

Project PAM

A Reference Design for

Photoresin Additive Manufacturing for

The Open Source Community

Saluki Engineering Company

Reference Number: S14-75-3DPR

Date

|  |  |
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# Transmittal Letter: CWB

2014-11-18

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1230 Lincoln Drive

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Mr. Blair,

On behalf of the Saluki Engineering Company, I would like to thank you for including us in the bid for a project to design a digital light processing printer. Attached is a design report for a DLP photoresin printer, Project PAM. Along with this report, we have included the computer host software code and build instructions of the prototype.

Talk about Prototype here

Project PAM proposes a reference Photoresin Additive Manufacturing (PAM) system which maximizes accessibility to the hobbyist. It is intended to be flexible by allowing for configurations of hardware available or easily obtainable to the end user. This is achieved through extensive use of currently available or easily fabricated hardware and open-source software. The reference design will be open-source hardware and software to the lowest practical level. Thorough documentation will provide the necessary means for the end user to go from an empty table to a functioning printer.

Please feel free to contact me at (815) 214 9661 or by email, burdickjp@siu.edu, if you have questions about this project.

Sincerely,

Jeffrey P Burdick

Project Manager

Project PAM: Team75-3DPR

Saluki Engineering Company

(815) 214-9661

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# Acknowledgements: CWB

To begin we would like to express our thanks to Dr. Spyros Tragoudas and Dr. Rasit Koc along with the Electrical and Computer Department and the Mechanical Department for the support and financial contributions. The project would not have been possible without their financial backings.

We would also like to take the time to thank the backers of the crowed funding campaign. Very person’s contribution was very much accommodating to the needs of our group. We would like to thank them for not only their financial report but their words of encouragement and belief in our project.

From the beginning of the project Dr. Lizette Chevalier has given priceless words of encouragement and advice that has been very critical to the success of the project.

At this time we would like to thank Lakendria Kenner of WSIU, Scott J. Grunewald of 3D Printing Industry, Eddie Krassenstein of 3D Print, and Austin Miller of Dailey Egyptian for the kind words in their articles. Their articles have help spread the work of Project PAM out to the global community.

We would like to take this opportunity to thank Dr. James Mathias for him allowing us to have use to his laboratory space giving Project PAM a place to call home.

We also would like to express a deep sense of gratitude to the team’s Faculty Technical Advisors; Dr. James Mabry and Joe Lennox, for their constant support, valuable guidance, and professional advice throughout the various stages of the design project.

We are grateful for the assistance of Tim Attig of the SIUC Machine Shop. His vast machining skills and knowledge have been a great part of the project’s success. Tim’s time and technical advice was invaluable to the team.

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# Table of Contents: CWB

[Transmittal Letter: CWB 2](#_Toc404195208)

[Acknowledgements: CWB 3](#_Toc404195209)

[Table of Contents: CWB 4](#_Toc404195210)

[Table of Figures: CWB 4](#_Toc404195211)

[Table of Tables: CWB 4](#_Toc404195212)

[Table of Drawings: CWB 4](#_Toc404195213)

[1 Executive Summary:CWB 6](#_Toc404195214)

[2 Project Description: 6](#_Toc404195215)

[2.1 Introduction: CWB 6](#_Toc404195216)

[2.2 overall Printer Diagram: 6](#_Toc404195217)

[3 Costs: 6](#_Toc404195218)

[4 Schedules: 7](#_Toc404195219)

[5 Subsystem Descriptions: 7](#_Toc404195220)

[5.1 Mechanical Motion-JPB 7](#_Toc404195221)

[5.2 Chassis-JPB 7](#_Toc404195222)

[5.2.1 Process of Design 7](#_Toc404195223)

[5.2.2 Process of Assembling 7](#_Toc404195224)

[5.2.3 IMPLEMENTATION SCHEDULE 7](#_Toc404195225)

[5.2.4 Equipment Needed 7](#_Toc404195226)

[5.2.5 Health and Safety Issues 7](#_Toc404195227)

[5.2.6 Conclusions and Recommendations 7](#_Toc404195228)

[5.3 Printer Control Software- DMO 7](#_Toc404195229)

[5.4 Hardware-Software Interface- NAL 7](#_Toc404195230)

[5.5 Resin Management-CWB 7](#_Toc404195231)

[5.6 Optics-CWB 7](#_Toc404195232)

[5.7 Vat-NBT 7](#_Toc404195233)

[5.8 Coupler-NBT 7](#_Toc404195234)

[6 References: CWB 8](#_Toc404195235)

# Table of Figures: CWB

[Figure 1: Overall Printer Block Diagram (WW) 11](file:///E:\Documents\Homework\SIUC\Senior%20Design%203D%20Printer\Design%20report\Design%20Report%20v2.docx#_Toc385446916)

[Figure 2: SEC Semester Schedule, As planned and as worked (ALL) 13](file:///E:\Documents\Homework\SIUC\Senior%20Design%203D%20Printer\Design%20report\Design%20Report%20v2.docx#_Toc385446917)

[Figure 3: Implementation Schedule (PZ) 14](file:///E:\Documents\Homework\SIUC\Senior%20Design%203D%20Printer\Design%20report\Design%20Report%20v2.docx#_Toc385446918)

[Figure 4: Original design of the frame (PZ) 15](file:///E:\Documents\Homework\SIUC\Senior%20Design%203D%20Printer\Design%20report\Design%20Report%20v2.docx#_Toc385446919)

[Figure 5: Original design of the X/Y carriage and platforms (PZ) 16](file:///E:\Documents\Homework\SIUC\Senior%20Design%203D%20Printer\Design%20report\Design%20Report%20v2.docx#_Toc385446920)

[Figure 6: Second design of the frame (PZ) 16](file:///E:\Documents\Homework\SIUC\Senior%20Design%203D%20Printer\Design%20report\Design%20Report%20v2.docx#_Toc385446921)

[Figure 7: Third design of the frame (PZ) 17](file:///E:\Documents\Homework\SIUC\Senior%20Design%203D%20Printer\Design%20report\Design%20Report%20v2.docx#_Toc385446922)

[Figure 8: Bottom base of frame (PZ) 18](file:///E:\Documents\Homework\SIUC\Senior%20Design%203D%20Printer\Design%20report\Design%20Report%20v2.docx#_Toc385446923)

# Table of Tables: CWB

[Table 1: Prototype Costs 11](#_Toc385423812)

[Table 2: Implementation Costs 11](#_Toc385423813)

[Table 3: Detail of parts in frame subsystem (HL) 21](file:///E:\Documents\Homework\SIUC\Senior%20Design%203D%20Printer\Design%20report\Design%20Report%20v1.docx#_Toc385423814)

[Table 4: Prototype cost of frame subsystem 25](file:///E:\Documents\Homework\SIUC\Senior%20Design%203D%20Printer\Design%20report\Design%20Report%20v1.docx#_Toc385423815)

[Table 5: Implementation cost of (PZ)frame subsystem 25](file:///E:\Documents\Homework\SIUC\Senior%20Design%203D%20Printer\Design%20report\Design%20Report%20v1.docx#_Toc385423816)

[Table 6: Prototype cost of X/Y translation subsystem (JC) 31](file:///E:\Documents\Homework\SIUC\Senior%20Design%203D%20Printer\Design%20report\Design%20Report%20v1.docx#_Toc385423817)

[Table 7: Implementation cost of X/Y translation subsystem (JC) 31](file:///E:\Documents\Homework\SIUC\Senior%20Design%203D%20Printer\Design%20report\Design%20Report%20v1.docx#_Toc385423818)

[Table 8: Production cost of roller mechanism subsystem (JC) 34](file:///E:\Documents\Homework\SIUC\Senior%20Design%203D%20Printer\Design%20report\Design%20Report%20v1.docx#_Toc385423819)

# Table of Drawings: CWB

[Drawing 1: Makerslide cross section (JC) 90](file:///E:\Documents\Homework\SIUC\Senior%20Design%203D%20Printer\Design%20report\Design%20Report%20v1.docx#_Toc385423866)

[Drawing 2: Roller plate - Motor (JC) 91](file:///E:\Documents\Homework\SIUC\Senior%20Design%203D%20Printer\Design%20report\Design%20Report%20v1.docx#_Toc385423867)

[Drawing 3: Pwdr. Project's X/Y Translation assembly drawing (JC) 92](file:///E:\Documents\Homework\SIUC\Senior%20Design%203D%20Printer\Design%20report\Design%20Report%20v1.docx#_Toc385423868)

[Drawing 4: Rolling Plate - Bearing (JC) 93](file:///E:\Documents\Homework\SIUC\Senior%20Design%203D%20Printer\Design%20report\Design%20Report%20v1.docx#_Toc385423869)

[Drawing 5: Makerslide belt clip (JC) 94](file:///E:\Documents\Homework\SIUC\Senior%20Design%203D%20Printer\Design%20report\Design%20Report%20v1.docx#_Toc385423870)

[Drawing 6: Makerslide motor mounting plate (JC) 95](file:///E:\Documents\Homework\SIUC\Senior%20Design%203D%20Printer\Design%20report\Design%20Report%20v1.docx#_Toc385423871)

[Drawing 7: Makerslide eccentric nut (JC) 96](file:///E:\Documents\Homework\SIUC\Senior%20Design%203D%20Printer\Design%20report\Design%20Report%20v1.docx#_Toc385423872)

[Drawing 8: Rolling Mechanism Flange (JC) 97](file:///E:\Documents\Homework\SIUC\Senior%20Design%203D%20Printer\Design%20report\Design%20Report%20v1.docx#_Toc385423873)

[Drawing 9: Base Panel (PZ) 98](file:///E:\Documents\Homework\SIUC\Senior%20Design%203D%20Printer\Design%20report\Design%20Report%20v1.docx#_Toc385423874)

# Executive Summary:CWB

Project PAM proposes a reference Photoresin Additive Manufacturing (PAM) system which maximizes accessibility to the hobbyist. It is intended to be flexible by allowing for configurations of hardware available or easily obtainable to the end user. This is achieved through extensive use of currently available or easily fabricated hardware and open-source software. The reference design uses open-source hardware and software to the lowest practical level. Thorough documentation provides the necessary means for the end user to go from an empty table to a functioning printer.

The major subsystems of Project PAM include: Mechanical Motion, Chassis, Printer Control Software, Hardware-Software Interface, Resin Management, Optics, Vat, and Coupler. Our teams is still striving to achieve the optimist solution to achieve the highest level of quality.

Several of the design activities and decisions show how Project PAM is more desirable than the competition. One example of this is Project PAM’s build size. The maximum build size is almost double that of any other DLP printer. This is achieved by supporting the use of two 1080p projectors. As consumer resins increase with quality this feature will allow the PAM system to grow. Though the maximum build size would use up to nine liters, Project PAM’s flexible design allows the use of multiple vats and build tables. This will lead to minimal resin waste, saving the user money.

This printer is expected to have the capability of producing high quality prints. The initial goals of Project PAM included: keep the cost of the project under $700 excluding the price of the projectors, support the use of two projectors, have a maximum build size of 20X20X19 cm, layer thickness as thin as 100 µm, and have a printing resolution error within 100 µm.

Talk about Prototype here.

This report consists of: a project description that will introduce the report and project, a cost analysis allowing the open-source community to see the end cost, expected build time schedule, detailed subsystems descriptions along with recommendations, and an appendix.

# Project Description:

## Introduction: CWS

Today when one uses the term "3D printing" they referring to the manufacturing process that allows three dimensional drawing on the computer to be built before their eyes with just a click of a button. 3D printing is unique from other machining processes because it implements what's known as additive manufacturing rather than the more common techniques of drilling or cutting to remove material. 3D Printers are able to accomplish this by slicing the virtual models into several two dimensional layers and then printing those layer one by one to build up the object. This is advantageous because it is much less wasteful than traditional techniques. A 3D printer is also capable of building nearly any object which allows manufacturers to change products without having to buy any new equipment.

The first 3D printer was built in 1984 by Chuck Hall [1] but the process has not been widely available until the early 2010's. Printers are most commonly used for cheap and rapid prototyping but the process has shown potential in a number of fields, including architecture, automotive design, and even the biomedical field to print human tissue and organs. Because of this potential the industry is estimated to be worth more than $2.2 billion today [2].

There are several techniques used to accomplish this layer-by-layer building operation, the most common of the additive manufacturing processes today is extrusion deposition. With this extrusion deposition each 2D layer is built by extruding a bead of material which will harden almost instantly upon leaving the extruder nozzle. The nozzle head moves across a surface depositing the material in the shape of the given layer and then moves on to build the next layer of the object. As each layer is added the print object gains volume. This method is simple and inexpensive but is less accurate than other techniques and also error prone since any defect can lead to a jam or clog in the extruder.

However, another method that is slowly gaining popularity is using light and photocurable resins to build these layers. The resin is exposed to some form of UV light which hardens the resin. This hardened section of resin is one layer of the object. The print area then moves down and the process is repeated to build the next layer. This is known as photopolymerization and the most common form of photopolymerization is using a DLP projector to project images onto the resin. DLP printing has several advantages over the previously mentioned extrusion deposition method, the first of which is speed. Instead of moving an extrusion nozzle slowly across a surface to build the individual layers, DLP printers project an image of the entire layer and cure it all at once. Another advantage is that since there is no physical contact between the projector and the building material there is not possibility for jamming. However, DLP printing’s greatest strength lies in its ability to produce extremely precise and detailed print objects since its resolution is only limited by the resolution of the projector used.

## overall Printer Diagram:



Figure 1. Flow Diagram for Project PAM printer control software

# Costs:

# Schedules:

# Subsystem Descriptions:

## Mechanical Motion-JPB

## Chassis-JPB

### Process of Design

### Process of Assembling

### IMPLEMENTATION SCHEDULE

### Equipment Needed

### Health and Safety Issues

### Recommendations

## Printer Control Software- DMO

## Hardware-Software Interface- NAL

## Resin Management-CWB

### Process of Design

As Project PAM was unfolding, the decision to become a photoresin printer emerged. The first design of the resign was to use a custom product from Momentive. Momentive Specialty Chemicals Inc. serves the global wood and industrial markets through a broad range of thermoset technologies, specialty products and technical support for customers in a diverse range of applications and industries [3]. This would have allowed Project PAM complete control over the wavelength needed to cure the resin, over the color, over the density, and over the curing agents.

Because of the goal of the project to be completely open source, this idea was abandon for buying resins that will be more accessible to the open source community. While looking through photoresin system forums, there was one company that had shown up on mutable post as being reliable and cost effective, MakerJuice [4]. MakerJuice is an American company first started in 2013 with a focus of quality and low cost resins aimed for the hobbyists’ community [5]. They have sold over eight-thousand items and have over two-thousand customers since their start [5]. This gave Project PAM the facts it needed to use MakerJuice for the prototype.

### Health and Safety Issues

Resins by MakerJuice are in compliance of USA and Canada standards [5]. Safety Data Sheets (SDS) for all of their products can be found on their website. The SDS for the resin G+, ordered by Project Pam can be found in this report at 7.1.

G+ is a category 2 skin corrosion, category 1 serious eye damage, and a category 1 for skin sensitization set by the 2012 OSHA Hazard Communication Standard [5]. The precautionary prevention steps are as follows: Wash face, hands and any exposed skin thoroughly after handling, wear protective gloves/protective clothing/eye protection/face protection, avoid breathing dust/fume/gas/mist/vapors/spray, and contaminated work clothing should not be allowed out of the workplace [5].

The precautionary response steps are as follows: If in the eyes; Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing. Immediately call a POISON CENTER or doctor/physician. If on the skin; Wash with plenty of soap and water. Take off contaminated clothing and wash before reuse. If skin irritation or rash occurs: Get medical advice/attention [5].

### Recommendations

There are several different types of resins that are open to the hobbyist community. Some resins cure harder than other resin, but this can result in a longer cure time. Different types of resins can allow for the end print to be flexible, like MakerJuice’s Flex [5].

There are a few things to keep in mind while shopping for resin. The first thought is the cost. There are several companies that are based out of the US who have cheaper resins but the shipping cost is sometimes up to triple the cost of their product. Another thought is the shrink percent. MakerJuice’s G+ substance has an experimental shrinkage of 3.3%, while their G substance has an 8% experimental shrinkage [5]. Shrinkage is the most common problem with prints with a build volume over 100cm3 [4]. The G+ was $45.00 a liter, and the G was $40 a liter in May of 2014 [5]. The user will have to decide if it is worth the extra $5 to ensure precise prints.

To help offset the use of resin several hobbyist have had success of using saltwater [4]. The resin floats on top of the saltwater. This means that a hobbyist only needs to put as much resin in the vat as what is needed for the build or the layer thickness. With the price of most resins being around $50, this idea is a great way to save resin and money.

## Optics-CWB

### Design

The project is the biggest investment of the project. ­­­­There are several things to keep in mind when making a choice on what projector to go with. There are several different types of projectors. The two main projectors are light-emitting diode (LED) and digital light processing (DLP). For the truest and highest quality of prints the best choice to use is DLP. DLP uses a mirror for each pixel in the projected image. This allows each pixel to be controlled individually unlike the LED were groups of pixels work together to make an image.

Another big decision is the native pixel resolution. The resolution will directly decide the quality of the prints and the size of the build area. The higher the number, the higher the max build area and better the quality. A full HD 1080p is actually at the ratio of 1920 by 1080 pixels. This allows a max build area with a 100µm precision to be 20 cm by 10 cm.

Another major component of the projector that will impacted the quality of the prints is the throw ratio. This effects the screen size or in printing terms the build area. Personal off-the-shelf projectors are not made for projecting images less than a foot away from the lens. The farther back the projector is from the build area will mean a larger build area, but at the sacrifice of pixel resolution. Depending on the projector this may be fixed by opening up the projector and modifying or replacing the lens to account for the shorter distance [1].

Aside from the pixel resolution is the lumen output. Depending on the type of resin that is used for the print will decide how many lumens it takes to cure. MakerJuice’s resin takes 2000 lumens to cure [5].

### Recommendations

Though Project PAM’s design is flexible to allow use of almost all consumer projectors, the prototype used View Sonic’s PJD7820HD 1080p 3D Home Theater Projector. This projector outputs 3000 lumens allowing faster build times. It has a 15000:1 contrast between a fully on pixel and off pixel. It supports HDMI in, dual VGA in, and VGA out giving great flexibility to the user. The projector has a filter-less design. It also has a 3-year limited warranty on parts and labor; and a 1-year warranty on the lamp. All of this comes in a 4lb plastic case, making it ideal for mounting it over head. [6]

Most importantly the 1.2x Optical Zoom lens and throw ratio of 1.25-1.5:1 is able to give Project PAM the build area and resolution without modifying the lens [6]. This was found by doing a test. The project was set 21 cm away from the screen to simulate the space between the build layer and the lens. The zoom was then set to give a build area of 10.2 cm by 18.4 cm, which is close to the desired 10 cm by 20 cm. The focus was then adjusted until font size 8 was easily readable.

## Vat-NBT

## Coupler-NBT

# References: CWB

|  |  |
| --- | --- |
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| [2] | "3D Printing Scales Up," *The Economist,* 7 September 2013. |
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| [5] | "MakerJuice," MakrJuice Labs, 2014. [Online]. Available: www.makerjuice.com. [Accessed May 2014]. |

# Appendix

## MakerJuice Safety Data Sheet

Issue Date 19-Nov-2013 Revision Date 22-May-2014 Version 2

1. IDENTIFICATION OF THE SUBSTANCE/PREPARATION AND OF THE COMPANY/UNDERTAKING

Product identifier

Product Name SUBSTANCE G+

Other means of identification

Synonyms SubG+

Recommended use of the chemical and restrictions on use

Recommended Use General Purpose UV Cure Resin

Uses advised against No information available

Details of the supplier of the safety data sheet

Manufacturer Address

MakerJuice Labs LLC

14100 Santa Fe Trail Drive

Suite #105

Lenexa, KS 66215 USA

Email: josh@makerjuice.com

Website: http://www.makerjuice.com

Emergency telephone number

Company Phone Number (913) 777-4996 [9-5PM CST, M-F]

2. HAZARDS IDENTIFICATION

Classification

OSHA Regulatory Status

This chemical is considered hazardous by the 2012 OSHA Hazard Communication Standard (29 CFR 1910.1200)

Skin corrosion/irritation Category 2

Serious eye damage/eye irritation Category 1

Skin sensitization Category 1

Label elements

Emergency Overview

Danger

Hazard statements

Causes skin irritation

Causes serious eye damage

May cause an allergic skin reaction

Appearance viscous Physical state liquid Odor Ester

Precautionary Statements - Prevention

Wash face, hands and any exposed skin thoroughly after handling

Wear protective gloves/protective clothing/eye protection/face protection

Avoid breathing dust/fume/gas/mist/vapors/spray

Contaminated work clothing should not be allowed out of the workplace

Precautionary Statements - Response

IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.

Immediately call a POISON CENTER or doctor/physician

IF ON SKIN: Wash with plenty of soap and water

Take off contaminated clothing and wash before reuse

If skin irritation or rash occurs: Get medical advice/attention

Precautionary Statements - Disposal

Dispose of contents/container to an approved waste disposal plant

Hazards not otherwise classified (HNOC)

Not Applicable

Other Information

Unknown Acute Toxicity 0% of the mixture consists of ingredient(s) of unknown toxicity

3. COMPOSITION/INFORMATION ON INGREDIENTS

Chemical Name CAS No. Weight-% Trade Secret

acrylate ester proprietary >60 \*

photoinitiator proprietary <1 \*

\* If CAS number is "proprietary", the specific chemical identity has been withheld as a trade secret. The exact percentage

(concentration) of composition has been withheld as a trade secret.

4. FIRST AID MEASURES

First aid measures

General advice If symptoms persist, call a physician.

Eye contact Immediately flush with plenty of water. After initial flushing, remove any contact lenses

and continue flushing for at least 15 minutes. Keep eye wide open while rinsing. If

symptoms persist, call a physician.

Skin Contact Avoid UV-radiation/sunlight. Wash off immediately with soap and plenty of water while

removing all contaminated clothes and shoes. If skin irritation persists, call a physician.

Wash contaminated clothing before reuse.

Inhalation If fumes from reactions are inhaled, move to fresh air immediately. If symptoms persist,

call a physician.

Ingestion Rinse mouth. Drink plenty of water. Do NOT induce vomiting. Call a physician immediately.

Self-protection of the first aider Use personal protective equipment as required.

Most important symptoms and effects, both acute and delayed

Symptoms May cause allergic skin reaction.

Indication of any immediate medical attention and special treatment needed

Note to physicians May cause sensitization of susceptible persons. Treat symptomatically.

5. FIRE-FIGHTING MEASURES

Suitable extinguishing media

Dry chemical, CO2, alcohol-resistant foam or water spray.

Unsuitable extinguishing media: Do not use a solid water stream as it may scatter and spread fire.

Specific hazards arising from the chemical

In the event of fire and/or explosion do not breathe fumes. May cause sensitization by inhalation and skin contact. Thermal

decomposition can lead to release of irritating and toxic gases and vapors.

Hazardous combustion products: Formaldehyde.

Explosion data

Sensitivity to Mechanical Impact: None.

Sensitivity to Static Discharge: None.

Protective equipment and precautions for firefighters

Wear self-contained breathing apparatus for firefighting if necessary.

6. ACCIDENTAL RELEASE MEASURES

Personal precautions, protective equipment and emergency procedures

Personal precautions Ensure adequate ventilation, especially in confined areas. Use personal protective

equipment as required. Avoid contact with eyes and skin. Evacuate personnel to safe

areas. Keep people away from and upwind of spill/leak.

Environmental precautions

Environmental precautions Do not flush into surface water or sanitary sewer system. See Section 12 for additional

ecological information.

Methods and material for containment and cleanup

Methods for containment Prevent further leakage or spillage if safe to do so.

Methods for cleaning up Soak up with inert absorbent material. Pick up and transfer to properly labeled containers.

After cleaning, flush away traces with water.

7. HANDLING AND STORAGE

Precautions for safe handling

Advice on safe handling Use only in well-ventilated areas. Avoid breathing fumes from hot material. Use personal

protective equipment as required. Do not breathe dust/fume/gas/mist/vapors/spray.

Conditions for safe storage, including any incompatibilities

Storage Conditions Keep out of the reach of children. Keep containers tightly closed in a cool, well-ventilated

place. Keep in properly labeled containers. Protect from direct sunlight and ultraviolet (UV).

Keep away from heat.

Incompatible materials Strong oxidizing agents. Strong acids. Strong bases.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Control parameters

Exposure Guidelines This product, as supplied, does not contain any hazardous materials with occupational

exposure limits established by the region specific regulatory bodies.

Appropriate engineering controls

Engineering Controls Ensure adequate ventilation, especially in confined areas.

Individual protection measures, such as personal protective equipment

Eye/face protection Tight sealing safety goggles.

Skin and body protection Wear protective nitrile rubber gloves.

Respiratory protection In case of insufficient ventilation, wear suitable respiratory equipment.

General Hygiene Considerations When using do not eat, drink or smoke. Wash face, hands and any exposed skin thoroughly

after handling. Wash contaminated clothing before reuse. Regular cleaning of equipment,

work area and clothing is recommended.

9. PHYSICAL AND CHEMICAL PROPERTIES

Information on basic physical and chemical properties

Physical state liquid

Appearance viscous Odor Ester

Color red, yellow, green, blue, black, white Odor threshold No information available

Property Values Remarks • Method

pH No information available

Melting point/freezing point No information available

Boiling point / boiling range No information available

Flash point > 100 °C (> 212 °F)

Evaporation rate No information available

Flammability (solid, gas) No information available

Flammability Limit in Air

Upper flammability limit: No information available

Lower flammability limit: No information available

Vapor pressure No information available

Vapor density No information available

Specific Gravity Approx. 1

Water solubility Low solubility

Solubility in other solvents No information available

Partition coefficient No information available

Autoignition temperature No information available

Decomposition temperature No information available

Kinematic viscosity No information available

Dynamic viscosity 90 cP @ 20 °C

Explosive properties No information available

Oxidizing properties No information available

Other Information Softening point No information available

Molecular weight No information available

VOC Content (%) No information available

Density No information available

Bulk density No information available

10. STABILITY AND REACTIVITY

Reactivity

No data available

Chemical stability

Stable under recommended storage conditions.

Possibility of Hazardous Reactions

None under normal processing.

Conditions to avoid

Heat, flames and sparks. Extremes of temperature and direct sunlight. To avoid thermal decomposition, do not overheat. UVradiation/sunlight.

Incompatible materials

Strong oxidizing agents. Strong acids. Strong bases.

Hazardous Decomposition Products

Formaldehyde.

11. TOXICOLOGICAL INFORMATION

Information on likely routes of exposure

Product Information

Inhalation No data available.

Eye contact Risk of serious damage to eyes.

Skin Contact May cause sensitization by skin contact.

Ingestion

Component Information

No data available.

Chemical Name Oral LD50 Dermal LD50 Inhalation LC50

acrylate ester = 4600 mg/kg ( Rat ) > 2 g/kg ( Rabbit ) -

Information on toxicological effects

Symptoms May cause an allergic skin reaction.

Delayed and immediate effects as well as chronic effects from short and long-term exposure

Corrosivity Risk of serious damage to eyes.

Sensitization May cause sensitization by skin contact.

Germ cell mutagenicity No information available.

Carcinogenicity May release formaldehyde when heated to high temperatures [> 150 °C (> 212 °F)] in

the presence of air. Formaldehyde is a known skin and lung sensitizer and is regulated

as a carcinogen.

Reproductive toxicity No information available.

STOT - single exposure No information available.

STOT - repeated exposure No information available.

Aspiration hazard No information available.

Numerical measures of toxicity - Product Information

Unknown Acute Toxicity 0% of the mixture consists of ingredient(s) of unknown toxicity

12. ECOLOGICAL INFORMATION

Ecotoxicity

Toxic to aquatic life

Persistence and degradability

No information available.

Bioaccumulation

No information available.

Other adverse effects No information available

15. REGULATORY INFORMATION

International Inventories

TSCA Complies

Legend:

TSCA - United States Toxic Substances Control Act Section 8(b) Inventory

US Federal Regulations

SARA 313

Section 313 of Title III of the Superfund Amendments and Reauthorization Act of 1986 (SARA). This product does not contain any

chemicals which are subject to the reporting requirements of the Act and Title 40 of the Code of Federal Regulations, Part 372

SARA 311/312 Hazard Categories

Acute health hazard Yes

Chronic Health Hazard No

Fire hazard No

Sudden release of pressure hazard No

Reactive Hazard No

CWA (Clean Water Act)

This product does not contain any substances regulated as pollutants pursuant to the Clean Water Act (40 CFR 122.21 and 40

CFR 122.42)

CERCLA

This material, as supplied, does not contain any substances regulated as hazardous substances under the Comprehensive

Environmental Response Compensation and Liability Act (CERCLA) (40 CFR 302) or the Superfund Amendments and

Reauthorization Act (SARA) (40 CFR 355). There may be specific reporting requirements at the local, regional, or state level pertaining to releases of this material

US State Regulations

California Proposition 65

This product does not contain any Proposition 65 chemicals

U.S. State Right-to-Know Regulations

This product does not contain any substances regulated by state right-to-know regulations

Canada

This product has been classified in accordance with the hazard criteria of the Controlled Products Regulations (CPR) and the MSDS contains all the information required by the CPR WHMIS Hazard Class

D2B - Toxic materials

16. OTHER INFORMATION

NFPA Health hazards 2 Flammability 0 Instability 0 Physical and Chemical

Properties -

HMIS Health hazards 2 Flammability 0 Physical hazards 0 Personal protection X

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Disclaimer

The information provided in this Material Safety Data Sheet is correct to the best of our knowledge, information and belief at the date of its publication. The information given is designed only as a guidance for safe handling, use, processing, storage, transportation, disposal and release and is not to be considered a warranty or quality specification. The information relates only to the specific material designated and may not be valid for such material used in combination with any other materials or in any process, unless specified in the text.

End of Safety Data Sheet