ENGINEERED FLUIDS

The SLIC Primer

The Guide to Full Immersion Cooling of Electronics

with Single-phase, Liquid Immersion Coolants

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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 consider 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 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 = Power use per Miner in Watts
W_{PS} = Power use per Power Supply Watts

Q_M = Quantity of Miners in Tank
Q_{PS} = Quantity of Power Supplies in Tank

$X_{SafetyFactor}$ = A percentage of 15-25% to provide a safety factor for flow and dry cooler sizing.

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

$W_{TOTAL} \times 100\%+20\%_{SafetyFactor} / 1000W = KW_{DryCooler}$ (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 often use CR line of inline pumps, very simple, price competitive 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:
https://www.usplastic.com/catalog/item.aspx?itemid=23570&catid=1014
http://www.haywardflowcontrol.com/shop/en/flow-control/r-series-magnetic-drive-pumps-200233--1/r-series-magnetic-drive-pumps
http://www.haywardflowcontrol.com/shop/en/flow-control/pumps/c-series-centrifugal-pumps-200226--1/c-series-centrifugal-pumps

Bell and Gosset - They offer a massive line-up of pumps of all sizes:
http://bellgossett.com/pumps-circulators/end-suction-pumps/
http://bellgossett.com/pumps-circulators/circulator-pumps/heating-cooling-circulators/nrf-system-lubricated-iron-body-circulators/

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 Materials Compatibility Guide (https://www.engineeredfluids.com/material-compatibility) for the product you are considering 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 and carbon fiber 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:
https://grundfos.portal.intelliquip.com/?utm_medium=web&utm_source=lp-grundfos&utm_campaign=CRXL-2019&utm_content=newcr

Here is a link to the Bell and Gosset pump sizing tool
http://documentlibrary.xylemappliedwater.com/wp-content/blogs.dir/22/files/2012/07/B-311A-Series-3530-Quantek-Pumps.pdf?_ga=2.79235088.520413890.1521307748-1838108130.1513227515

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 straight forward:
  - Schedule 40 and Schedule 80 Chlorinated PVC (cPVC) are 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.
    https://www.aetnaplastics.com/site_media/media/attachments/aetna_product_aetnaproduct/204/PVC%20Sch%2080%20Pipe%20Dimensions.pdf
  - Iron, Steel, Stainless, Copper, and Aluminum pipe are all fully compatible.
- 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

- We regularly use Tygon Versilon A-210 tubing on all our test rigs in our lab.
  - https://www.usplastic.com/catalog/files/specsheets/Versilon-C210A.pdf
- Another 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
  - http://ph.parker.com/us/en/push-lok-plus-multipurpose-hose-801
- For the connectors you must use either:
  - Series 82 Push On Field Attachable Fittings http://ph.parker.com/us/en/82-series
  - HY Series Fittings - Crimp Style Hydraulic Hose Fitting http://ph.parker.com/us/en/hy-series

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=WY23SHAXWZ71KKX3T546&pd_rd_w=6MNNf&pd_rd_wg=xAJMQ&psc=1&refRID=WY23SHAXWZ71KKX3T546

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Heat Rejection Devices

Heat Rejection Devices – Dry Cooler

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 convention 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.

Photos courtesy of our partner www.DryCoolers.com

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

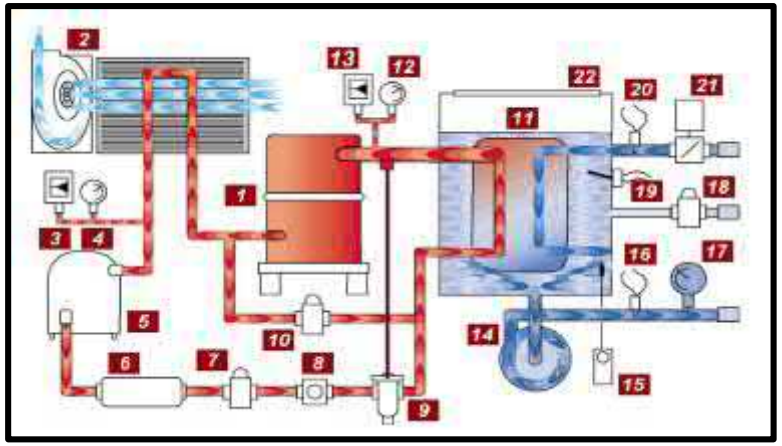
A **water chiller** is a machine that removes heat from a liquid via a vapor-compression or absorption refrigeration cycle. This liquid (typically water) can then be circulated through a heat exchanger to cool equipment. As a necessary by product, refrigeration creates waste heat that must be exhausted 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



Heat Rejection Devices – Cooling Tower

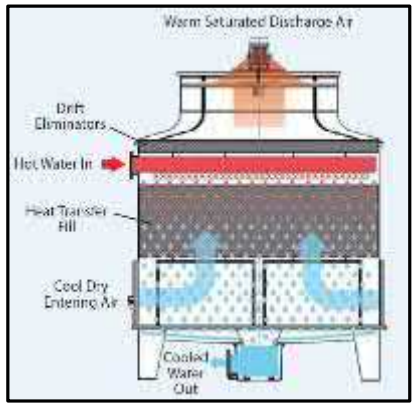
A **cooling tower** is a passive heat rejection device. The heated water coming from the heat exchanger is brought to the cooling tower through pipes. The water is then sprayed through nozzles onto banks of material called "fill," which slows the flow of water through the cooling tower, and exposes as 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.

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.



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

Comparisons against other forms of cooling

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 -10C 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 Coolant is the highest performance biodegradable, non-toxic dielectric thermal management fluids available for specifically for ASIC Based mining devices

Key Characteristics of BitCool Dielectric Coolant

Product ID	BC-888
Application	Single-phase, Liquid Immersion Cooling of ASIC-based Cryptocurrency Mining Devices
Key Characteristic	Compatibility with ASIC Mining Devices
Appearance	Light Green Tint
Pour Point (C)	< 0
Flash Point (C)	>130
Density, g/cc @ 16C	0.82
Coefficient of Thermal Expansion, volume/C	0.00068
Viscosity (cSt) @ 40C	<10
Viscosity (cSt) @ 100C	<4.0
Thermal Conductivity (W/m*K) 40C	0.1373
Thermal Conductivity (W/m*K) 100C	0.1339
Specific Heat 0C	2054.00
Specific Heat 40C	2203.20
Updated	20180608.gt

BitCool BC-888 - Compatible ASIC-based Miners

Manufacturer	Miners
Baikal Miner	BK-B,N70, N+, X
BitMain ANTMINER™	A3, B3, D3, E3, G2, L3++, R4, S1 gi, T9+, V9, X3, Z9
Canaan Creative	Avalon 6, 741, 821, 841
Ebang	E9.2, E9.3, E10
GMO Miner	B2 (Pending Release and Testing)
Halong Mining	16T, B29, B52, T1
Innosilicon	A4+, A5+, A6, A5, A8+, A8C, A9, D9, S11,T2
Pangolin Miner	M3, MX3

For full technical data please see our website:
https://www.engineeredfluids.com/bitcool

ElectroCool® Dielectric Coolants for Servers / 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.

For full technical data please see our website:
https://www.engineeredfluids.com/electrocool

CHARACTERISTICS OF ELECTROCOOL DIELECTRIC COOLANTS

Product ID		EC-100	EC-110	EC-120	EC-130	EC-140
Typical Application		General electronics cooling with excellent material compatibility	Outdoor and sealed system electronics cooling & insulation	Enterprise grade cooling of servers, semiconductors, & electronics	Cooling of high temperature electronics, battery & charging systems	Extreme temp semiconductor & electronics cooling and insulation
Appearance		Light Blue	Clear			
Fluid Behavior		Non-Compressible, Isotropic, Newtonian				
Dielectric Strength		>40kV	>60kV			
Resistivity (ohm-cm)		>1x10^{14}				
Dielectric Constant		2.2	2.1	2.1	2.2	2.3
Refractive Index n_D^{20}		N/A	1.440	1.442	1.453	1.465
Pour Point (°C)		-42	-58	-66	-60	-54
Flash Point (°C)		160	170	157	228	280
ISO 4460 Particle Cnt.		10/10/2012	10/10/2012	10/10/2012	10/10/2012	10/10/2012
Total Sulfur (ppm)		0	0	0	0	0
Density, g/cc @ 15.6°C		0.80	0.81	0.80	0.82	0.84
Coefficient of Thermal Expansion, volume/°C		0.00065	0.00065	.00067	0.00065	0.00063
Kinematic Viscosity (cSt)	0°C	27.43	27.45	18.99	144.00	794.61
	40°C	5.30	5.41	5.02	19.01	66.46
	100°C	2.00	2.02	1.70	4.10	9.53
Thermal Conductivity (W/m*K)	0°C	0.1382	0.1382	0.1383	0.1478	0.1600
	40°C	0.1359	0.1359	0.1361	0.1459	0.1584
	100°C	0.1325	0.1325	0.1329	0.1430	0.1561
Specific Heat (kJ/kg*°C)	0°C	2.0608	2.0601	2.0608	2.0575	2.0460
	40°C	2.2121	2.2120	2.2121	2.2060	2.1912
	100°C	2.4390	2.4388	2.4390	2.4288	2.4090
Global Warming Potential		0	0	0	0	0
Biodegradability		>93%	>96%	>96%	>70%	>50%
Materials Compatibility Warranty		Yes	Yes	Yes	Yes	Yes
Product Operational Warranties (Yrs) [1]		0, 5	0, 5, 10	0, 5, 10	0, 5, 10	0, 5, 10
Shelf Life (Yrs) [2]		25	25	25	25	25

1) *See product specific warranty statement for terms and conditions.*
2) *Shelf Life duration is stated for a sealed original container, Shelf life period is included in the warranty period.*

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 135C 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

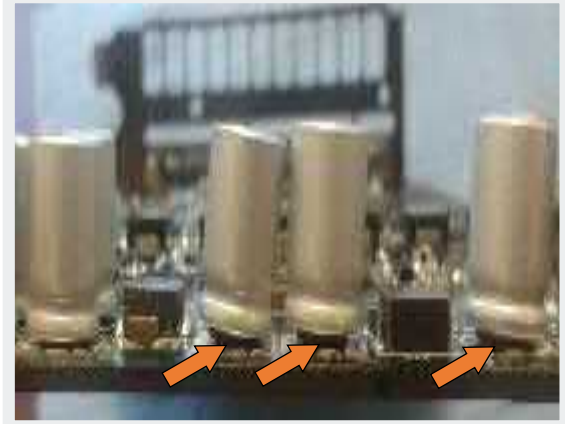
Mineral oils are commodities made by many oil refineries. Their compatibility profiles differ widely from one brand to another, and operational characteristics differ from batch to batch. They are sold without any guarantee of critical dielectric characteristics.

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 have very high Global Warming Potential (GWP)

Unlike ElectroCool and BitCool both 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)

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)

Fluorinated Fluids are very hygroscopic

Fluorinated fluids actively absorb water from their surroundings, particularly in humid environments, this absorption has two negative effects a) it reduces the dielectric strength of fluid, and b) the metal parts of the equipment rust. These rust particles will also breakoff during the boiling process and become suspended in the coolant.

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!

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For more information…

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