Epoxy Resins & Recyclable Systems

Snowsports Industries America

Summit Series, Sundance, UT

March 7, 2024

Presented by David Woodcock

ABG STORY

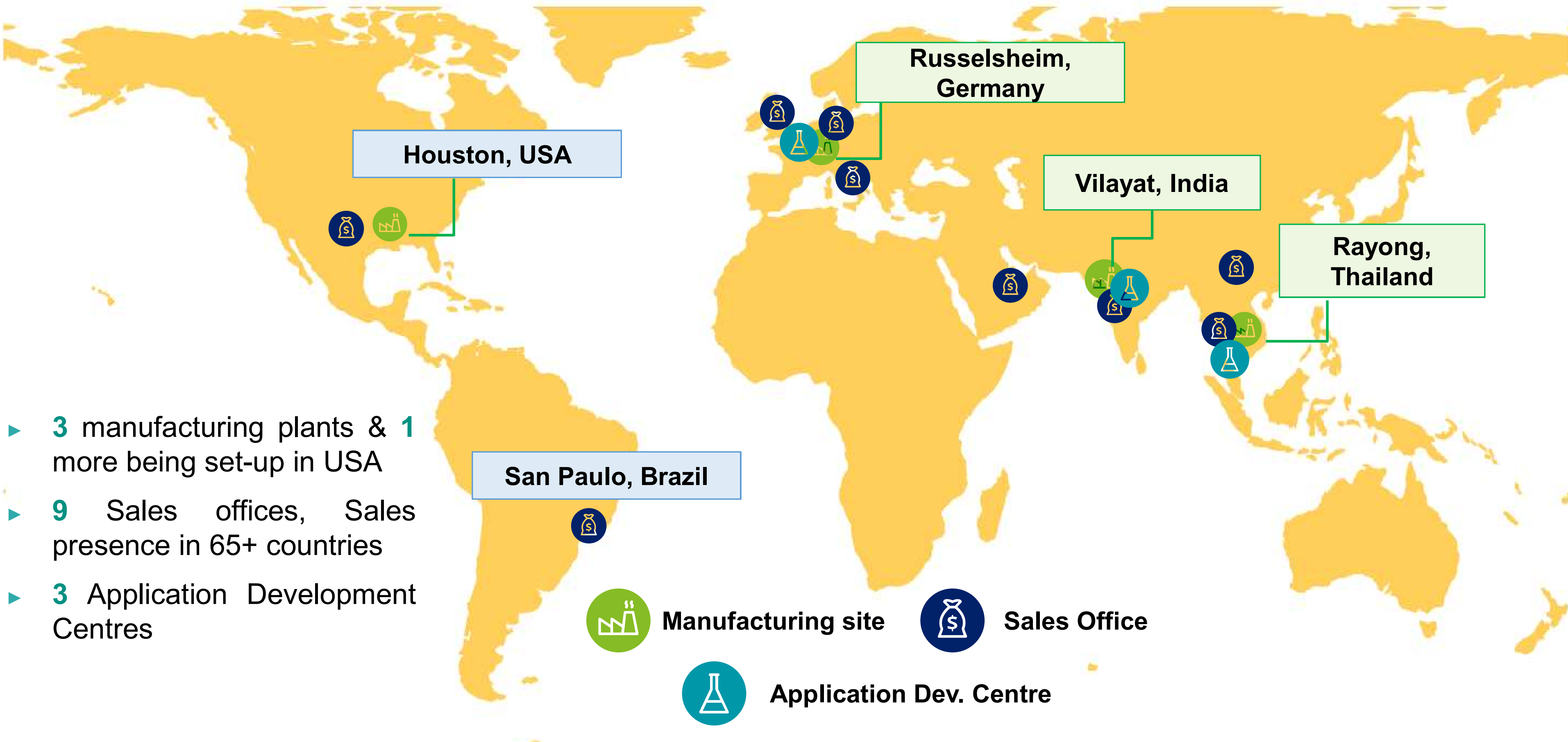
BIG IN YOUR LIFE

A **US$ ≈75** billion conglomerate across **6** continents and **41** countries **178** state-of-the-art manufacturing units globally with **187,000+** employees of **100** nationalities catering to **300** million customers

ABG Chemicals: A **global chemicals** player with a **diversified portfolio** and **leadership positions** across businesses

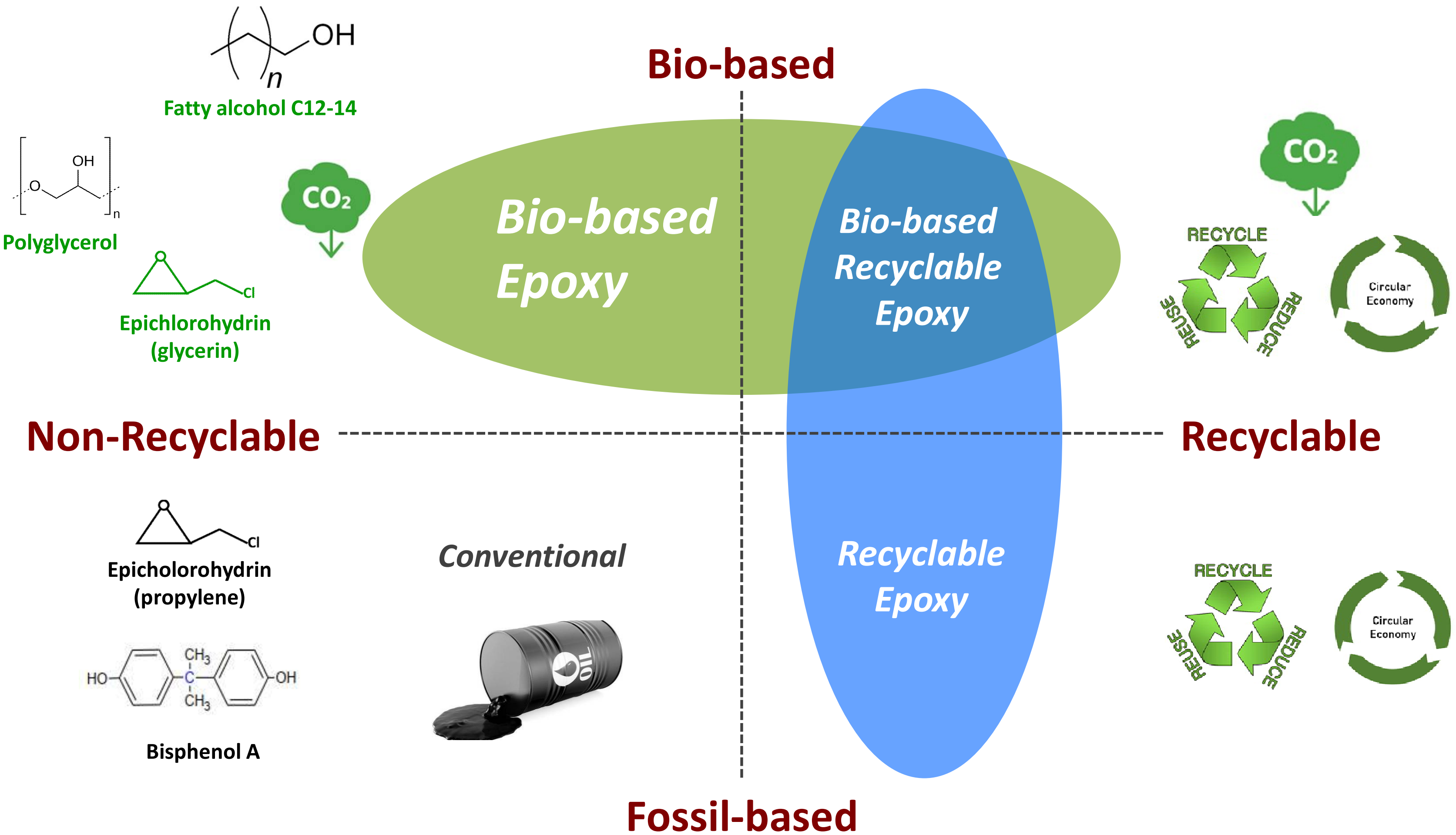
- Largest Indian Chlor-Alkali player & top 10 globally
- Top 3 specialty solution provider in Epoxy Resins
- Leading player in food-grade phosphates & quality Sulphites

Advanced Materials (epoxy resins) business has presence in more than 60+ countries, with supply from 3 plants



- **3** manufacturing plants & **1** more being set-up in USA
- **9** Sales offices, Sales presence in 65+ countries
- **3** Application Development Centres

Epoxy Resins and Sustainability with Bio-based materials



Overview of Briozen Bio-based Epoxy Resins

	OH compounds from petroleum (BPA, BPF, Novolac resin, etc.)	OH compounds from **plant oils:** glycerol, fatty acid, castor oil, aliphatic alcohol etc.	OH compounds from **renewable & bio sources:** sorbitol, isosorbide, fermentation based mat.
ECH from **glycerol** (Glycerol is by-product from biodiesel production)	**Briozen** **Partial bio-based epoxy resins** **(Bio-content = 28-31%)**	**Briozen** **100% bio-based epoxy resins**	**Briozen** **Renewable 100% bio-based epoxy resins**
ECH from from propylene (Petroleum)	**Epotec** **Conventional epoxy resin** **(Zero bio-content)**		

Bio-based Epoxy Resins

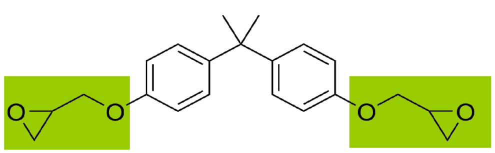
Bio-based Epoxy Resins – type of resin that contains bio-based or renewable content characterized by bio-based carbon content based on ASTM D6866-18.

Bio-based Carbon Content – the amount of bio-based carbon as a percent of the total organic carbon in the product.

$$\text{\% Biobased carbon content} = \frac{Biobased\ Carbon}{Total\ Organic\ Carbon} \times 100$$

Bio-based ECH + **Bisphenol A (BPA)** = **Epoxy Resin**

100% Bio-based carbon content | 0% Bio-based carbon content | 28% Bio-based carbon content (theoretical)



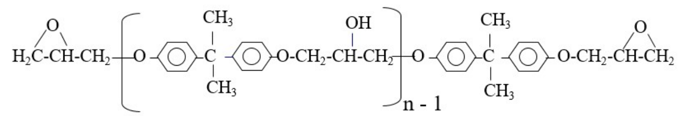
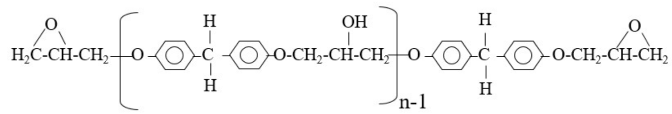
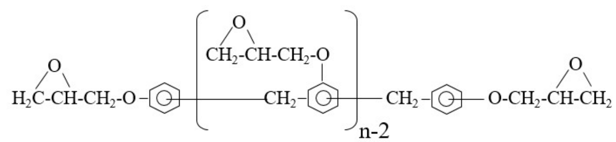
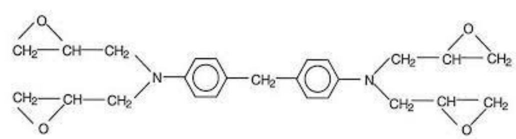
Bisphenol A diglycidyl ether

4 MT CO_2e/MT

% Bio-based carbon content of Bisphenol A diglycidyl ether (theoretical)

$$= \frac{6}{21} \times 100 \approx 28\,\%$$

Bio-based Epoxy Resins

Bio-based feed stock	Epoxy resin	% bio-carbon
Palm oil 	**Diglycidyl ether of Bisphenol A** 	28
 Soybean oil	**Diglycidyl ether of Bisphenol F** 	31
 Rapeseed oil	**Epoxy Novolac Resin** 	30
 Sunflower oil	**Multifunctional epoxy resin** 	41

Briozen Partial Bio-based Epoxy Resins

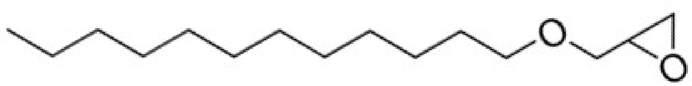
Grade name	Chemical name	Bio-content (%)	Epoxy Equivalent Weight (g/eq)	Viscosity at 25°C (mPa.s)	Features
YD 128 G	Diglycidyl ether of Bisphenol A	26 - 29	185-194	11,000-14,000	Standard liquid epoxy resin for ambient and elevated cure application.
YD 127 G	Diglycidyl ether of Bisphenol A (low viscosity)	26 - 29	180-188	9,000-12,000	Low viscosity liquid epoxy resin for ambient and elevated cure application.
YDF 170 LC G	Diglycidyl ether of Bisphenol F	28 - 31	165-175	3,000-5,000	Improved crystallization resistance.
YDF 173 G	Epoxy Novolac Resin	28 - 31	167-175	11,000-15,000	Functionality of 2.5 for improved chemical resistance.
YDPN 638G	Multifunctional semi-solid phenol novolac epoxy resin	28 - 31	175-182	Semi solid	Functionality of 3.6 for improve chemical resistance and thermal resistance.

Bio-based Epoxy Resins (reactive diluents) with 100 % bio-carbon content

% Biobased carbon content $= \frac{Biobased\ Carbon}{Total\ Organic\ Carbon} \times 100$

Bio-based ECH + **Bio-polyol** = **Epoxy Resin**

100% Bio-based carbon content | 100% Bio-based carbon content | 100% Bio-based carbon content (Theoretical)

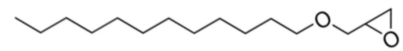
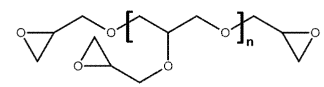
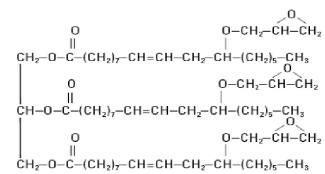
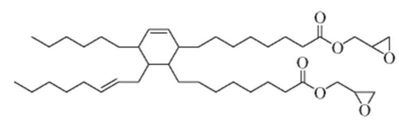
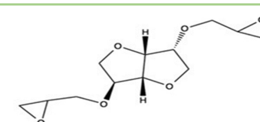
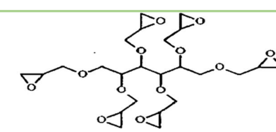


C12-C14 diglycidyl ether

% Bio-based carbon content of C12 –C14 diglycidyl ether (theoretical)

$$= \frac{15}{15} \times 100 = 100\ \%$$

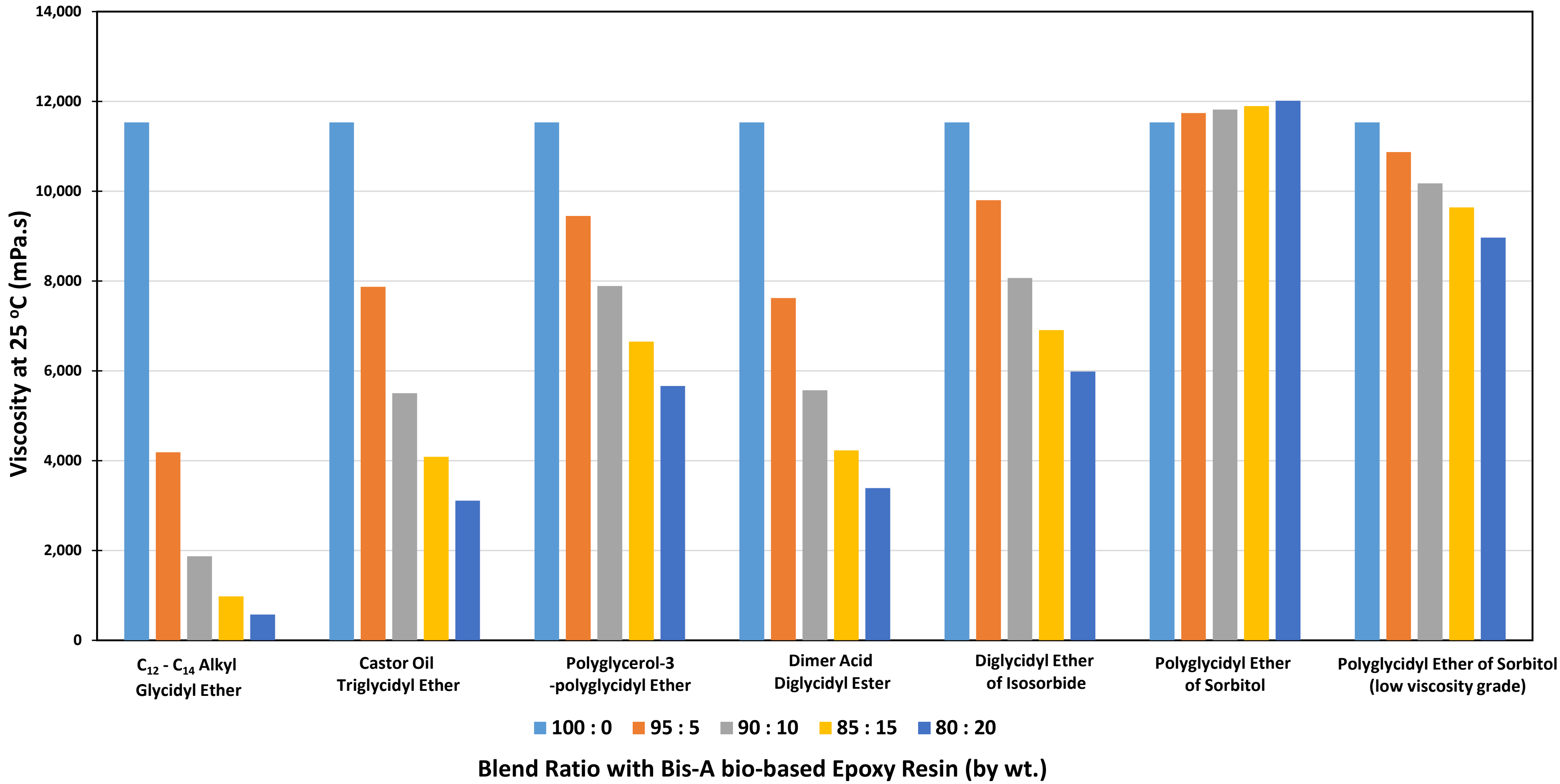
Bio-based Epoxy Resins & Reactive Diluents

Bio-based feed stock	Reactive Diluents		% bio-carbon
Palm oil 	**Monoglycidyl ether of C_{12}-C_{14}**		100
	Triglycidyl ether of polyglycerol		100
 Castor oil	**Triglycidyl ether of castor oil**		100
 Tall oil  Canola oil Cottonseed oil 	**Diglycidyl ester of dimer acid**		100
Corn starch   Potato starch Berries 	**Diglycidyl ether of isosorbide**		100
	Polyglycidyl ether of sorbitol		91-100

Briozen 100% Bio-based Epoxy Resins & Reactive Diluents

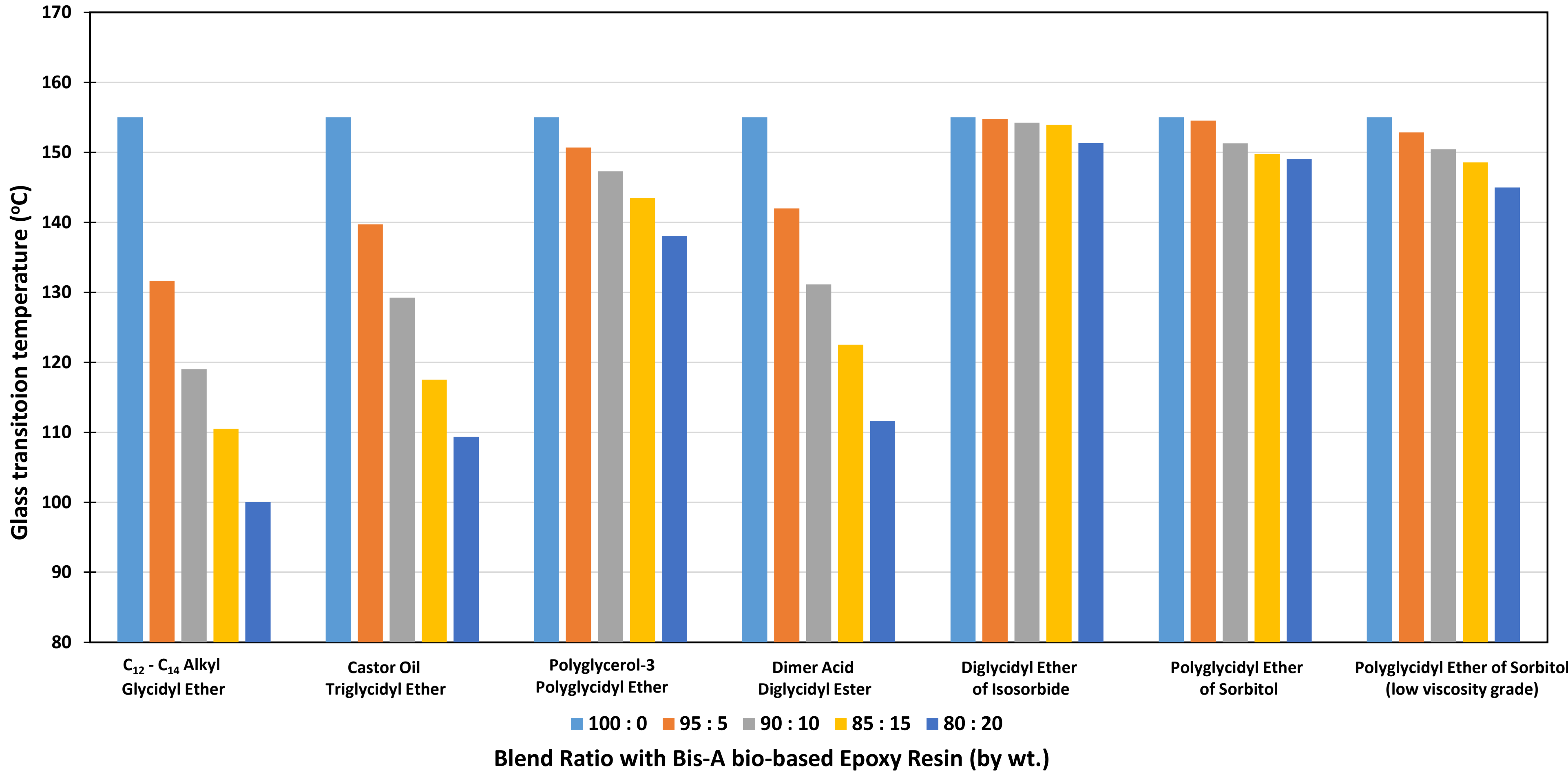
Grade name	Chemical name	Bio-based source	Bio-content (%)	Epoxy Equivalent Weight (g/eq)	Viscosity at 25ºC (mPa.s)	Features
RD 108 G	Monoglycidyl ether of C_{12}-C_{14}	Palm oil	100	270 - 300	5 - 10	Good diluent and morphology , improved impact strength
RD 124 G	Triglycidyl ether of castor oil	Castor oil	100	500 - 650	250 - 500	Imparts flexibility and impact resistance. Low odor and non-volatile
RD 131 G	Polyglycidyl ether of polyglycerol	Palm oil	100	160 - 180	1,000 - 1,360	Tri-functional reactive diluent : adhesion promoter
RD 133 G	Diglycidyl ester of dimer acid	tall oil, canola oil, cottonseed oil	100	390 - 470	400 - 900	Low viscosity flexibilizer, improves toughness
RD 135 G	Diglycidyl ether of isosorbide	Corn starch/ potato starch/ Berries	100	150 - 160	1,000 - 2,000	Di-functional reactive diluent ; used for coatings
RD 143 G	Polyglycidyl ether of sorbitol	Corn starch/ potato starch/ Berries	100	160 - 195	8,000 - 18,000	Poly-functional : used as additive as accelerator with other epoxy resin

Dilution Efficiency of Bio-based Epoxy Resins & Reactive Diluents



Test results of typical batch, ASTM D 2196.

Glass transition Temp.(Tg) of Bio-based Epoxy Resins & Reactive Diluents



Test results of typical batch.

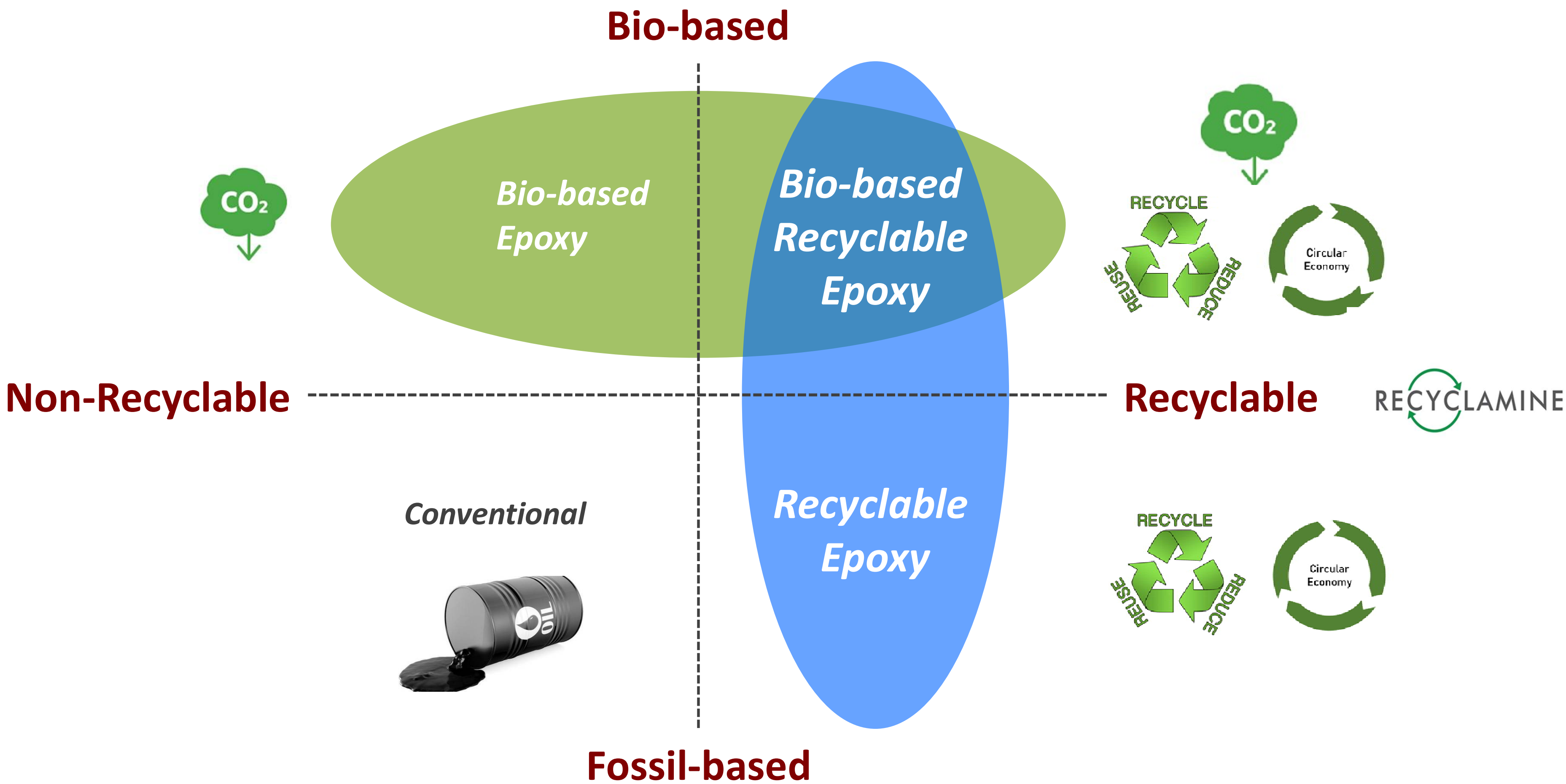
* With Isophorone Diamine (IPDA), cured at 140 ºC/ 4 hrs. , ISO 11357-2.

Example of Bio-based Epoxy Resin System for Composites

Property	Unit	Conventional System	Green Epoxy System
Theoretical bio-based carbon content of resin	**%**	-	**48.9**
Mixing ratio of resin and hardener	by weight	100 : 32	100 : 19
Theoretical bio-based carbon content of system	**%**	-	**41.1**
Processing Properties			
Initial mix viscosity @ 25°C	mPa.s	252.4	184.1
Pot life, 100 gms mix @ 25°C (time to reach max. temp.)	minutes	364.5	379.0
Glass transition temperature* (Tg, mid)	°C	125.21	126.32
Mechanical Properties of Neat Cured System*			
Tensile strength	MPa	66.28	72.99
Tensile strain	%	4.37	4.88
Elastic modulus	MPa	2,636	2,913
Flexural strength	MPa	110.7	128.0
Flexural strain	%	6.48	5.66
Elastic modulus	MPa	2,537	3,084

*Curing condition: 80°C/ 25 minutes + 140°C/ 4-6 hours.

Epoxy Resins and Circularity with Recyclamine®



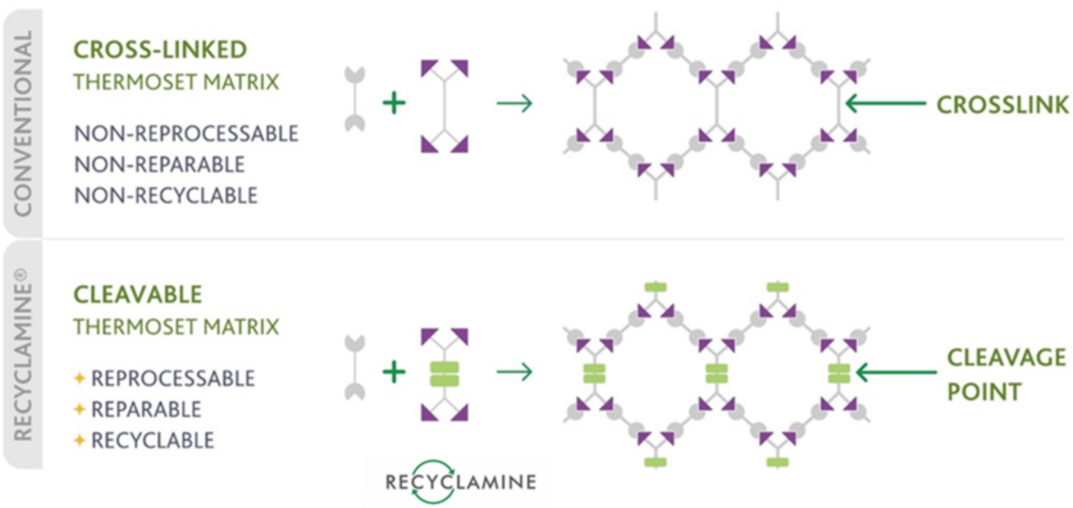
Recyclamine® Technology and Recyclable Epoxy Systems

The Recyclamine® Technology

- **Recyclamine® - path breaking disruptive technology (patented) comprising novel polyamines curing agents**

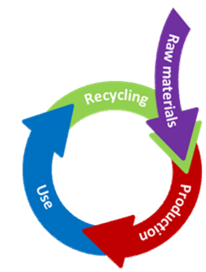
"capable of making epoxy thermosets recyclable"

- **Platform with wide spectrum of curing agents from fast to slow reactivity-low to high temperature resistance**



Cross linked Thermoset Matrix (Non-Recyclable)

Cleaved Thermoset Matrix (Recyclable Thermoplastic)



Recycling enables recovery of Epoxy Resin Matrix (as Thermoplastic) and Reinforcement in Composite

Recyclamine® Technology as a Platform Chemistry

- **Technology Platform comprising of series of polyamine molecules**

  R100, R300, R400, R500, R700, R800 and R900

- **Synthesized from different chemical backbones to enable**

  Wide range of process & performance properties - versatile for range of applications.

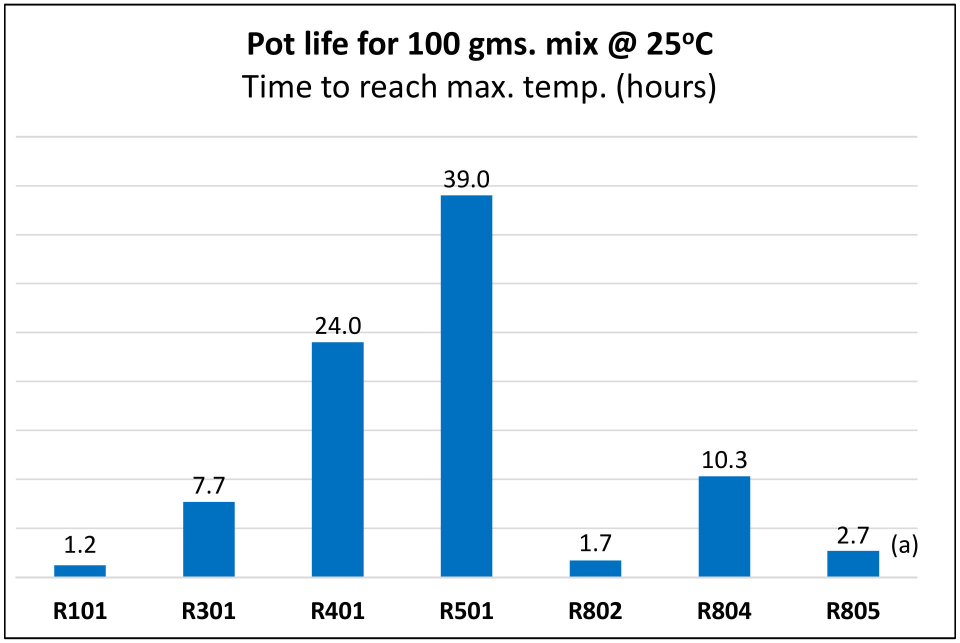
Platform 1	R101	R102	R103		
Platform 2	R301	R302	R303		
Platform 3	R401	R402	R403		
Platform 4	R501	R502	R503		
Platform 5	R701	R702	R703	R704	R705
Platform 6	R801	R802	R803	R804	R805
Platform 7	R901	R902	R903	R904	R905

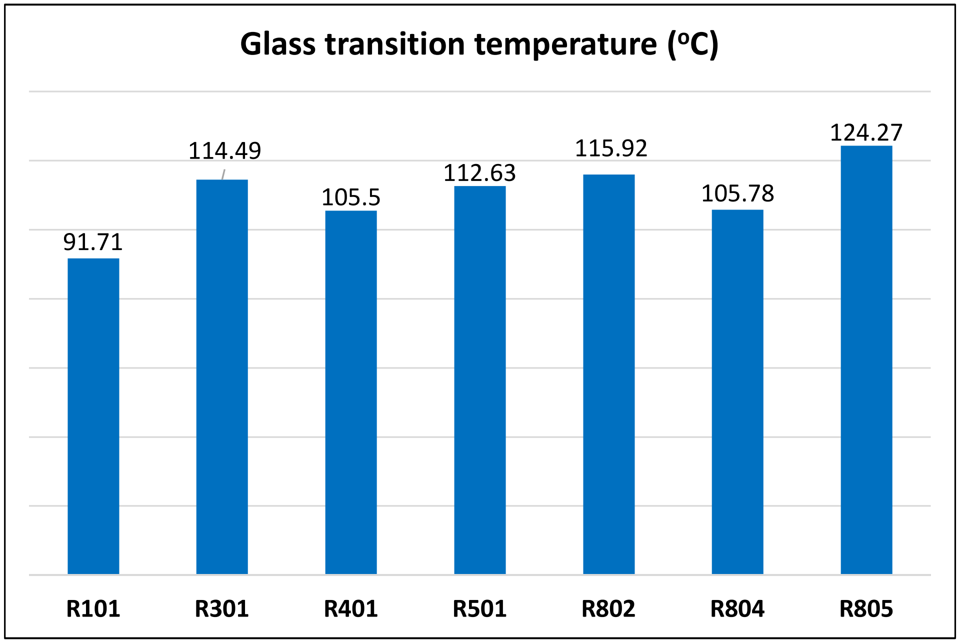
Reactivity: Fast (top) → Slow (bottom)
Temp. Resistance: Low (top) → High (bottom)

Chemical Resistance: Low → High
Reactivity: Fast ← Slow

Process Properties of Select Recyclamine®

Pot life and Glass Transition Temperature (Tg) of Recyclamine®

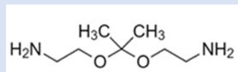
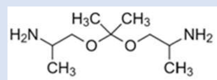
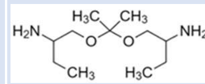
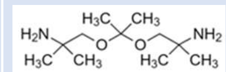
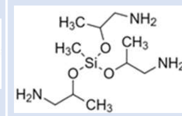
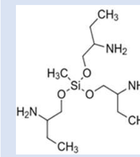
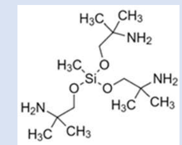




(a) at 40ºC, time to reach 50ºC.

Note: Results of typical batch
Pot life and Tg determined with Bis-A Bio-based Epoxy Resin Epotec YD128 (EEW 180-190 gm/eq) , Curing Condition : 80ºC/ 25 minutes +140ºC/4 hours

Performance Properties of Select Recyclamine®

Property	Unit	Test Method	R101	R301	R401	R501	R802	R804	R805
									
Mixing ratio	by wt.	-	100 : 22	100 : 27	100 : 29	100 : 29	100 : 25	100 : 29	100:28
Pot life (100 g mix @25°C)	minutes	ASTM D2471	72	463	≈ 1,440 (24 hrs.)	≈ 2,340 (39 hrs.)	101	616	164 (@40°C, time to 50°C)
Glass transition temp. (Tg_2)	ºC	ISO 11357	91.71	114.49	105.50	112.63	115.92	105.78	124.27
Tensile strength	MPa		68.33	72.87	74.52	70.30	57.30	57.10	75.27
Elongation at break	%	ISO 527	8.15	6.31	6.90	5.99	3.11	2.97	5.87
E-Modulus	MPa		2,658	2,782	2,765	2,764	2,874	2,789	2,713
Flexural strength	MPa		121.57	127.46	125.11	119.52	114.41	121.34	127.71
Flexural strain	%	ISO 178	6.69	6.76	7.42	7.24	5.00	6.25	7.55
E-modulus	MPa		3,037	3,024	2,838	2,817	3,118	2,908	2,708
Dielectric strength (t = 2mm)	KV/mm	IEC 60243	22.13	22.2	24.80	27.06	21.21	22.77	23.16
Dielectric constant (@ 25 °C, 1MHz)	-	IEC 60250	3.03	2.99	3.06	3.58	3.25	3.93	3.87
Dissipation Factor (tanδ) (@ 25 °C, 1 MHz)	%		3.7	2.7	2.5	2.5	3.8	3.3	3.6
Comp.Tracking Index(CTI)	Volts	IEC 60112	>600	>600	>600	>600	>600	>600	>600

Note: Results of typical batch
Mechanical , Electrical and Thermal Properties with Bis-A Bio-based Epoxy Epotec YD128G (EEW 180-190 gm/eq) ,curing condition : 80ºC/ 25 minutes +140ºC/4 hours

Example of Bio-based Epoxy Resin Systems for Composites

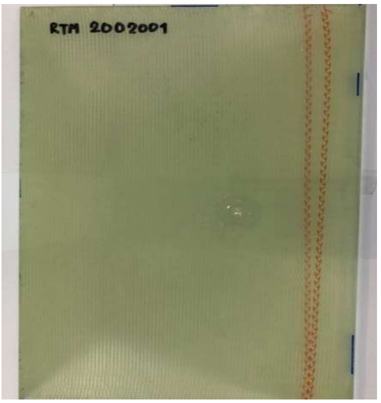
Property	Unit	System A	System B	System C	System D	System E	System F
Physical and Process Properties			**Wet lay-up Systems**			**Infusion/ VARTM Resin Systems**	
Mixing ratio	by wt.	100:38	100:28	100:26	100:24	100:27	100:28
Theoretical bio-based carbon content of system	**%**	**22.5**	**24.2**	**24.6**	**26.1**	**25.5**	**24.8**
Resin viscosity @ 25°C	mPa.s	3,803	3,014	1,230	2,681	1,488	1,488
Hardener viscosity @ 25°C	mPa.s	110.9	213.7	8.4	11.2	9.5	8.6
Initial mix viscosity @ 25°C	mPa.s	964.6	1,104.0	294.0	263.9	224.0	227.5
Pot life, 100 g mix @ 25°C	minutes	23.0	38.0	310.5	39.5	276.0 (1 kg mix)	635.0 (1 kg mix)
T_g, cured @ 80°C/ 4 hours	°C	62.62	78.45	79.03	80.91	85.49	88.40
Mechanical Properties							
• **Tensile Test (ISO 527)**							
Tensile Strength	MPa	64.65	64.43	69.48	70.65	76.95	79.78
Tensile Strain	%	3.53	4.24	4.38	3.96	4.48	4.50
E-Modulus	MPa	3,144	2,917	2,956	3,120	3,144	3,214
• **Flexural Test (ISO 178)**							
Flexural Strength	MPa	109.94	113.26	119.68	118.79	134.46	135.86
Flexural Strain	%	4.91	5.83	5.75	5.18	5.92	5.95
E-Modulus	MPa	3,263	3,112	3,155	3,280	3,387	3,368

Proof of Concept

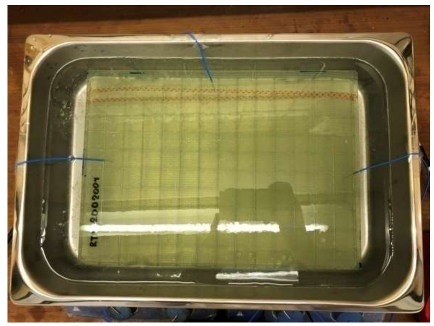
Recycling of Glass Reinforced Epoxy Laminate

(made from Recyclable Infusion System "E")

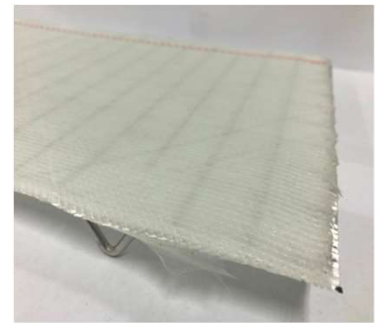
Recovery of Glass Fabrics



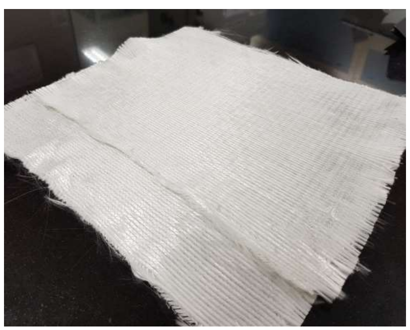
GRE Laminate
(from 3Ax 1200 gsm)



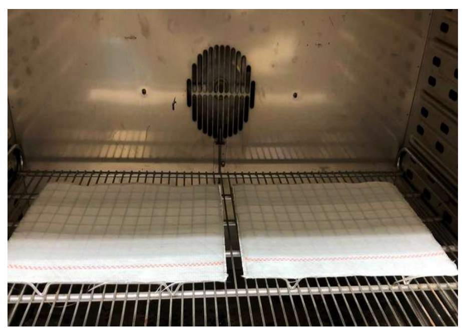
GRE Laminate immersed in recovery solution
& Conditioned @ 80-90°C for 6 hrs.



Recovered glass fabric
after recycling process



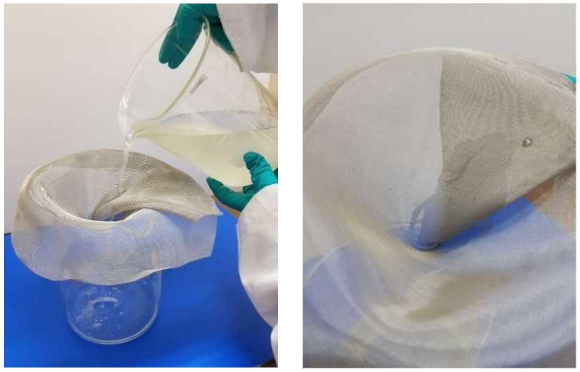
Dried - Recovered glass fabric



Drying at 120°C/ 2 hrs.

Rinsing with potable water

Recovery of Epoxy- Matrix as Thermoplastic



Filtration of Recovery Solution
(comprising of recovered Resin)

Neutralization and Coagulation

Recovered Epoxy Matrix
(as thermoplastic)

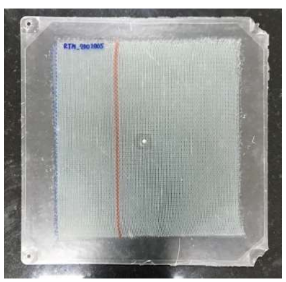
Re-Use of Recovered Glass Fabrics and Thermoplastic

(Closing the Loop)

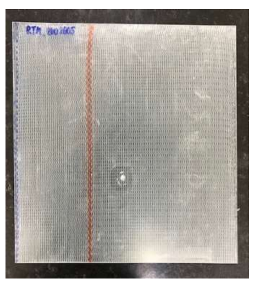
Re-Use of Recovered Glass Fabrics

Laminate Preparation by VARTM Process

Type of Fabric	: Triaxial fabric, 1200 gsm
Layer of Fabric	: 2 layers.
Fabric Dimension	: 320 x 320 mm
Recyclable System	: E
Mold Temperature	: 25 +/- 2 deg.C
Vacuum	: 1 mbar (until material full the mold)
	: 100 mbar (during curing)
Post curing	: 8hrs. @ 80 deg.C



De-molded GRE Laminate



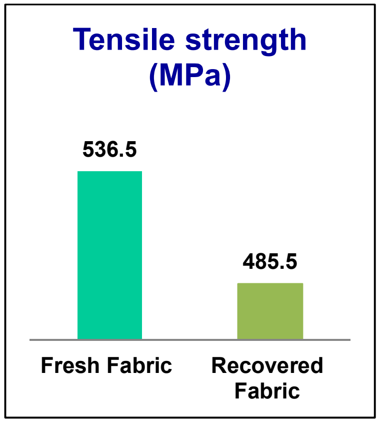
GRE Laminate (after trimming)

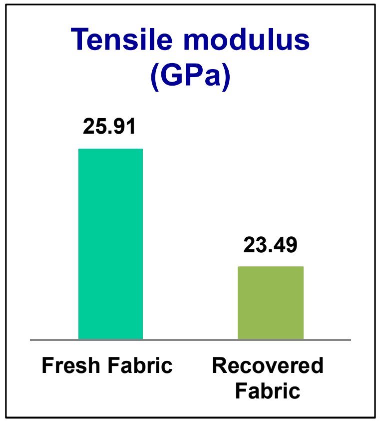
Tensile Specimens

VARTM Set-up

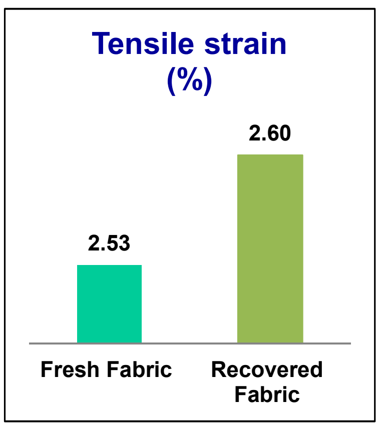
Comparative Mechanical Properties of GRE Composite

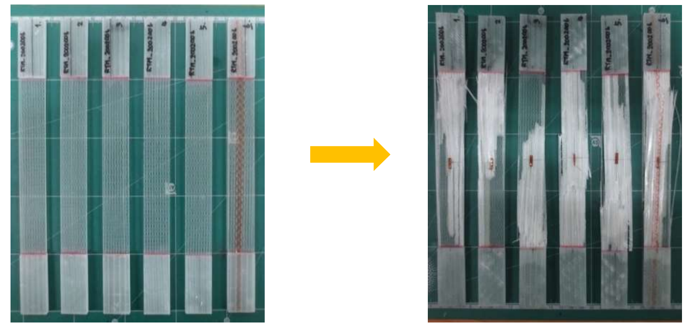
Fresh and Recovered Fabrics



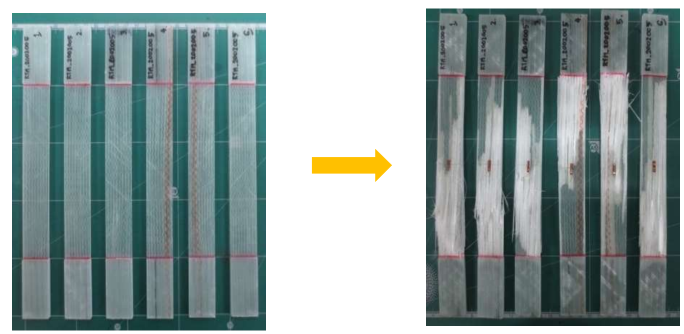


Nominal Reduction in strength and stiffness by 10%



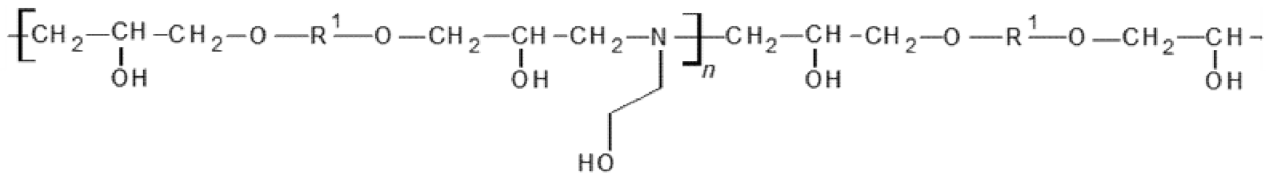


Composite Specimens from Fresh Fabrics (Before & After Test)



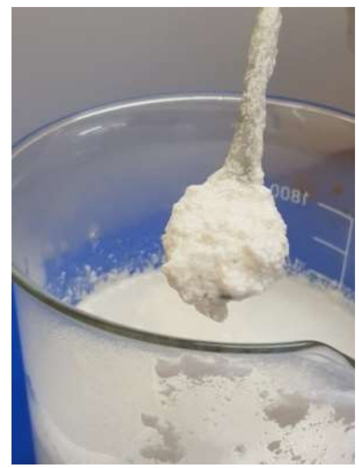
Composite Specimens from Recovered Fabrics (Before & After Test)

Characterization of Recovered Thermoplastic



Generic Structure of Hydroxy-Functional Phenoxy-ether Thermoplastic polymer

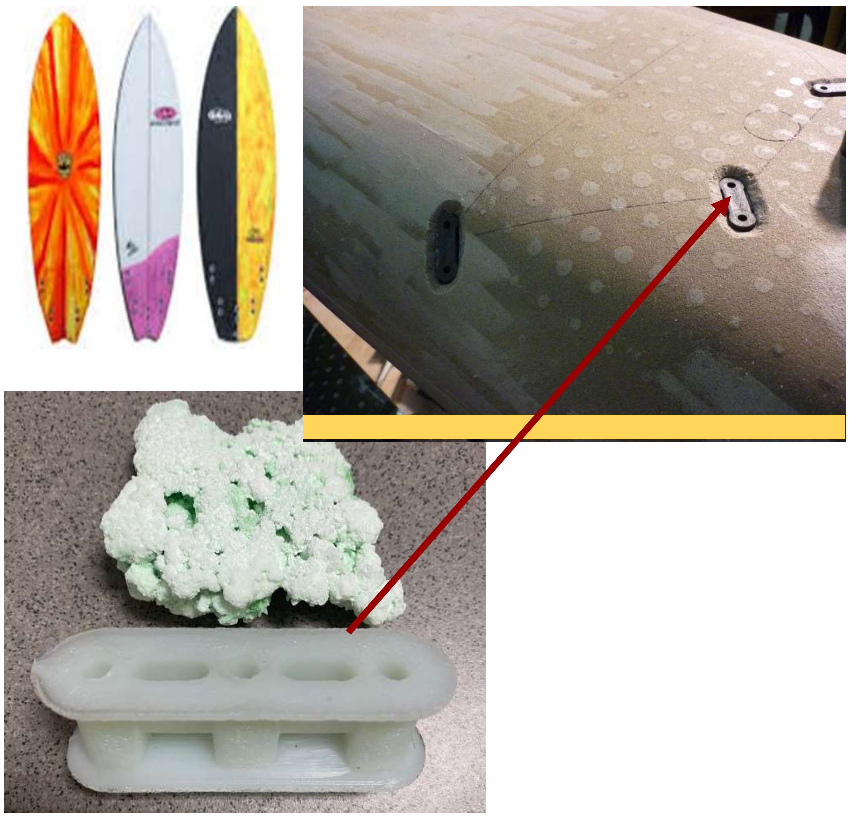
Recovered Thermoplastic	Test Method	Unit	Results (typical batch)
Melt Flow Index (190°C @ 2.16 kg)	ASTM D 1238	gm/minutes	10
Specific gravity	ASTM D 792	gm/cm^3	1.19
Glass Transition Temperature	ASTM D 3418	°C	78
Tensile Strength		MPa	51.2
Tensile Modulus	ASTM D 638	GPa	2.9
Elongation at break		%	30-110
Flexural Strength	ASTM D 790	MPa	100
Flexural Modulus		GPa	2.7



Recovered Thermoplastic

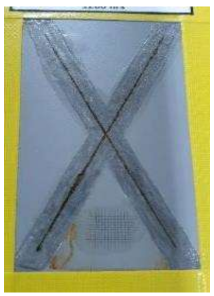
Re-Use of Recovered Thermoplastic

Foot Strap Insert in Surfboards



Heat Cured Metal Coatings

Property	Aluminum	Tin Plated Steel
Curing Schedule Temperature (˚C) / Time (min)	205˚C / 13 minutes	205˚C / 15 minutes
Coating Thickness / GSM	7 - 10	5 - 10
MEK Double Rubs	100 - 120	100 - 120
Wedge bend/ Flexibility (% Coating Unbroken)	50 - 80	50 - 80
Retort Resistance (Deionised Water) (123°C / 90 min)		
Cross-cut Adhesion After Testing, (% Coating Remaining)	95 - 100	90 - 100
Blush Rating (0 - 10, 0 - White, 10 Unchanged)	7 - 10	7 - 10
Coefficient Of Friction / Slip test (mm/min)	0.05 - 0.1	0.05 - 0.1

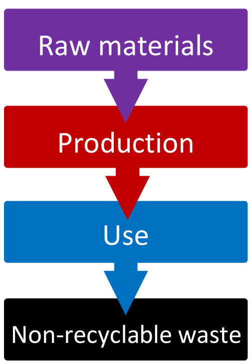


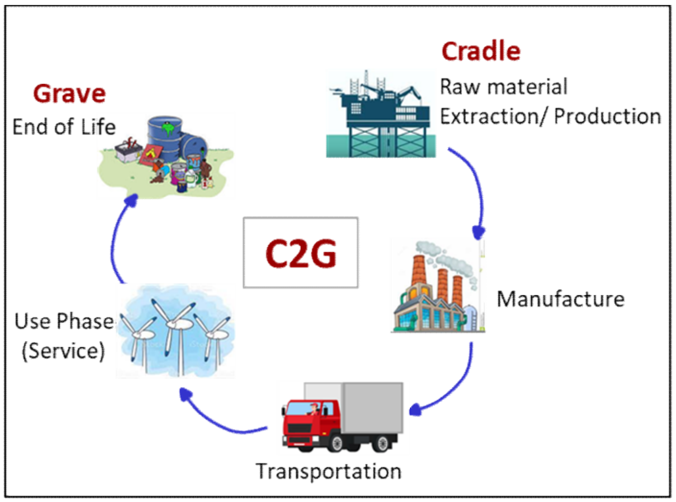
Circular Economy with Recyclable Epoxy Systems

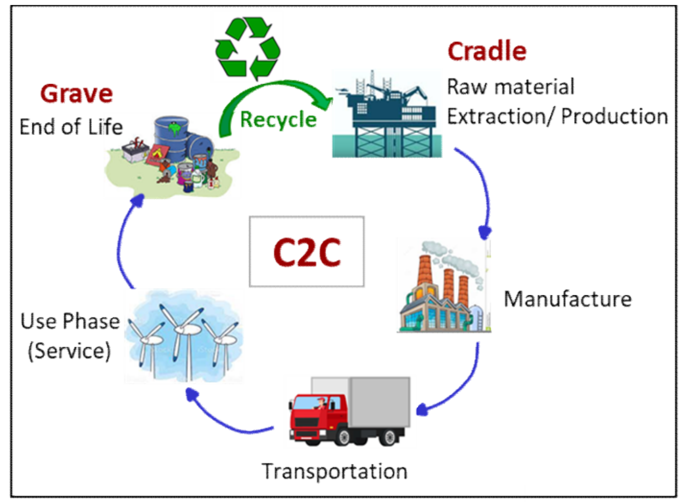
Cradle-To-Grave

Cradle-To-Cradle

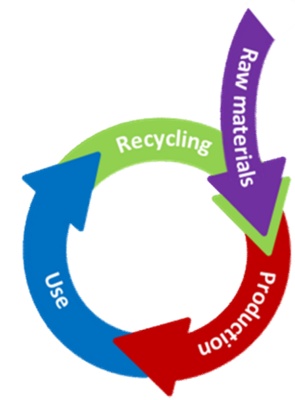
Linear Economy





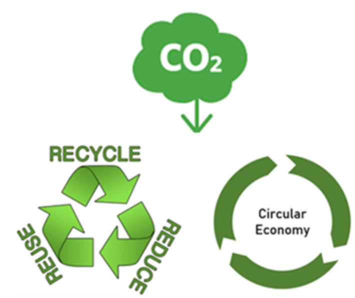


Circular Economy



Conventional
THERMOSETS

Bio-based Epoxy



Bio-based + Recyclable Epoxy

Industrial Applications of Recyclable Epoxy Systems

COBRA

JEC INNOVATION AWARDS WINNER 2020

Recyclable Fins and Molds
Cobra International, Thailand

Recyclable Composite Ski
G3,Canada

Recyclable Wind Turbine Blade
Siemens Gamesa, Denmark

JEC WORLD INNOVATION AWARDS WINNER 2022

POLITO SAILING TEAM

Recyclable Composite Racing Boat
Polito Sailing Team, Italy

Carbon/Aramid Hybrid Recyclable Kayak
NCC, UK

Thank you for the kind attention

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Summary

- **Aditya Birla** is a World Premier Epoxy Supplier with a broad & diverse Specialty Portfolio
- **Utilization of our integrated network strength** provides high value and sustainable specialties to solve Sherwin Williams growth targets
- **Innovative and sustainable product range:** Green LER, Bio-Source reactive diluents and Waterborne epoxy resins, along with systems for recyclable thermosets
- **Asset Foot Print in all Regions** provides supply chain and logistics solutions



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