Sustainability in the

For chemical-based industries, the ability to make environmentally sustainable changes in the long term requires sustainable profits and cash flow in the short term.

Paints and Coatings Industry: Far More than Just a "Good Idea"

By George R. Pilcher, The ChemQuest Group, Inc.

I would like to begin this article with a study in "perspective," an exercise that man alone, among all living creatures, is capable of undertaking. Working forward from the distant past:

- 240 years ago—The beginning of the Fossil Fuel Age: natural gas first used to light houses and streets
- 130-140 years ago—Coal burned to produce heat for homes; oil followed almost immediately
- 100 years from now—The currently anticipated depletion of proven oil and natural gas reserves
- 150 years from now—The currently anticipated depletion of proven coal reserves
- 180 years from now—End of the "Fossil Fuel Age" (Lasted ~420 years)

Human civilizations have actively occupied the Planet Earth for the past 6,000 years, and for 5,760 of those years, man depended upon wood and peat as sources of material to be burned for both heat and light. Only for the past 240 years have fossil fuels (e.g., coal; crude oil and its various derivatives; natural gas; and bitumen) played a significant role in civilized societies, and—in this short timespan—they have only played major, "front and center" roles in the generation of power for less than a century-and-a-half. Based upon the best currently available estimates, fossil fuels will be depleted within this same timeframe: the coming century-and-a-half. Roughly 400 years out of a total of 6,000 years of civilization. Think about this, and let this staggering fact sink in. . . .

Fossil fuels have, from the very beginning, been combusted principally as sources of heat, light, and energy, amounting to an 84.3% share of primary energy consumption in the world. NOTE: Non-fossil sources include nuclear (4.3%); hydroelectric (6.4%); and other renewables (5.0%, including geothermal, solar, tidal, wind, wood, and waste).[1] These numbers represent the 93% of fossil fuel consumption which is used for the generation of energy. What about the remaining 7% which accounts for the myriad "other uses" category, containing a vast number of chemicals routinely derived from fossil fuel feedstocks?[2]

Fossil fuels can be consumed, but not combusted, when they are used directly as construction materials, chemical feedstocks, lubricants, solvents, waxes, and other products. Common examples include petroleum products used in plastics, natural gas used in fertilizers, and coal tars used in skin treatment products. In 2017, about 13% of total petroleum products consumed were for non-combustion use. Natural gas non-combustion use accounted for about 3% of total natural gas, while non-combustible chemicals derived from coal represented less than 1% of coal use.[3] For all intents and purposes, the organic raw material requirements for the entire paint and coatings industry consist of "non-combusted" fossil fuels, which means that it isn't a large slice—less than 2% of all fossil fuel consumption. Nonetheless, as fossil fuels become scarcer, they are likely to be shifted from the "other uses" category to sustain energy production, so the need for industries like paint and coatings to convert to sustainable products and processes with be even more intense in the future. This is a sobering thought that receives great lip service throughout the global paint and coatings industry, but dismayingly little substantive action.

Much has been made of "green" chemistry for plastics, fuel, and paints and coatings. This makes eminently good sense, because petroleum-based chemistries will eventually require alternatives there is only so much oil in the ground, and no more. Replacing fossil fuels and fossil-based chemicals, however, cannot happen overnight, nor should it.

For chemical-based industries, the ability to make environmentally sustainable changes in the long term requires sustainable profits and cash flow in the short term. "Green" chemistry development continues, but to what degree does it affect the various segments of the coatings industry? These chemistries from novel, non-petroleum sources are often more expensive than their petroleum-based analogs.

With crude oil prices displaying frenetic behavior over the past 12 months, going from an historic low of -$37.64 per barrel on April 20, 2020 (unleashing a barrage of articles in news services globally, and causing oil stocks to drop) to $64.60 per barrel on March 17, 2021, with a likely average price for 2021f (forecast) of the mid-$50s per barrel, can these new chemistries make a sufficiently sizable entrée into the various coatings segments and regional markets for them to acquire and maintain a solid, commercially viable foothold? The COVID-19 pandemic set many dominoes tumbling into each other, and each domino that hits the ground has the potential to affect any number of economic forces that may put a damper on significant growth in biosourced material for paint and coatings, at least for the near-term future. The more important question, however, is "SHOULD relatively low average prices for crude put a damper on significant growth in biosourced material for paint and coatings?" In my view, the answer is a qualified "NO."

Why "qualified," and why "NO"? To address these two questions, it is necessary to begin defining the long-term issues that are currently, and indiscriminately, represented by "green," "sustainable," "biosourced," "recyclable," and a few other terms. Such terms have heretofore been used by some writers and advocates in limited, even specific, terms; in general, however, they tend to be used interchangeably, which dramatically dilutes both their meaning and their ability to address both change and the actions necessary to effect change.

The only term that covers both the products that we need to develop for the future, and the types of actions that we need to take to develop those products is: "sustainable." Sustainable raw materials; sustainable finished products; sustainable processes. The United Nations defines "sustainability" in a list of 17 goals[3], all of which are ultimately dependent upon each other; some, such as "No Poverty," "Zero Hunger," "Gender Equality," "Reduced Inequalities," and several others, are difficult to tie to steps that specialty chemical manufacturers and end-users will need to target as we move into the future. A few of those pillars, however, represent aspirational goals that should definitely inform the strategic planning process for specialty chemical industries, in general, and the paints and coatings industry, in particular. They are as follows:

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1. Clean Water and Sanitization
2. Affordable and Clean Energy
3. Industry Innovation and Infrastructure
4. Sustainable Cities and Communities
5. Responsible Consumption and Production
6. Climate Action
7. Life Below the Water
8. Life on Land

All of these sustainability issues have either direct or indirect relationships with fossil fuels, carbon dioxide and other greenhouse gases, volatile organic compounds (VOCs), biosourced materials, or any of the other issues that we tend to associate with the current products and processes that are dependent upon fossil fuels, and also with the replacement products and processes not based upon fossil fuels that will be required in the future, when the "Fossil Fuel Age" has run its course. Less easily intuited is the fact that all of these "pillars" are interrelated, although some of the connections are certainly more obvious than others.

Nonetheless, with the passage of time, the paint and coatings industry is extremely likely to play a direct and vital role in at least eight of the United Nations' 17 pillars. It is, therefore, time for it to begin changing from the very general usage of multiple terms to describe, in a very vague manner, issues that ultimately have to do with moving away from raw materials that are based upon fossil fuels; embracing energy sources that are not derived from fossil fuels; and developing processes that do not generate carbon dioxide or other greenhouse gases.

I would suggest that the term "sustainable," when used in the paint and coatings industry—and as used in this article—should incorporate at least the following elements, not necessarily in this order and not necessarily at the same time. These are elements of strategy, after all, and planning and implementing strategy takes both time and careful thought:

1. Raw materials derived from biosources
   a. **Food use/crop-based.** Examples would be corn and soybeans; sugar cane and sugar beets. These should, in general, be avoided, although some use may be unavoidable—e.g., sensible and productive use of seed oils such as soybean, coconut, corn, and rape seed are currently in use, and may need to be for the foreseeable future, at least to some degree.

      More interest should be focused on non-food oils, however, such as CNSL (cashew nutshell liquor), castor bean, Jatropha, karanja (Millettia pinnata), polanga, tamanu (Calophyllum inophyllum), neem, rubber tree seed, mahua oil and others.

      The same for both increasing and altering the focus on starches, currently derived from corn, wheat, rice and potatoes to starches derived from non-food sources, such as corn stover (stems, husks and leaves); cattails; bullrushes; wheat straw and others.
   b. **Non-food use.** The leading example is currently biomass from agricultural waste, but there are many other sources/potential sources, such as sawdust, bark and wood chips, garbage, et al.
   c. **Non-food, non-land use.** A good example being currently explored is the use of carbon dioxide as a starting material for making a variety of carbon based chemicals; this category should also cover water crops, such as algae and non-food plants from which oils, starches, sugars and biomass could be derived.
2. Less toxic raw materials
   a. Increasing use of waterborne paints and coatings, especially

if the amount of co-solvent/VOC coalescent/VOC plasticizer demand can be reduced to zero or near-zero (<10g/l).

b. Continual improvements in crosslinking reactions to eliminate isocyanates, aziridines, etc.

c. Reduction in use of pigments that contain heavy metals, and pigments that are known or suspected carcinogens, teratogens, and/or mutagens.

d. Replacement of catalysts, emulsifiers, etc., such as organotin compounds, APEO (alkylphenol ethoxylates), PFOA (perfluorooctanoic acid) and others that have been shown to have negative health and/or environmental effects.

e. 100% solids paint and coatings that require no VOC components, in both powder and liquid form.

3. Less energy-intensive processes, such as advances in compact processes in automotive.[4]

4. Products that can be either recycled into different articles of equal or greater value, or down-cycled following their effective use period—paints and coatings that will not interfere with converting the substrates to which they have been applied into other articles.

5. Waste reduction—Products that can be completely recycled; especially polymers that can be easily and economically "unzipped" so that their starting components can be reused in either the same—or different—polymers.

The is nothing wrong with keeping the terms "green" and "biosourced" to discuss one aspect of sustainability, which is raw materials derived from non-fossil fuel sources—but it should mean something, not just be a catch-all phrase used to "greenwash" a product or process. More to the point, "green" alone is only one approach to a paint and coatings industry that is producing sustainable products. There will need to be several synergistically matched approaches to lower energy usage, biodegradability, recyclability, and lower/no toxicity that will need to be built either into the products or employed to manufacture the products. If one looks at the situation in this manner, it just makes sense to begin thinking about, and planning for, paint and coatings products that are truly "sustainable," rather than merely "green."

CURRENT MACRO ECONOMIC FORCES: OIL DEMAND, PRODUCTION, AND THE STRENGTH OF THE U.S. DOLLAR

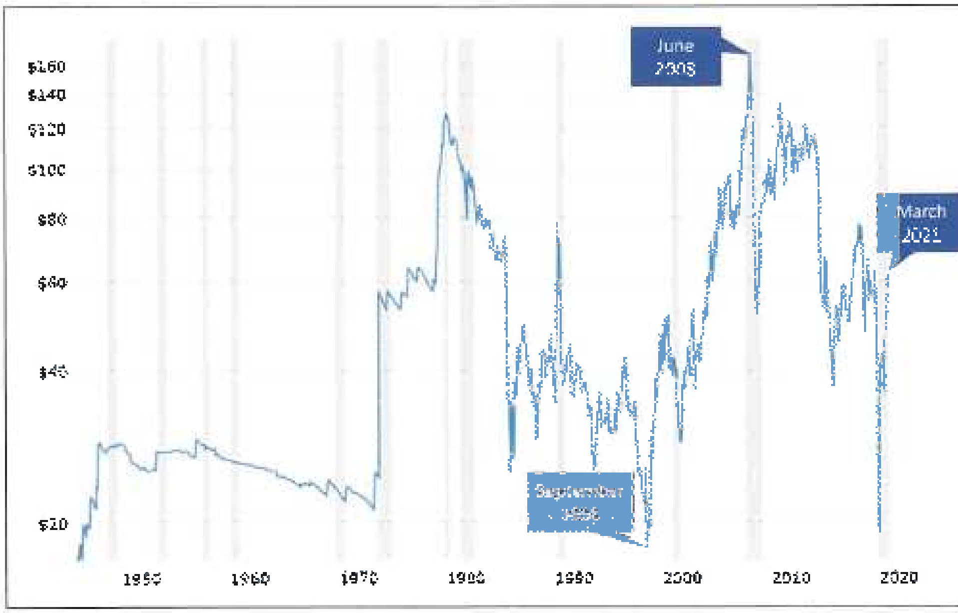
Taking a look at global macroeconomics, we project:

- Demand for crude oil in 2020 was 92.2 million barrels per day, a 9% decline from 2019.[5]
- Of signal importance to the global paint and coatings value chain, there is generally a 2–3% (occasionally as great as 5%) change in raw material costs for every $10/barrel change in the price of Brent Crude.
- U.S. supply of shale oil and alternative fuels such as ethanol has increased. In 2018, the United States became the largest global producer of oil and is currently a net *exporter* of oil. This is likely to remain the situation, at least for the near term.[6]
- Since the price of crude oil is denominated in U.S. dollars, and oil transactions are paid in U.S. dollars, oil pricing weakens as the U.S. dollar strengthens.
- With regard to petrochemical prices, it is difficult to look with any reasonable certainty beyond 2025 because:
  - Extraction technology is continuously improving, leading to lower production costs.
  - Actions taken by OPEC and/or measures taken by individual countries, such as Saudi Arabia and Russia, to either decrease or increase production, can have a profound effect on the price of crude.
  - Economic growth drives consumption, but many factors (such as COVID-19, recessions, et al.) cannot be accurately anticipated.
  - Cost of renewable energy is declining, but it is not possible to predict for how long the price decline will last, or at what point it will stabilize.

Since many coatings raw materials are derived from oil, their price is affected the cost of oil. *Figure 1* looks at a 70-year history, through March 2021, of the price of West Texas Intermediate.

Figure 1 also demonstrates that oil pricing shows "average pricing" in increments of about five years and

FIGURE 1—West Texas Intermediate Oil Price, 70-year History (shaded bars are recessions and other economic events—such as COVID-19—that have had a significant effect on oil pricing)



Source: MacroTrends.net[7]

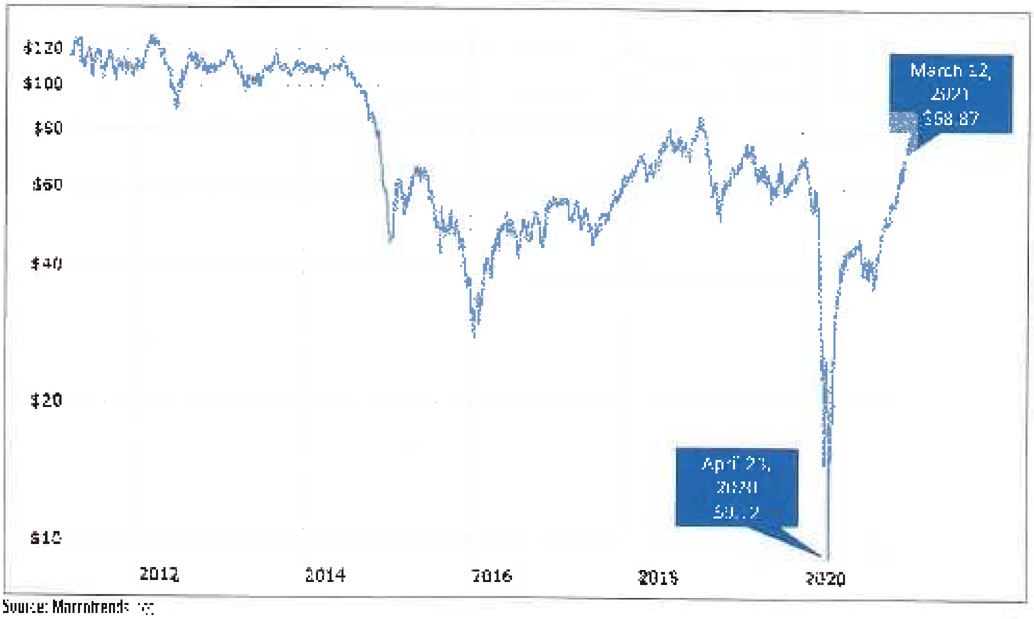
corresponds to global events like the Great Recession of 2008 and, most recently, the COVID-19 pandemic. Wild fluctuations date as far back as the 1940s and 1950s.

If we turn our attention to Brent Crude pricing, and looking at the recent history, one can see a similar shift in pricing in the aforementioned timeframes, as shown in *Figure 2*.

Although the precipitous drop that oil has experienced during the first quarter of 2020 is stunning, an early-March Brent Crude price forecast[16] places it at approximately $55 per barrel in December 2025, as shown in *Figure 3*.

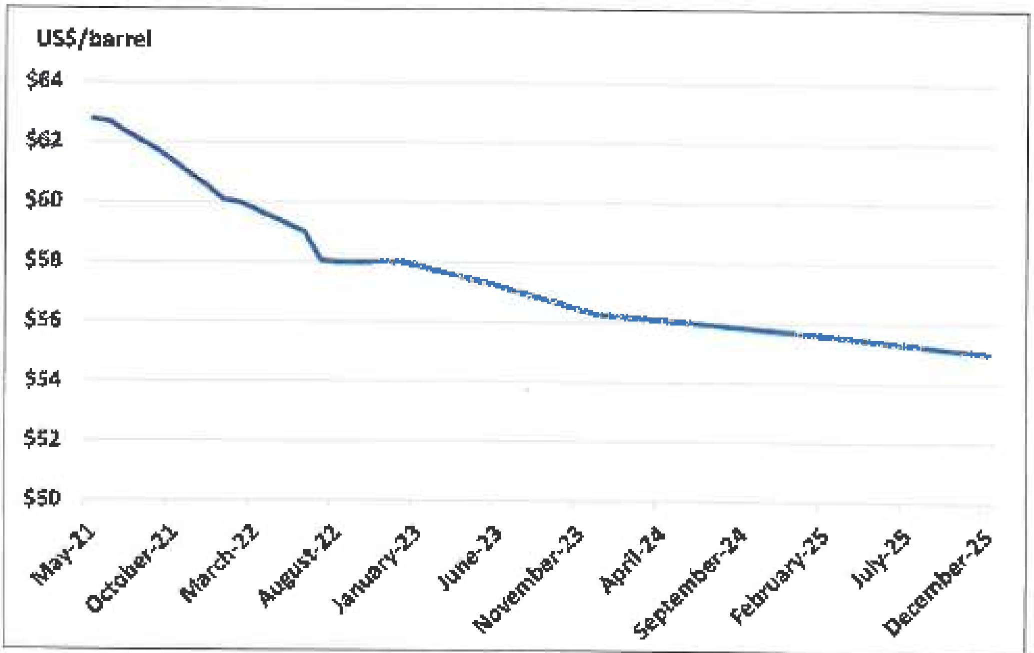
When all is said and done, paint and coatings are definitely affected by global and regional economic factors, especially when one or more of those factors, such as the price of crude oil, have a direct

FIGURE 2—Brent Crude Oil Prices, Past 10 Years, through March 2021



Source: Macrotrends.net

FIGURE 3—Brent Crude Price Forecast



Source: Ice.com[7]

effect on raw material costs. Nonetheless, the price and availability of crude oil are only two, albeit very important, factors in determining how the global and regional paint and coatings industry will perform at any given time. What effect the price of oil will have on biosourced materials, in general, cannot be known for certain, but it is reasonable to posit that the dynamics driving the use of biosourced materials are somewhat different than those driving the use of petrochemical-based analogs, including regulatory fiat, health and safety concerns, environmental issues, energy requirements, consumer preferences, et al. There is, therefore, no reason to believe that the price of crude oil will have any greater effect on interest in, and use of, more sustainable paints and coatings in the post-COVID world than it did in the pre-COVID world.

SUSTAINABLE CHEMISTRY: THE FUTURE?

Biosourced materials, are renewable on a routine basis each year, and are, therefore, sometimes referred to as "renewable chemistry," but really should be folded into the concept of "sustainable chemistry," because these materials will become an increasingly necessary component of future product analogs of raw materials and finished products that were once produced from fossil fuel components.

> ***There is, therefore, no reason to believe that the price of crude oil will have any greater effect on interest in, and use of, more sustainable paints and coatings in the post-COVID world than it did in the pre-COVID world.***

No matter the name, it is chemistry that converts living organic feedstock, through a variety of chemical processes, to produce useful chemicals that can serve as finished product components or as reactants to produce a broad range of specialty chemicals, including oligomers and polymers. *Table 1* offers an overview of some types of crops and feedstocks used to produce sustainable, biobased raw materials.

TABLE 1—Biosourced Materials: Origins and High-Level Considerations

MAIN FEEDSTOCKS	EXAMPLE CROPS	PRINCIPAL CHEMICAL PROCESSES	EXAMPLE USES	HIGH-LEVEL CONSIDERATIONS
OILS	• Soybean • Rapeseed • Palm • *Jatropha Curcas*	• Transesterification → Biodiesel • Catalysis → Olefins	• Biodiesel • Multiple Olefins	• Most Expensive • Transportable (Energy Dense) • Easily Refined • Storable
STARCHES	• Grains: Corn, Wheat, Rye, Millet, and Others • Tubers: Cassava, Potatoes	• Direct Fermentation • Enzymatic Pathways: Starch → Fermentable Sugars → Alcohols and Other Chemicals	• Ethanol • Butanol (4 isomers) • Other Fuels	• Moderately Expensive • Easily Transported & Stored • Easily Converted to Sugar • Food Crops
SUGARS	• Sugar Beets • Sweet Sorghum • Sugarcane	• Direct Fermentation • Catalysis (Alcohols → Other Chemicals)	• Ethanol • Butanol (4 Isomers) • Other Fuels • Polyethylene Terephthalate • Bio-isoprene • Succinic Acid • 1,4-butanediol • Many other chemicals	• Moderately Expensive • Direct Source of Fermentable Sugar • Processing Must Be Immediate
BIOMASS	• Biomass Sorghum • Bagasse • Perennial Grasses • Wastes and Residues • Short Rotation Woody Crops (SRWC—Poplar, Willow, et al.)	• Fermentation • Pyrolysis (Syngas → Methane; Bio-oil; Biochar) • Gasification (700 °C + O_2 → Syngas + Slag)	• Fuels • Many Chemicals	• Least Expensive • Low Bulk Density (Transport Limited) • Storable • Difficult Processing

Source: The ChemQuest Group, Inc.

If one considers *all* uses of biosourced chemistry, *Table 2* offers some insight into selected chemicals that currently appear to hold the greatest potential for large-scale future use, many of which hold potential for use in the area of paints and coatings; the biosourced materials from which they are being produced; the chemical pathways used to convert biomaterials into these chemicals; and for which applications these sustainably produced chemicals are either currently being used, or for which there appears to be significant potential for future use.

PAINTS AND COATINGS: OPPORTUNITIES FOR SUSTAINABLE CHEMISTRY

The breakdown on *all* components (from any source, petrochemical or biomaterials) used in paint and coatings production in the global coatings market in 2020 is illustrated in *Figure 4*.

In 2020 estimates (noted as 2020e), approximately 38.9 MMT of chemicals in the form of pigments, resins, solvents, and additives were used in the global production of paints and coatings. A large category (12.5 MMT) is comprised of pigments, and it is safe to say that inorganic pigments, such as titanium dioxide, fillers, and other inorganic-colored pigments can never be sourced from biomaterials, although it is possible that some may be made from sustainable sources, such as iron, which is indefinitely recyclable. Some organic pigments may be able to use sustainable precursor chemistry, but, as the graph shows, colored organic pigments represent only a small sliver (0.2 MMT) by volume, of total pigment consumption. Producers of these materials, however, constantly strive to reduce the energy needed to manufacture the pigments, minimize the waste, and maximize the yield. In this regard, pigment manufacturers are contributing to the overall sustainability of paints and coatings.

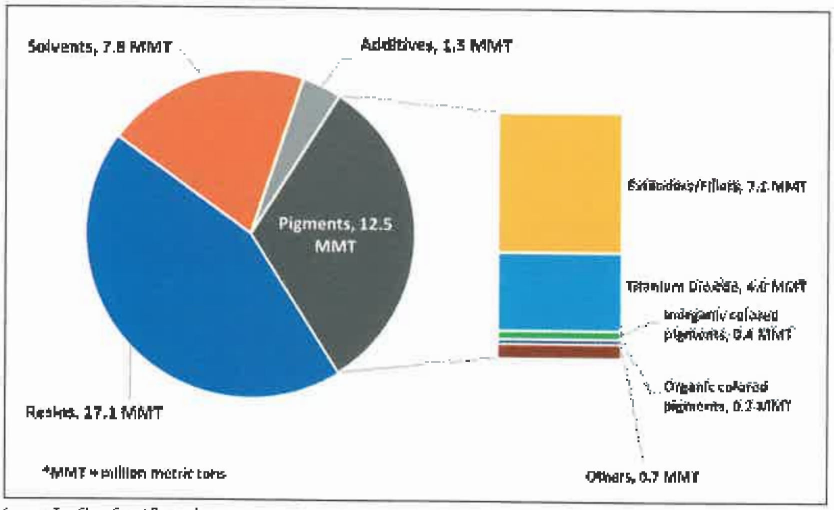
SUSTAINABLE SOLVENTS

Although pigments may not present the most significant opportunity for use in sustainable products, organic solvents used in paints and coatings do. As a portion of all raw materials used in coatings, the solvent category is large, and appears to offer quite a few opportunities for biobased, sustainable products. Since the paint and coatings industry represents, on a global basis, the largest usage category for solvents, this is a natural area in which to concentrate research, both for raw material suppliers and paint and coatings formulators (*Figure 5*).

While the growth in solvent usage in coatings is only about 1-2% compound annual growth rate (CAGR), sustainable solvents growth in coatings shows a faster growth rate—approximately 6-7% CAGR.

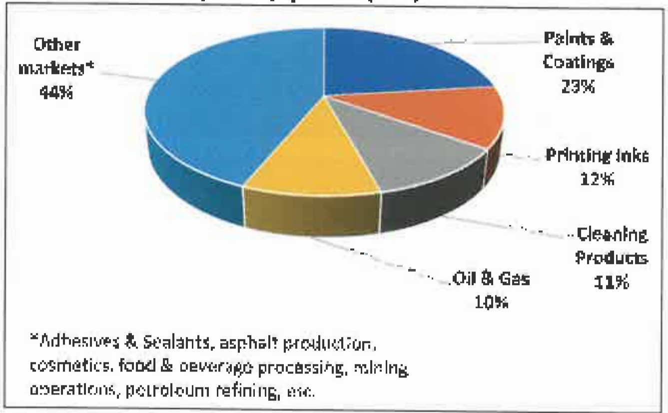
In 2020e, the worldwide market for biobased solvents used in all applications (e.g., inks; coatings; adhesives; household, industrial and institutional cleaners (HI&I); and others) is estimated by ChemQuest to be $5 billion–$6 billion, and the global solvent market for all solvents is estimated to be $35 billion–$40 billion. While the growth in solvent usage in coatings is only about 1-2% compound annual growth rate (CAGR), sustainable solvents growth in coatings shows a faster growth rate—approximately 6-7% CAGR—as they make headway in

FIGURE 4—Global Paint and Coatings Industry, by Component (Volume), 2020e, 38.9 MMT* (does not include 23.6 MMT water)



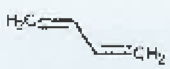
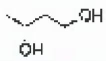
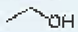
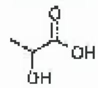
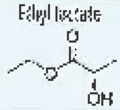
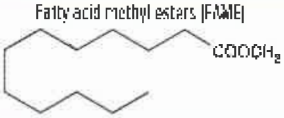
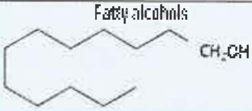
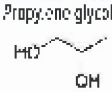
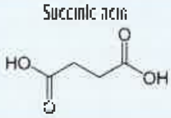
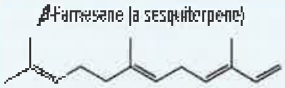
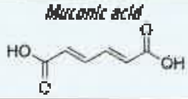
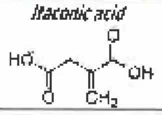
Source: The ChemQuest Group, Inc.

FIGURE 5—Solvent Use by Market, by Volume (2019)



Source: The ChemQuest Group, Inc., estimates

TABLE 2—Selected Biosourced Chemicals That Currently Hold Promise for Significant Future Use

SUSTAINABLE CHEMICAL	USE	SUSTAINABLE CHEMISTRY PATHWAY
Furfural 	Starting component to produce other biobased compounds. Possible furfural to distillate fuel pathway for drop-in replacement for petroleum-derived distillate fuels (jet and diesel)	Dehydration of xylose, a monosaccharide often found in large quantities in the hemicellulose fraction of lignocellulosic biomass
1,3-Butadiene 	Polybutadiene and styrene butadiene rubbers: used in the production of tires for passenger cars and light-duty vehicles	Convert furfural (above) to tetrahydrofuran, and then via pyrolysis to 1,3-butadiene
1,4-Butanediol 	Building block for the production of polymers, solvents, and specialty chemicals	Fermentation of sugars (e.g., beetroot) and cellulosic (e.g., crop and wood residue) feedstocks
Ethanol 	Gasoline blend, solvent	Fermentation of sugars
Lactic acid 	Food, pharmaceuticals, personal care products, industrial uses, and polymers; precursor for polylactic acid for use in food packaging, disposable tableware, shrink wrap, 3-D printers	Microbial fermentation of carbohydrates
Ethyl lactate 	Industrial solvent	Esterification of ethanol and lactic acid
Fatty acid methyl esters (FAME) 	Biodiesel, industrial solvents	Transesterification of fatty acids from vegetable oil with methanol, under alkaline conditions
Fatty alcohols 	Anionic and non-ionic surfactants for household cleaners, personal care products, and industrial applications	Hydrogenation of FAME
Glycerol 	Biodiesel and soap production; humectant (hygroscopic substance) in food and personal care products	Biproduct of biodiesel production
1,3-Propanediol 	Polymers, personal care products, solvents, and lubricants production	Fermentation of glycerol
Propylene glycol 	Various consumer products (antiperspirants, suntan lotions, eye drops, food flavorings, etc.); used in the production of unsaturated polyester resins for marine vessels, passenger vehicles, and consumer appliances; as an engine coolant and as airplane and runway deicer	Hydrogenolysis of glycerol over mixed-metal catalysts, or hydrocracking of sorbitol
Succinic acid 	Starting compound for specialty chemicals, polymers, surfactants, and solvents; possible starting component for polycyclic pigments	Fermentation of corn, wheat, cassava, rice, sugarcane, sugar beets, and forest waste
Para xylene 	Starting compound in production of terephthalic acid (TA) and dimethyl terephthalate (DMT); both are raw materials used to produce polyethylene terephthalate (PET) bottles. Also used as solvent, and for gasoline blending	Pyrolysis or fermentation of biomass
β-Farnesene (a sesquiterpene) 	Conjugated diene structure lends itself to possible butadiene and isoprene; polymerization chemistries include anionic, radical, coordination, and cationic polymerization	Fermentation of sugars by yeast
FDCA 	Renewable building block as a possible substitute for terephthalic acid (PTA); possible diacid for polyester resins	Biocatalytic conversion of hydroxymethylfurfural, itself formed by the dehydration of certain sugars
Muconic acid 	Possible precursor to bio adipic acid, possible diacid for polyester resins	Biological conversion of sugars and lignin
Itaconic acid 	Diacid for possible use in polyester resins; UV-cure polymers could take advantage of the vinyl group	Fermentation of carbohydrates

Source: The ChemQuest Group, Inc.

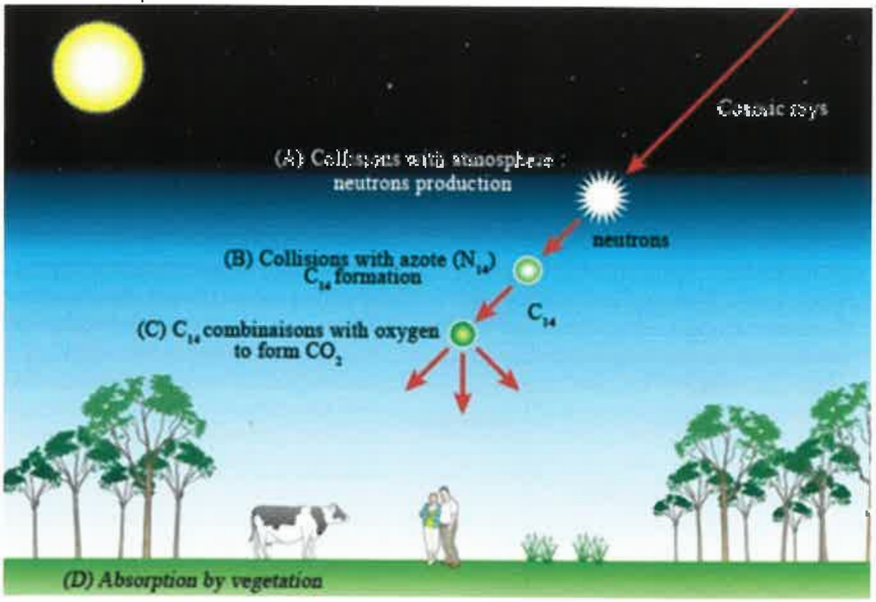
replacing some petroleum-based, conventional solvents. Growth will certainly continue into the foreseeable future, albeit at a lower rate, given the environmental and regulatory pressure on the use of solvents, regardless of source, and a desire to reduce the dependence on petrochemical solvents in the major paint-producing global regions—North America, Europe, and Asia-Pacific.

Sustainable solvents can include a variety of products, such as biobased ethanol from corn, and methyl soyate from soybean oil. Bioethanol is used largely as a blend with gasoline but can be used in many coatings formulations to replace petrochemical-derived ethanol. Methyl soyate is produced by transesterification of soya fatty acid with methanol. Methyl soyate is the principal component of biodiesel fuel and has the potential for use as a solvent in certain types of paints and coatings. Fatty acid methyl esters (FAME), generally referred to as "green solvents" that are analogous to methyl soyate, are biodegradable and may not be considered to be VOCs, depending upon usage and the regulatory environment in which they are being used.

Ethyl lactate is another "green solvent," as long as it is produced from the esterification of bioethanol and biolactic acid that is gaining traction as a replacement for a variety of commonly used oxygenated petrochemical-derived solvents. Lactate ester solvents can be used in many industrial coatings.

Ethyl acetate, *n*-butanol, and acetone, though normally sourced from petrochemical stocks, can be produced through fermentation of sugars from renewable feedstocks. These solvents are selectively used in paints, coatings, and inks. Usage is not substantial, however, partly as a result of price and partly as a result of the fact that "partially" sustainable does not appear to resonate in a significant manner with end-users. This is a shame, because the road between "petrochemical-based paints and coatings" and "sustainable paints and coatings" is likely to be paved with "partially sustainable paints and coatings" as progress is made over time. One potential marketing solution to this issue is to determine the actual percentage of biomaterial that is used in any given paint and coatings product and/or line of products, by assessing the ratio of Carbon 14 to Carbon 12, using ASTM D6866,

FIGURE 6—Atmospheric Carbon Dioxide



Source: Radioactivity.eu.com[14]

which indicates how much of the total formulation is from sustainable, biobased components. This has the potential to be an important marketing tool, if employed in the right way. (See discussion later in this article for details.)

Derived from citrus rinds, *d*-Limonene is a sustainable solvent now commonly used in cleaning products for both industrial and household applications and certainly has the potential to be used as an aliphatic solvent in alkyds, and perhaps other coatings systems.

Although North America was an early adopter of sustainable solvents (30% share in the worldwide "green" solvent market in 2014"), all global regions are considering—or are already using—green/sustainable solvents. Nonetheless, petroleum-based solvents are low-cost, readily available, with a well-established infrastructure, and provide a low carbon footprint as a result of process efficiency, all of which offer significant headwinds for green/sustainable solvents with their associated feedstock costs and more complex manufacturing processes. These, in turn, affect the cost of these sustainable materials. Manufacturers of sustainable solvent chemistry, however, continue their research into ways to make these solvents more commercially available and economically viable.

SUSTAINABLE RESINS

Another way for green chemistry to enter the paint and coatings business is through the production of biobased monomers that are used to make important polymers for paints and coatings. Before discussing these monomers, it is important to remind ourselves that a type of "sustainable" resin has been used for several centuries, even though its imminent demise has been predicted for the past six decades: alkyd resin chemistry.

Alkyd resins, both traditional solventborne (S/B) and new waterborne (W/B) versions that have been slowly introduced over the past 50 years or so, continue to stymie those who cannot imagine why they are still around. Part of the reason is that emerging economies need good, solid, proven coatings that are easily manufactured, with both protective and decorative potential, ease of application and affordability. Alkyds also typically contain a certain percentage of biobased content, from plant oils, that gives them "green/sustainable" content. Even in more developed regions of the world, countries such as China still use alkyds in significant quantities—as much as 18% of all paints and coatings produced in China and Southeast Asia are based on alkyd platforms. In the United States, this number is much smaller (3-4%), but it is stable, and the actual volume of alkyd resins, paints and coatings is increasing at very close to the same pace as the overall paint and coatings market.

Because alkyds typically contain significant amounts of biobased content from seed oils, they have an automatic head start within the context of "paints and coatings," and increased use of alkyds is being encouraged by work in both resin and coatings laboratories, such as OPC Polymers in Columbus, Ohio; at universities and research institutes, such as the University of Akron's Polymer Engineering Department, chaired by Professor Mark D. Soucek, Ph.D., North Dakota State University, and the University of Southern Mississippi; and at independent, third party research institutes, such as the ChemQuest Technology Institute, in South Boston, VA, led by Douglas Corrigan, Ph.D., vice president. There is, currently, significant interest in the potential for waterborne alkyd dispersions that can be produced without resort to high levels of surfactants. That said, there is a great deal of potential growth in the use of any resins based wholly or in part on bio-derived monomers, but—despite a certain amount of proactive work be done by forward-looking companies on sustainable epoxies, polyesters, polyhydric alcohols, polybasic acids, et al.—the work necessary to do this is largely ahead of us, not behind us.

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The U.S. Department of Agriculture (USDA) created a program called "BioPreferred" to stimulate investment and production of renewable feedstocks to create biobased raw materials. Federal law, the Federal Acquisition Regulation, and Presidential Executive Orders direct that all federal agencies purchase biobased products in categories identified by the USDA. To date, USDA has identified 139 categories (e.g., cleaners, carpet, lubricants, paints, et al.) of biobased products for which agencies and their contractors have purchasing requirements. Each mandatory purchasing category specifies the minimum biobased content for products within the category.

FIGURE 7—Evolving Interest in Biobased Materials

Sources: The ChemQuest Group, Inc.; European Coatings Journal[1]

Products participating in the voluntary labeling initiative have their biobased content measured using ASTM D6866 as part of the certification process.

One presumes, without knowing for certain, that the "minimum biobased content" required in products subject to the "BioPreferred" guidelines will be certified by the manufacturers. Lest any vendors should attempt any slight-of-hand subterfuge, however, the biobased content of a coating can be determined using carbon dating. This method measures and compares the ratio of Carbon 14 (^{14}C) to Carbon 12 (^{12}C) in the coating. ^{14}C forms in our atmosphere as cosmic rays interact with nitrogen (^{14}N). The percentage of biobased material is simply the ratio of ^{14}C (i.e., new carbon, from biosources), divided by total carbon (i.e., new carbon plus "old" carbon, from petroleum). *Figure 6* describes the source of ^{14}C.

Approximately 99% of atmospheric CO_2 is based on ^{12}C; the other 1% of CO_2 is based on ^{14}C. The half-life of ^{14}C is 5,700 years, which means that after $^{14}CO_2$ is formed and after 5,700 years, ½ of the ^{14}C decays to ^{12}C; after another 5,700 years, ½ of the remaining ^{14}C decays to ^{12}C. Since crude oil, natural gas, shale oil, bitumen, and other fossil fuel feedstocks were formed about 100 million years ago, their carbon content is 100% ^{12}C. Living plants, and animals that eat those plants, are constantly ingesting CO_2 (99% $^{12}CO_2$ and 1% $^{14}CO_2$). Using sensitive radiometric techniques (see ASTM D6866-20 "Standard Test Methods for Determining the Biobased Content of Solid, Liquid, and Gaseous Samples Using Radiocarbon Analysis"), it is possible to quantify how much ^{14}C and ^{12}C is in the coating, and this ratio can be used to conform to a sustainable chemistry specification for biobased content.

In the USDA BioPreferred program, and using the USDA link to Product Categories[1], one can see that the U.S. federal government is required to purchase:

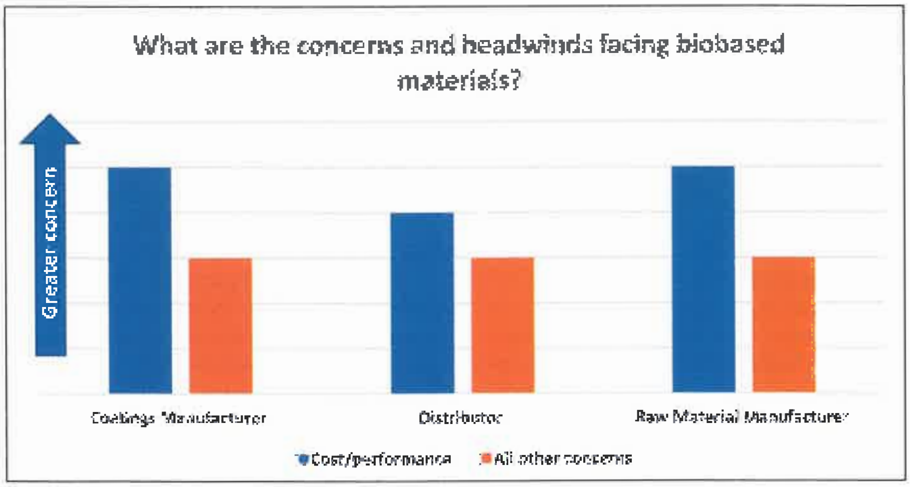
- Exterior paint and coatings with a biobased content of 83%
- Solventborne interior paints and coatings with a biobased content of 67%
- Waterborne interior paints and coatings with a biobased content of 20%
- Traffic and zone-marking paints with a biobased content of 30%

That's the U.S. federal government. What about the industrial sector? Beyond the "greenwashing" that is omnipresent in the global paint and coatings market, one wonders what suppliers, distributors, and formulators actually think about biobased materials. In a survey of 160 coatings experts, the *European Coatings Journal* (*ECJ*) confirmed some interesting trends. In *Figure 7*, there is a clear indication that interest in biobased materials is growing.

Having an interest in a new raw material is one thing; using a material in commercial applications is quite another thing. Respondents in the *ECJ* survey, however, offered insights into headwinds facing biobased raw materials, shown in *Figure 8*. It should come as no surprise that the cost/performance concern was the greatest. All other concerns carried more or less the same weight and were grouped together as "All Other Concerns."

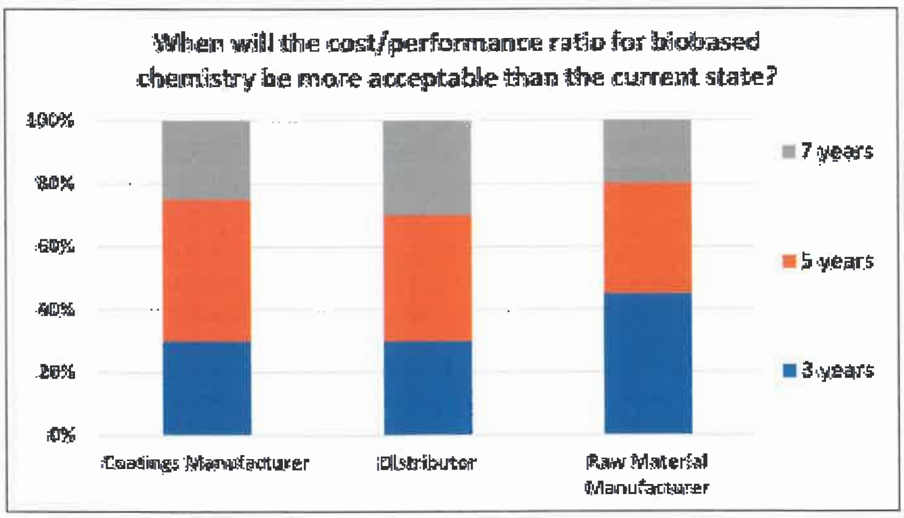
The most intriguing aspect of this survey is the time horizon before the respondents felt that biobased materials would be positioned as an important aspect of the global paints and coatings market space. Most respondents felt these materials were three–five years away, but a not insignificant number of respondents placed the timeframe at seven years out.

FIGURE 8—Headwinds Affecting Biobased Materials



Sources: The ChemQuest Group, Inc.; European Coatings Journal[7]

FIGURE 9—Cost/Performance Considerations for Biobased Chemistry



Sources: The ChemQuest Group, Inc.; European Coatings Journal[7]

BEYOND THE "BIO BUZZ"

The results of the *European Coatings Journal* article support "Anderson's Axiom," first promulgated in 2010 by Susan M. Anderson, prominent coatings and adhesives industry observer and specialty chemicals management consultant, and director, The ChemQuest Group, Inc., to wit:

> *Perhaps 5–8% of individual consumers will pay a ≥5% premium for "green" paint. ("Sustainability" is not yet a concept fixed in the average consumer's vocabulary.) In the world of industrial coatings, however, you are unlikely to be able to command a premium for products that are "green," "sustainable," "biosourced," are better for the environment, made with less energy, or produced with a lower carbon footprint. You are, however, more likely to achieve a "more favored status" by selling such products at competitive pricing and realizing a greater share of any given customer's business, as a result.*

There is greater interest in biobased materials, but it needs to be expanded into an interest in "sustainable products and processes," because that is what the future will require as we approach the end of the fossil fuel age.

There is greater interest in biobased materials, but it needs to be expanded into an interest in "sustainable products and processes," because that is what the future will require as we approach the end of the fossil fuel age. Currently, things really come down to a common hurdle that all new raw material producers face in the paints and coatings arena and that paint and coatings producers face, in turn, in their end-use customers: a cost/performance ratio. If a new material is more expensive, it must provide one or more positive attributes that justify the higher price. One of these attributes might very well be "sustainability," which will satisfy a variety of national and local regulatory mandates and be of compelling interest to a certain percentage of both businesses and consumers for whom "sustainability" adds value to a product and justifies its value-added pricing. For the majority of users of paints and coatings, however, the tipping point where "value-added" pricing of sustainable products meets the "cost/performance" requirements of the industry is going to occur a minimum of five–seven years into the future, and there are no guarantees that they will meet all criteria implied by the term "sustainable."

Currently, the percentage of businesses and consumers with a serious interest in manufacturing and marketing sustainable products and articles is quite low, but over time it must increase, and it *will* increase, as long as every participant in the value chain does its part to engineer more sustainable raw materials, for use in more sustainable products, for more sustainable end uses, all of which can be recycled at some point, so that we can arrive at a truly global circular economy. It's not a question of "if," but rather of "when." We could easily be looking 20 or more years down the road for this to happen, but 20 years will go by in the twinkling of an eye, so the time to start replacing fossil fuel components with sustainable, biosourced, and other renewable/recyclable components is NOW. ❖

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