case of ERM-3K3UA to replace these components and use BitCool as your coolant it will void the manufactures warranty.
Koolance ERM-3K3UA Upgrade Components

Step 1: Remove the 12 screws from the top cover.

Step 2: Disconnect fan leads and remove cover, place aside.

Step 3: Entirely remove the vinyl input and output tubing by opening the hose clamps on both sides.

Step 4: Remove the 2 screws on the sides of the front cover and the 4 screws on bottom of the front cover.

Step 5: Remove the front face panel, watch out for the wires connected to the control panel on the front right side, as they are short, and the connector is hard to reconnect.

Step 6: Remove the pump by removing the 4 mounting screws

Step 7: Open the pump by turning the large diameter circular cap and replace the pump O-ring with PN: 5267T193 0.137" Thick x 2.43" OD (Dash 227)

Step 8: Replace the front cover and all screws.

Step 9: Replace hoses with PN: 5549K39 / AEM02038

Versilon 1/2" I.D. x 3/4" O.D. x 1/8" Wall (C-210-A)

Step 10: Replace top cover on unit and all screws

Step 11: Replace fill port O-ring with PN: 5267T25

0.068" Thick x 0.618" OD (Dash 014)

Clicking on the above links brings you to www.McMaster.com

Notes: the radiator is on the return / hot side of the circuit.
Fan Deletion Circuit

This clever solution came to us courtesy of Chase Blackmon

Thank you Chase for sharing!
Fan Deletion Circuit

Fan deletion is probably the most common problem we hear about when moving to SLIC systems.

Here is a simple solution that uses an adjustable frequency square wave generator that sends the sense signal to the S9 controller board spoofing it to thinking you have a fan attached and spinning at the right RPM.

Chip: ICStation 2 Channel PWM Pulse Adjustable Frequency Square Wave Digital Display Signal Generator Module

Cost: About $3.00


AMAZON: [https://www.amazon.com/gp/product/B01MA1M7Y9](https://www.amazon.com/gp/product/B01MA1M7Y9)
ICStation 2 Channel PWM Pulse Generator

**Product Overview:**
- Operating Voltage: 5-30V; support micro USB 5.0V power supply
- Frequency Range: 1Hz-150KHz
- Frequency Precision: 2%
- Signal Load Capacity: 8-30mA
- Output Range: 5V
- Ambient Temperature: -30~70 Celsius

**Features:**
- Two independent PWM generators can set the frequency, duty cycle
- The wide frequency range, high accuracy
- Support serial communication.

**Applications:**
- As square wave signal generator which generates a square wave signal
- To provide a signal to the stepping motor driver
- Adjustable pulse generation for chip use
- Produce variable pulse signal, the control-related circuit
  (PWM dimming, speed)

**Module Description:**
- Frequency is divided into three ranges:
  - 1.XXX (no decimal point)
    - the smallest unit is 1Hz, the range 1Hz-999Hz
  - 2.XX.X (decimal point in ten):
    - The minimum unit is 0.1Khz, the range 0.1KHz-99.9KHz
  - 3.X.X.X
    - (Three decimal points): smallest unit is 1Khz, the range 1KHz-150KHz

**Frequency Display Example:**
- "100" indicates that the PWM output pulse of 100Hz
- "54.1" indicates that the PWM output pulse of 54.1KHz
- "1.2.4." Indicates that the PWM pulse output 124KHz
- Duty Cycle in the range: 0 to 100
- Three frequencies duty cycle is the same, all the parameters non-volatile

**Serial Port Control:**
- Baud rate: 9600 bps
- Data bits: 8
- Stop bits: 1
- Parity bit: none
- Flow control: none

**Set The PWM Frequency**
- 1)'S1FXXXXT': setting PWM1 frequency of XXX HZ (001 ~ 999)
- 2)'S1FX.XXT': setting the frequency of PWM1 XX.X KHZ (00.1 ~ 99.9)
- 3)'S1FX.X.XXT': setting PWM1 frequency of XXX KHZ (0.0.1 ~ 1.50.
- 4)'S1': PWM1
- 5)'S2': PWM2
- 6)'F': Frequency
- 7)'D': Duty Cycle
- 8)'T' is the end flag

**Set The PWM Duty Cycle**
- 1)'S1DXXXXT': setting PWM1 duty cycle XXX;(001-100)
- 2)'S2DXXXXT': setting PWM2 duty cycle XXX;(001-100)
- 3)'Setting Successful Return: DOWN'
- 4)'Setting Failback: FALL'
Old and New Controller Boards: Antminer S9

AntMiner S9 Fan Pin Out

<table>
<thead>
<tr>
<th>Pin</th>
<th>Name</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GND</td>
<td>black</td>
</tr>
<tr>
<td>2</td>
<td>+12VDC</td>
<td>red</td>
</tr>
<tr>
<td>3</td>
<td>Sense</td>
<td>yellow</td>
</tr>
<tr>
<td>4</td>
<td>Control</td>
<td>blue</td>
</tr>
</tbody>
</table>

Controller Board Version 1

Controller Board Version 2
Fan Connectors: Ver. 3 Controller Board
Wiring up the PWM Pulse Generator

- Disconnect and remove both fans.
- Wire the Black and Red (Pins 1 & 2) of Fan Connector A to the PWM-PG’s VIN+ and VIN-.
- Wire PWM-PG’s PW1 to Pin 3 of Fan Connector A
- Wire PWM-PG’s PW2 to Pin 3 of Fan Connector B
- You do not need to wire up Pin 4 as this controls the fan’s speed and is no longer necessary
- Set the Frequency on the PWM to 30kHz for a signal rate of 6K RPM

AntMiner S9 Fan Pin Out

<table>
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12VDC Fan Pin Out

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<th>Name</th>
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<tbody>
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<td>4</td>
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<td>blue</td>
</tr>
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</table>

Four Wire Fan Control Specs can be found here:
Photos of Fan Deletion Installed
Single-phase, Liquid Immersion Example System Photos
Engineered Fluids’ SLICTank048
48 S9 Miners overclocked to 140% with a PUE=1.015
Dual Loop System with Heat Exchanger
Engineered Fluids’ SLICTanks – BitCool BC-888
Midas Green Technologies – EC-100
Submer SmartPod – EC-130
Servers and Bit Miners in ElectroCool
ImmersionSystems.IO - BitCool BC-888
Engineered Fluids – 48x 2kW ASIC Miners
Engineered Fluids – Test Systems – EC-130
Outdoor SLIC Pod – 16x 1000W Servers
5MW SLIC – 1kW 4x Node Intel Servers
Container Based Mining Operation
Coriant Optical Router in ElectroCool
SLIC Videos: Engineered Fluids Channel

https://vimeo.com/channels/engineeredfluids

You can also visit our Vimeo Video Channel to see:

• Live Demonstrations of our products
• Discussions with live customers Q&A
• Explanations of use cases
• Customer feedback on our products

You can also subscribe to our channel to get notified when we post new materials!
Heat Rejection Devices
A **dry cooler** is an air-cooled radiator unit, that utilizes a liquid heat transfer solution, such as water, Ethylene Glycol/Water, or Propylene Glycol/Water, or ElectroCool Dielectric Coolant to transfer heat in lieu of refrigerant and compressors. The coolant absorbs heat from miners in the tank and transfers it outside to the dry cooler. Depending on the climate the dry cooler may operate entirely passively through convection due to the heating of the air pocket within the dry cooler. When the temperature of the coolant is not being offloaded to the environment fastest enough dry coolers will switch on a series of condensing fans to perform its cooling. A significant benefit of this type of system is that no liquid evaporation takes place, which eliminates the need for make-up coolant. Dry coolers can often reject larger amounts of heat in a much smaller footprint than traditional direct expansion air cooled condensing units, which can be a benefit for projects with limited ground or roof space.

**PROs**
- Easy to size to any heat load by adding more modules in series
- Simple to operate uses convection or fans
- Lowest operating cost of all heat rejection
- When properly sized for the climate, the fans on a dry cooler should only be operated for no more than 15-20% of the time and only during the hottest times of day.
- Very low maintenance – clean the coils and maintain fans.

**CONs**
- Can require a lot of space depending on size.
- If placed on a roof, it may require a two loop system to prevent the fluid from draining into the tank.
Heat Rejection Devices – Water Chiller

A water chiller is a machine that removes heat from a liquid via a vapor-compression or absorption refrigeration cycle. This liquid (typically water) can then be circulated through a heat exchanger to cool equipment. As a necessary by product, refrigeration creates waste heat that must be exhausted to ambience, or for greater efficiency, recovered for heating purposes. Water chillers can be water-cooled, air-cooled, or evaporatively cooled.

PROs
• Very low temperature water source for high density cooling
• Can be scaled to a precise service size

CONs
• Units suitable for mining are very expensive.
• It require a lot of space depending on size.
• If placed on a roof, it may require specific roof loading requirements.
• Expensive to run as they have only one speed on or off.
• Expensive to buy and to operate.
• Expensive to maintain
A cooling tower is a passive heat rejection device. The heated water coming from the heat exchanger is brought to the cooling tower through pipes. The water is then sprayed through nozzles onto banks of material called "fill," which slows the flow of water through the cooling tower, and exposes as much water surface area as possible for maximum air-water contact. As the water flows through the cooling tower, it is exposed to air, which is being pulled through the tower by the electric motor-driven fan at the top of the tower. When the water and air meet, a small amount of water is evaporated, creating a cooling action. The cooled water is then pumped back to the heat exchanger where it absorbs heat.

Heat Rejection Devices – Cooling Tower

**PROs**
- Very efficient at providing a source of chilled water.
- Can be scaled to a precise service size
- Relatively inexpensive to operate
- Medium complexity to maintain
- Medium cost relative to dry coolers and water chillers.

**CONs**
- Takes up a lot of space and generally cannot be put on a roof.
- Requires a source of available water to make up for evaporated water during cooling.
- Noisy in operation due to fans and dripping water.
BitCool® & ElectroCool®
Dielectric Coolants

Simple, Cost Effective and Safe
Benefits of Cooling with ElectroCool® & BitCool®

Single-phase Immersion with BitCool Dielectric Coolant Eliminates Complexity and Cost

- Eliminates all water in the data room and the associated catastrophic failure scenarios
- Silent and simple - no CRAC, no fans, no vibration, no air filters, no airborne contaminants
- Lower costs – significantly reduced capital and operational costs
  - Elimination of all internal air-cooling infrastructure.
  - Only requires a 5 -10°C input and output temperature delta to provide highly efficient cooling
  - Can use inexpensive passive heat dumps in the form of dry-coolers, or utilize standard active chilled water systems
- Eliminate or repurpose the physical space required for obsolete air-cooling infrastructure
- Highly efficient – up to 50% lower power requirements to cool the data center
  - Repurpose cooling power to billable CPU power!

BitCool Coolants are highly effective, safe, and improves reliability

- 1600x more thermally efficient than air.
- Biodegradable, non-allergenic, non-toxic.
  - No vapors or smell in the workplace, no respiratory or skin irritations or allergic reactions.
- Not flammable per OSHA
- Zero Global Warming Potential in use and manufacturing
- Increases reliability and the service life of device and electronic components
  - Reduces Failure Mechanisms of corrosion, vibration, thermal expansion cycling, maintains constant temperature, no airborne contaminants, eliminates failures due to zinc and tin whisker growth.
ElectroCool® Dielectric Coolants

*High Performance Coolants for use in Electrical Applications*

**Industries & Applications for Dielectric Coolants:**

**Aerospace**
- Aeronautic and space instrumentation and radar cooling

**Automotive & Robotics**
- Electric motors & EM controller cooling & lubrication
- Battery cooling and thermal runaway suppression
- Kinetic Energy Recovery Systems (KERS) cooling and hydrostatic energy transfer
- Undersea pressure compensation and lubrication for submersibles

**Power and Transmission Engineering**
- Transformer Cooling

**Semiconductor & Communications**
- Electronics Immersion Cooling - CPU / GPU / FPGA / SSD and servers
- Amplifiers, Power Vacuum Tubes, & RF Transmitter cooling
- Optical & Laser Diodes cooling
BitCool® Dielectric Coolants for ASIC Miners

BitCool Dielectric Coolants are the highest performance biodegradable, non-toxic dielectric thermal management fluids available for specifically for ASIC Based mining devices.

BitCool BC-888 - Compatible ASIC-based Miners

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Miners</th>
</tr>
</thead>
<tbody>
<tr>
<td>BitFenix Miner</td>
<td>BK-R/NX, N+ X</td>
</tr>
<tr>
<td>Bitmain ANTMINER™</td>
<td>A3, B3, D3, E3, G2, L3, R3, S2, T3, T4, V9, X3, Z9</td>
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<tr>
<td>Canaan Creative</td>
<td>Avalon 6, 741, 821, 841</td>
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<td>Ebinet</td>
<td>E9.2, E9.3, E10</td>
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<td>GMO Miner</td>
<td>Px (Pending Release and Testing)</td>
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<td>Halong Mining</td>
<td>16T, D2, D5, T1</td>
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<td>Innosilicon</td>
<td>A4, A5, A8, A5, A8, ABC, A8, D9, E12</td>
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<td>Pun Designs</td>
<td>M3, MX3</td>
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Key Characteristics of BitCool Dielectric Coolant

<table>
<thead>
<tr>
<th>Product ID</th>
<th>BC-888</th>
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<tbody>
<tr>
<td>Application</td>
<td>Single-phase, Liquid Immersion Cooling of ASIC-based Cryptocurrency Mining Devices</td>
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<tr>
<td>Key Characteristic</td>
<td>Compatibility with ASIC Mining Devices</td>
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<tr>
<td>Appearance</td>
<td>Light Green Tint</td>
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<td>Pour Point (°C)</td>
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<tr>
<td>Flash Point (°C)</td>
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<tr>
<td>Density, g/cc at 25°C</td>
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<tr>
<td>Coefficient of Thermal Expansion, 0°C</td>
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<tr>
<td>Viscosity @40°C</td>
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<tr>
<td>Viscosity @100°C</td>
<td>&lt;4.0</td>
</tr>
<tr>
<td>Thermal Conductivity (W/mK) @40°C</td>
<td>0.1373</td>
</tr>
<tr>
<td>Thermal Conductivity (W/mK) @100°C</td>
<td>0.1333</td>
</tr>
<tr>
<td>Specific Heat (C)</td>
<td>205±0.0</td>
</tr>
<tr>
<td>Specific Heat (20°C)</td>
<td>220±0.20</td>
</tr>
<tr>
<td>Updated</td>
<td>20180608gt</td>
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</table>
ElectroCool® Dielectric Coolants for GPUs

ElectroCool Dielectric Coolants are the highest performance biodegradable, non-toxic dielectric thermal management fluids available.

ElectroCool Coolants feature the broadest material compatibility, highest safety, and widest useful temperature range.

<table>
<thead>
<tr>
<th>Product ID</th>
<th>EC-100</th>
<th>EC-110</th>
<th>EC-120</th>
<th>EC-130</th>
<th>EC-140</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical Application</td>
<td>General electronics cooling with excellent material compatibility</td>
<td>Outdoor and sealed system electronics cooling and insulation</td>
<td>Enterprise grade cooling of servers, semiconductors, and electronics</td>
<td>Data center cooling of servers, GPUs, semiconductors, and electronics</td>
<td>High temperature semiconductor &amp; electronics cooling and insulation</td>
</tr>
<tr>
<td>Fluid Behavior</td>
<td>Non-Compressible, Isotropic, Newtonian</td>
<td>Clear</td>
<td>&gt;50kV</td>
<td>&gt;1x10^4</td>
<td></td>
</tr>
<tr>
<td>Appearance</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dielectric Strength</td>
<td>2.3</td>
<td>2.3</td>
<td>2.1</td>
<td>2.2</td>
<td>2.3</td>
</tr>
<tr>
<td>Resistance (ohm-cm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dielectric Constant</td>
<td>1.452</td>
<td>1.440</td>
<td>1.442</td>
<td>1.453</td>
<td>1.465</td>
</tr>
<tr>
<td>Refractive Index no</td>
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<td>1.440</td>
<td>1.442</td>
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<td>1.465</td>
</tr>
<tr>
<td>Pour Point (°C)</td>
<td>-55</td>
<td>-57</td>
<td>-56</td>
<td>-57</td>
<td>-54</td>
</tr>
<tr>
<td>Flash Point (°C)</td>
<td>180</td>
<td>150</td>
<td>157</td>
<td>135</td>
<td>280</td>
</tr>
<tr>
<td>Density, g/cm³ @ 15.6°C</td>
<td>0.8133</td>
<td>0.7980</td>
<td>0.7980</td>
<td>0.9244</td>
<td>0.9300</td>
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<tr>
<td>Coefficient of Thermal Expansion, x10^-6/°C</td>
<td>0.0008</td>
<td>0.00058</td>
<td>0.00067</td>
<td>0.00065</td>
<td>0.00070</td>
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<tr>
<td>Kinematic Viscosity 40°C (cSt)</td>
<td>9.58</td>
<td>6.43</td>
<td>5.02</td>
<td>3.72</td>
<td>6.46</td>
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<tr>
<td>Kinematic Viscosity 100°C (cSt)</td>
<td>2.68</td>
<td>2.00</td>
<td>1.70</td>
<td>1.41</td>
<td>5.33</td>
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<tr>
<td>Thermal Conductivity 40°C (W/m·K)</td>
<td>0.1396</td>
<td>0.1382</td>
<td>0.1383</td>
<td>0.1404</td>
<td>0.1811</td>
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<tr>
<td>Heat Capacity 40°C (J/g·K)</td>
<td>20540</td>
<td>20608</td>
<td>20608</td>
<td>20577</td>
<td>20460</td>
</tr>
<tr>
<td>Specific Heat 40°C</td>
<td>22032</td>
<td>22121</td>
<td>22121</td>
<td>22030</td>
<td>21912</td>
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<tr>
<td>Global Warming Potential</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Biodegradability (28 Days)</td>
<td>&gt;93%</td>
<td>&gt;96%</td>
<td>&gt;96%</td>
<td>&gt;99%</td>
<td>&gt;50%</td>
</tr>
<tr>
<td>Material’s Compatibility</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<td>Warranty</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>Product Operational Warranties (Yrs.)</td>
<td>0.5, 10</td>
<td>0.5, 10</td>
<td>0.5, 10</td>
<td>0.5, 10</td>
<td>0.5, 10</td>
</tr>
<tr>
<td>Shelf Life (Yrs.)</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>
**ElectroCool is the Green Alternative**

*From power savings to impact on the environment – ElectroCool wins!*

ElectroCool power savings results in major reduction in greenhouse gases

- Immersive fluid cooling using BitCool reduces power consumption by up to 45%

**Assumptions:**

- 2016 US EIA data for average annual emissions for electricity generation *(a)*
  - 1kW/\(hr\) of electricity generation results in pounds of CO\(_2\) equal to:
  
<table>
<thead>
<tr>
<th></th>
<th>2016</th>
<th>Coal</th>
<th>Petroleum</th>
<th>Natural Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO(_2) (lbs/(kW.h))</td>
<td>2.16</td>
<td>1.74</td>
<td>0.92</td>
<td></td>
</tr>
</tbody>
</table>

- An Air-cooled datacenter 10MW IT Load with 1.5 PUE equals a total power load of 15MW
- 24hr/d * 365d/yr * 15,000kW = 131,400,000 kW/\(hr\) annually of total power usage

**Result:** ElectroCool nets significant CO\(_2\) emissions reductions for same 10MW IT Load:

<table>
<thead>
<tr>
<th>Data Center Electrical Generation Fuel</th>
<th>air-cooled CO(_2) mln.lbs /yr</th>
<th>ElectroCool Immersion CO(_2) mln.lbs/yr</th>
<th>Emissions Reduction CO(_2) mln.lbs/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>284</td>
<td>185</td>
<td>99</td>
</tr>
<tr>
<td>Oil</td>
<td>229</td>
<td>149</td>
<td>80</td>
</tr>
<tr>
<td>Nat Gas</td>
<td>121</td>
<td>79</td>
<td>42</td>
</tr>
</tbody>
</table>

BitCool® & ElectroCool® Dielectric Coolants
Simple, Effective and Safe

Comparisons against other forms of cooling
Engineered Fluids vs other Dielectrics

Comparison With Mineral Oil

Mineral Oil is highly flammable and subject to hazardous material storage requirements

The flashpoint of mineral oil is 135°C and is considered a flammable and hazardous material subject to all Occupational Health and Safety regulations including maximum storable quantities, building codes, handling regulations and state and local permits for use and storage.

Mineral Oil is toxic and a known carcinogen in humans

The National Toxicology Program: “Untreated and mildly treated mineral oils are known to be human carcinogens based on sufficient evidence of carcinogenicity from studies in humans.”

Mineral Oil is not biodegradable and must be handled and disposed of as a toxic material under OSHA regulations and the EPA.

“Thirty days before any person burns mineral oil dielectric fluid in the boiler, the person gives written notice to the EPA Regional Administrator for the EPA Region in which the boiler is located.”

Mineral Oil is not guaranteed to meet any operational characteristics

Mineral oils are commodities made by many oil refineries. Their compatibility profiles differ widely from one brand to another, and operational characteristics differ from batch to batch. They are sold without any guarantee of critical dielectric characteristics.

Mineral Oil is incompatible with some common semiconductors components and materials

This board was immersed in mineral oil for about 4mths. Material incompatibility caused swelling of rubber gasket material in the capacitors on this Nvidia Tesla K80 GPU. This swelling caused the boards to fail due to the capacitors breaking off the board.

Mineral Oils are not processed to be used with electronic circuitry

Mineral oils undergo little if any processing after refining. Commonly used to make engine oils, they are not filtered or dried, they are not formulated for use as a dielectric or even tested for materials compatibility.
Engineered Fluids vs other Dielectrics

Comparison with 3M Fluorinated Compounds

**Fluoroketones and fluoroethers affect the health of workers**
Worker sensitivity to halogenated compounds has been reported, including exposure by both inhalation and physical contact.

**Fluorinated fluids are not biodegradable and very high Global Warming Potential (GWP)**
Unlike ElectroCool with a GWP = 0, fluorinated ketones and ethers are not biodegradable. Atmospheric lifetimes for perfluorocarbon fluids range from 400 to 2000 years. The average GWP for Fluorinated fluids is 9,000 (according to [ww.epa.gov](http://ww.epa.gov)).

**Fluorinated fluids are extremely heavy**
Fluorinated fluids weigh twice as much as Engineered Fluids’ ElectroCool. The extra weight requires higher tank costs, floor loadings, and severely limits the applications.
( ElectroCool=6.84lbs/gal, Water =8.35lbs/gal, Fluorinert=14.02Lbs/gal)

**Micro-cavitation causes significant erosion of metals on cooled electronics**
Violent boiling causes micro-cavitation and metal erosion at pin-socket connections and all exposed metals in the system. This causes metallic particle contamination of the coolant and dielectric breakdown of the two-phase coolant. The US Department of Defense concluded that metallic whisker formation was so excessive in fluorocarbon immersion cooling that it increased equipment failures by more than 60x.

**Exposure to an electric arc creates toxic and hazardous substances**
Exposure to an electric arcs creates HF (hydrogen fluoride) and PFIB (perfluorinated isobutylene), both extremely hazardous, corrosive and toxic substances

**Fluorinated Fluids are expensive**
Boiling fluids leak from server chassis, requiring frequent and expensive replenishment at costs of over $400 per gallon!
2 Phase Immersion Cooling - 2PIC

Devices are fully immersed in low-temp boiling fluoroketone (halogenated fluids). Cools the server through vaporization of fluid by hot electronics. Heat is removed by recondensing the vaporized coolant with gas-to-water heat exchangers, dumping waste heat using fluid-to-fluid or fluid-to-air heat exchangers. Requires water cooling infrastructure to the rack, vapor containment, and pressurized sealed system.

- Fluid is vaporized by the heat of the electronics. Closed system is required to prevent the coolant from dispersing and evaporating.

- Requires chilled water plumbed into each tank for the vapor to be cooled through a gas to fluid condenser.

- The boiling action of the coolant creates micro-cavitation which erodes the heated metals in the device destroying them and contaminating the coolant with metallic particles making the coolant fully conductive.
Challenges of 2-Phase Immersion Cooling

*Applications using of 3M Fluorinated Compounds*

**Operationally Complex**
- Fully sealed and pressurized systems are required to eliminate coolant lost and maintain a safe operating environment. Custom solution is required per board similar to cold plates.
- Open bath systems contaminate the work environment with toxic vapors and require extensive vapor containment and exhaust systems. Coolant lost requires containment with complex material handling requirements are needed to ensure worker safety.
- Requires water cooling infrastructure in the data room.

**Reduced Reliability due to Materials Incompatibility and Micro-Cavitation**
- The micro-cavitation caused by the boiling of the fluid against the metallic components causes these metals to be eroded away causing micro-particle contamination that degrades the dielectric strength of the coolant. This causes catastrophic failure of the electronics due to arcing and grounding if the coolant is not replaced regularly.

**Very Costly**
- Constant coolant replenishment is required as coolant loss is excessive due to very low vapor pressure. 3M Novec coolants are very expensive (>$300 - $400/gallon)

**Significant Environmental and Employee Safety Issues**
- Environmentally unfriendly (toxicity, non-biodegradable, high Global Warming Potential)
- High risk due to handling and exposure due to vaporization and inhalation issues.
Water Cooling using Cold Plates


Indirect cooling of devices through the use of chip-specific, fluid-cooled heat exchangers mounted on each chip. Cools the chips through closed loop circulation of high pressure water through cold plates, dumping waste heat using fluid-to-fluid, fluid-to-air heat exchangers. Requires water cooling infrastructure to the rack, internal server plumbing, CRAC units, and fans.

Cold plates are micro-filters and fail due to fouling from bio slime other contaminants.

Every board & chip layout requires a custom plumbing and cold plate design.

Incoming water manifold pressures can exceed 200psi, requiring water plumbing rated at 1000psi per ASHRE.

Requires very expensive dripless connectors to prevent high-pressure water failure and intrusion.
Example: Lenovo SD650 Dual Node Server

**Water Cooled:** CPU up to 245W per processor / 700W per 2x CPU node (requires 4x fans)

**SLIC Cooled:** CPU up to 600W per Processor / 2000W per 2x CPU node (no fans required)

SLIC Node will provide an estimated 30-40% cost reduction in base hardware while increasing processor capabilities by ~200% vs the standard water cooled system.
Challenges of Cooling Electronics with Water

Water Cooled Solutions generally...
- Requires extensive water transport pipes and manifolds into the data room
- Costs related to 5X pressure overdesign of water transport required by ASHRAE Standards
- Operational problems including system clogging from biofilms and contaminates as well as water filters and water use
- Having water in the data room can increase insurance costs due to catastrophic failure potential

Cold Plates particularly...
- Requires a custom developed cold-plate design and plumbing for every chip and every board.
- High manifold pressure (often >500psi at the manifold on the rack!) is required to force water through serial layout of micro-channel cold plates.
- Clogging of micro-channels has a massive and serial impact on system level cooling by Cold-plates.
- “Point Cooling” – Cold plates only cool individual chips, the system still relies on air cooling for overall board cooling.
- Inefficient due to thermal resistance (chip/paste/heat spreader/paste/Al block/water), results in 25-40% thermal transfer losses due to thermal resistance, which results in higher water flow requirements.
- System still relies on air cooling, fans and now high pressure water pumps!
  - Increase failure rates of complex systems and general increase in electrical use and PUE of system

Back Door Radiators in particular...
- Still requires hot and cold aisles and associate wasted space
- System still relies on air cooling, extra fans and pumps actually raises PUE of system
For more information...

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