Recycling of Plastic Waste Using Supercritical Alkanes and Alkenes (SCA)

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Problem Statement: Plastics waste (PW) is a ubiquitous byproduct of modern society. Plastics are responsible for about 20 wt. % of landfill materials with only about 10% of plastics being recycled (30% for some sectors such as HDPE bottles in the absence of pigments). Many plastics such as multilayer flexible films are largely seen as non-recyclable, difficult to collect and difficult to separate from mixed waste streams. For these reasons, plastics are a bottleneck to a circular economy. 80% of the plastics waste stream is composed of polyethylene (PE) and isotactic polypropylene (iPP) according to the UKs REFLEX project. [1] Current efforts at depolymerization to monomer are hindered by additives and contaminants like about 5% talc and calcium carbonate, 2% PET from labels, 2% polystyrene, adhesives, food waste, bound paper, halogenated polyolefins, organic pigments and resins, antioxidants, anti-slip agents, carbon black as well as inorganic materials such as titania, and silica. [2,3] Multi-layer films are bound by tie-layers such as ethyl vinyl acetate. At a minimum, recycling processes must separate the PE and iPP components to their nascent form by separation of food contamination and additives, especially pigments and fillers and non-polyolefins (PO), for reuse in new plastics manufacture, depolymerization processes, and value-added streams such as Knudsen (nanoporous) super-insulation materials. It is proposed that this separation can be achieve using supercritical alkanes and alkenes (SCA) in a process that results in completely recycled solvent and complete separation of additives, food contamination and non-polyolefin polymers. SCA processing of POs was first published in the 1960s by Monsanto [4-7] and further developed in the 1990s [8-11]. P&G patented the SCA process in 2019. [8] Similar processes were published in 2005 and 2010 [9,10] for fractionation of branched POs and for demixing of polystyrene from HDPE.

The SCA process requires extremely high pressure (600 atm) and temperature (120°C) [6,7] but much less severe conditions than the commercial high-pressure continuous synthesis of LDPE, globally >30 million metric tons (66 billion lb)/year produced at 1000-3000 atm and > 200°C at a cost of ~$0.60/lb. The SCA process has been partly commercialized by a startup, PureCycle, which is a P&G spinoff company. Compared with alternatives for PO recycling such as depolymerization to monomer, conversion to fuels, up-cycling to value added polymers, and energy generating incineration, the SCA process has several advantages. The process is close to existing large-scale processes in the polyolefin industry, the supercritical solvent, propane, can be completely recycled in the process, supercritical fluids have very low viscosity so separation of insoluble components by high pressure filtration, decanting, settling and screening is simple, variation in pressure and temperature can be used to separate grades of POs and additives in the same process, the resulting PO aerogels may have value-added use as super-insulating, Knudsen-thermal transport materials. However, implementation of the SCA process requires adaptation of the plastics industry including understanding the phase behavior of the wide variety of commercial polyolefins, pigments, and other additives and containments found in the recycle stream.

Team Composition: The PI, Greg Beaucage, has previously worked with supercritical fluids for production of silica aerogels and for supercritical drying of polymers. [11-16] He has also worked with Paul Ehrlich on supercritically crystallized iPP using supercritical propane. [11]

Paul was the first to publish on supercritical alkane and alkene solvents for polyolefins in the 1960s. [4-6,17,18]

The development and deployment of SCA process must involve close interaction with the value chain, regulatory agencies and academics so that the process can be made commercially viable with necessary financial incentives that can only stem from regulation in the PO commodity market. The work must involve participants directly involved in the recycle stream and those in the plastics, pigments and additives industry. IP may exist in determining the most viable candidates for the SCA process among pigments, processing aids, fillers, grades of POs and targeted processing stages and conditions. The value of this IP will be largely determined by regulatory incentives. The low market cost of pristine POs (~ \$0.80/lb) and the small profit margin (~ \$0.20/lb) leaves little commercial motive for lower-grade recycled materials. As an estimate of the SPA cost, the comparable high-pressure synthesis process cost for LDPE (cost of monomer to polymer) is about \$0.30/lb. Collection and separation of recycle streams could more than double this cost making lower-grade recycled POs on par with petrochemically produced pristine POs. With cost parity there is no incentive for capital investment in the new SCA process in the absence of regulatory requirements. For this reason, a research project in the SCA arena will require a comprehensive approach working with the regulatory agency, polyolefin producers, additive manufacturers, and other stakeholders in the recycle stream, Table 1.

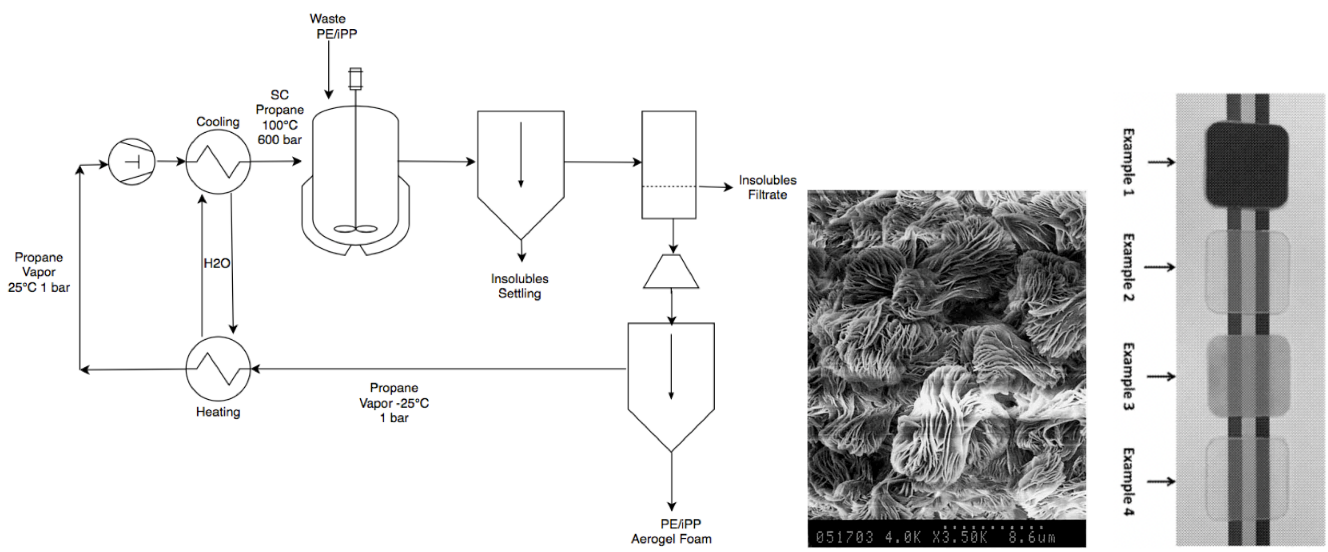
Table 1. Participants in SCA project (from DOE concept paper, most local to Cincinnati).

Partner	Interest	Capability	Proposed Contribution for DOE Concept Paper	Contact
LyondellBasell	Largest producer of polyethylene	PE/iPP synthetic capability, Full polymer processng pilot plant	1 FTE, Facilities, Cost Share	Harry Mavridis, Director of Research
Sun Chemical	Large producer of PO additives	Capability to provide design and selection of additives appropriate for the SCA process	1 FTE, Facilities, Cost Share	Russell Schwartz, Vice President for Research and Devleopment
Procter & Gamble	Consumer products corporation with large footprint in PO	Expertise in polymer processing for FP	1 FTE, Facilities, Cost Share	Paula Ray, Vice President for Research and Development
Avient (PolyOne)	Largest Manufacturer of Polymer Additive Concentrates	Large Processing Lab and Capabilities for Modification of Formulations to Adapt to SCA Process	1 FTE, Facilities, Cost Share	Amit Kulkarni, Director of Research and Development
Rumpke Recycling	Regional recycling center for Southwestern Ohio, South Eastern Indiana and Northern Kentucky	Can provide feedstock materials and suggestions on process improvement	Materials and Process Development for Feedstock and marketing of product, Cost Share	Steve Sargent, Director of Business Development
Cincinnati EPA Research Center	Regulatory aspects of PO recycling	Regional Center for Regualtory Oversight of Plastics Recycling	Participation in Project, 0.2 FTE, Facilities, Cost Share	E. Sahle-Demessie, Ph.D. Sr. Chemical Engineer
Universtiy of Cincinnati	Expertise in polyolefin processing and in supercritical fluid processing	Experience in Managing Large Projects and in Organizing Industrial Consortia, Wet Chemistry Labs, Polymer Characterization	PI 0.1 FTE, 1 FTE Post Doc, 1 FTE Graduate Student, 4 Undergraduate Researchers	Greg Beaucage, Professor of Chemical Engineering and Materials Engineering

This proposal is based on a DOE concept paper from the Fall 2021 for which a multi-sector team was assembled, Table 1. The DOE concept paper was not encouraged because UC lacked sufficient preliminary work which this proposal addresses. Lacking in the concept paper was lab-scale SCA equipment capable of screening polymers and additives, and identification of conditions for pilot plant investigation. This proposal seeks to develop this infrastructure and a track record of collaborative work to support a much larger industry, DOE, DOD, or NSF funded effort to develop IP in this arena. In support of this effort Sun Chemical has offered support for a graduate student to work on this project targeting identification of organic pigments compatible with the SCA process. LyondellBasell is partly supporting a student who would contribute to this project.

Discussions on support from P&G have also been made. The EPA can provide support for the development of regulations that could encourage use of SCAs. Rumpke recycling has agreed to closely work in the development of this approach making it amenable to their existing waste streams. Avient has also agreed to provide materials and support for the project.

The SCA Process: Paul Ehrlich and coworkers at Monsanto in the 1960's explored the use of supercritical olefins and alkanes as solvents for polyolefins. They showed that iPP and PE displayed good solubility in supercritical propane at reasonable temperatures and pressures (600 bar and 120°C) compared to existing polyolefin processing for LDPE (1000-2000 bar and >200°C). [4-6,17,18] Ehrlich later studied the crystallization behavior of these polyolefins under supercritical conditions, Figure 1b. [6,17,18] More recently, Folie et al. have studied crystallization in propylene for analytic separation of branch fractions. [7] Ehrlich mapped out the phase behavior [6,7] and viscosity [5] of iPP and PE in supercritical propane up to 10 % polymer. It was demonstrated that PE and iPP could be completely solvated in supercritical propane at below degradation conditions and that an aerogel nano-foam could be produced from the crystallized polymer on removal of the supercritical solvent by pressure reduction. PureCycle broadly patented a process for SCA [8] which served as the basis for commercialization. A pilot plant was constructed in 2019 and the company was listed on the NASDAQ exchange. While the downstream process has been protected, the upstream materials specifications are available for discovery. This may be the most lucrative area since profits in the downstream sector will heavily rely on regulatory mandates. Upstream production of compatible POs and additives tuned to perform in a complete recycling stream could be decisive to their commercial markets.



(a) (b) (c)

Figure 1. *a) Process schematic for separation of additives and fillers from PE/iPP waste plastic using supercritical propane. b) PE aerogel crystallized from supercritical propane. [17] c) Demonstration of separation of pigment from HDPE using the SCA process. [8]*

It is proposed to use the Erhlich method to solvate waste plastics using supercritical propane. Figure 1(a) shows a schematic of a possible process involving compression of propane to 600 bar and 120°C. Settling, decanting and filtration of the solution will be conducted using commercially available processing equipment. Expansion of the propane solution will result in a PE/iPP aerogel that is essentially pure polyolefin suitable for pelletization or other value-added uses such as Knudsen nanoporous super-insulation materials. [15] The recovered propane gas is essentially pure. It is recompressed for reuse in the separation process. Supercritical solvents have extensively tunable miscibility through manipulation of the pressure and temperature. It is possible that further separation of iPP, PE, copolymers, and other polymeric components could be achieved such as separation of different branch fraction PEs. [7]

Timeline/Outcomes: The project activities and outcomes are given in Tables 2 and 3.

Table 2. Breakdown of project activities.

Aim 1			Aim 2			Aim 3			Aim 4			Aim 5	Aim 6
Develop lab-scale SCA capabilities			**Develop phase mappings for classes of polyolefins**			**Develop phase mappings of organic and inorganic pigments**			**Demonstrate separation of POs in mixed streams with major non-PO plastics**			**Publication/ Patent**	**Industrial Consortium/ DOE/NSF/DOD Proposals**
Task 1	**Task 2**	**Task 3**	**Task 1**	**Task 2**	**Task 3**	**Task 1**	**Task 2**	**Task 3**	**Task 1**	**Task 2**	**Task 3**	**Task 1**	**Task 1**
Purchase labscale SCA equipment and materials	**Setup of SCA equipment**	**Safety evaluation of setup and demonstration**	**Aquire model LDPE, HDPE, iPP from LyondellBasell**	**Develop phase diagrams using SCA equipment**	**Design multi-stage expansions for staged separation of polyolefins**	**Aquire representative pigments and color conentrates from Sun and Avient**	**Determine phase diagrams and miscibilty using SCA**	**Design separation processes for pigments and fillers**	**Obtain samples of major grade plastics**	**Determine phase behavior of non-PO plastics**	**Demonstrate separation of POs from non-PO plastics**	**Initiate a publication of the first year of work and file for patents on useful technology**	**Develop future funding pathways**
Outcome/Assessment													
A functional SCA device will be produced with windows that allow the determination of phase separation as a function of temperature and pressure.			The relative miscibilty and phase separation conditions for LDPE, HDPE, and iPP will be determined. Design of processing routes for separations.			The relative miscibilty and phase separation conditions for representative pigments and color concentrates will be determined. Design of processing routes for separations.			Determine the relative miscibility of major grade non-PO plastics and demonstrate separation of these plastics from POs.			Draft of publication and filing of technology disclosures.	Develop future funding pathways and expansion of the research and devleopment at UC involving SCAs.

The equipment needed for a lab-scale SCA capability includes a high-pressure block type plunger pump capable of 600 bar pressure available from Cat pumps or MasterFlex (~ $10,000); a 100 ml high pressure stirred reactor (Ollital Technologies $5,000); two depressurization tubular stages and associated filtration and pressure gauges (~ $5,000). Total equipment costs are about $25,000. The remaining funds will be used to support two undergraduate coop students (~$10,000). A Materials Science PhD student, Ugo Ukoli, will work on this project funded by Sun Chemical. Ugo is already working with Sun and is available immediately. A second Chemical Engineering PhD student from LyondellBasell, Mike Camara, will spend part time on this project. The equipment will be setup in 552 Mantei Center (ERC) in a hood that is already equipped with gas handling equipment. The experimental setup will be reviewed for safety by high-pressure chemists from LyondelBasell, Dr. Sandor Nagy, and Dr. Chuck Holland.

Table 3. Project Timeline

		2022			**2023**		
	Aim	**May-July**	**August-October**	**November - January**	**February- April**	**May-July**	**August-October**
Aim 1	**Develop lab-scale SCA capabilities**	Purchase labscale SCA equipment and materials	Setup of SCA equipment	Safety evaluation of setup and demonstration			
Aim 2	**Develop phase mappings for classes of polyolefins**	Aquire model LDPE, HDPE, iPP from LyondellBasell		Develop phase diagrams using SCA equipment	Design multi-stage expansions for staged separation of polyolefins		
Aim 3	**Develop phase mappings of organic and inorganic pigments**	Aquire representative pigments and color conentrates from Sun and Avient		Determine phase diagrams and miscibilty using SCA	Design separation processes for pigments and fillers		
Aim 4	**Demonstrate separation of POs in mixed streams with major non-PO plastics**	Obtain samples of major non-PO plastics		Determine phase behavior of non-PO plastics	Demonstrate separation of POs from non-PO plastics		
Aim 5	**Publication/ Patent**				Initiate a publication of the first year of work and file for patents on useful technology		Submit publication and patent applications
Aim 6	**Industrial Consortium/ DOE/NSF/DOD Proposals**				Develop future funding pathways		

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3. B. A. Morris, *The Science and Technology of Flexible Packaging Multilayer Films from Resin and Process to End Use*, Elsevier Oxford UK, Cambridge MA (2017).
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16. G. Beaucage, D. W. Schaefer *Structural Studies of Complex-Systems using Small-Angle Scattering – A Unified Guinier Power-Law Approach* J. Non-Cryst. Solids **172** 797-805 (1994).
17. D. Pradhan, P. Ehrlich, Morphologies of Microporous Polyethylene and Polypropylene Crystallized From Solution in Supercritical Propane *J. Polym. Sci. Part B: Polym. Phys.* **33** 1053-1063 (1995).
18. P. J. Bush, D. Pradhan, P. Ehrlich, Lamellar Structure and Organization in Polyethylene Gels Crystallized from Supercritical Solution in Propane *Macromolecules* **24** 1439-1440 (1991).

BIOGRAPHICAL SKETCH

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NAME: Gregory (Greg) Beaucage

ACADEMIC POSITION TITLE: Professor of Chemical and Materials Engineering

EDUCATION/TRAINING *(Begin with baccalaureate or other initial professional education, include post-graduate, post-doc appointments, residencies, fellowships, etc..)*

Institution and Location	Degree	Completion Date	Field
University of Rhode Island Kingston, RI	BS	1980	Zoology
University of Rhode Island Kingston, RI	BS	1982	Chemical Engineering
University of Massachusetts Amherst, MA	Ph. D.	1991	Polymer Science and Engineering
Sandia National Laboratory Albuquerque, NM	Post-Doc	1991-1993	Organic Materials Group

NARRATIVE

A. Personal Statement

Greg Beaucage has made major contributions to the use of X-ray, neutrons, and light to understand structure and thermodynamics of polymers and nano-materials. Beaucage's main contribution is the Unified Scattering Function which enables the study of a variety of disordered materials that display hierarchical structure. The use of the Unified Function has paralleled and enhanced the dramatic development of scattering instrumentation covering wide q-ranges at high flux synchrotron and neutron sources around the world. Beaucage has used the Unified Function to study polymers in good solvent, branched polymers with quantification of branch content, star polymers, cyclics, protein folding, graphene and other crumpled planar structures, swollen networks, worm-like micelles, mass-fractal aggregates including studies of diesel engine exhaust streams and soot in flames, printed electronics, and bilayer membranes. Beaucage has also published significant work in the study of crystalline and nanoparticulate orientation in polymer films, and correlation of orientation at multiple length scales with transport, optical, and mechanical properties. Beaucage also pioneered the study of in situ measurements of nanoparticle aggregate growth in flames for the manufacture of polymer pigment and reinforcing filler materials. Beaucage was the first to use ellipsometry to measure the glass transition of thin polymer films. Beaucage's work has recently focused on quantification of nanocomposite dispersion using X-ray scattering and thermodynamic, structural, and dynamic studies of worm-like micelles. Beaucage has been active in links between US, UK and African Universities (Ethiopia, Tanzania, South Africa, and Lesotho) in the creation of university spinoff small businesses targeting social development. This work was spurred from a large collaborative project funded by the US Department of State in partnership with the University of Cape Town, *Nanopower Africa*, which Beaucage directed. Recently the work was supported by a multi-year Fulbright Global Scholar award. He is a fellow of the American Physical Society and of the American Chemical Society.

Regarding this proposal, Greg Beaucage has previously worked exensively with supercritical fluids for production of silica aerogels and for supercritical drying of polymers. [11-16] He has also worked with Paul Ehrlich on supercritically-crystallized iPP using supercritical propane. [11] Paul was the first to publish on supercritical alkane and alkene solvents for polyolefins in the 1960s. [4-6,17,18] Beaucage has also worked with Armstrong insulation on the development of polymer-based Knudsen super-insulation materials composed of nano-porous foams produced using supercritical solvents which do not have surface tension. Beaucage has extensive links with local and national members of the recycled PO value-chain. Beaucage is the Director of a proposed IUCRC center for hierarchical materials at the University of Cincinnati and the University of Delaware which is pending final approval from NSF. https://www.eng.uc.edu/~beaucag/CHEM/CHEM.html

B. Ongoing and recently competed/funded projects
IUCRC Planning Grant NSF Center for Hierarchical Emergent Materials (CHEM).
Enabling Design of Polymer Nanocomposites Guided by Mesoscale Simulations and Scattering Experiments. National Science Foundation

C. Honors, awards, positions, etc.
Fellow of the American Physical Society
Fellow of the American Chemical Society
Fellow of the Graduate School University of Cincinnati

D. Positions and Scientific Appointments (Date, Title)
2019 Visiting Professor, Department of Chemical and Metallurgical Engineering
University of the Witwatersrand, Johannesburg, South Africa
2018 Visiting Professor, Chemical Engineering Department
University of Sheffield, Sheffield, UK
2017-2019 Fulbright Global Scholar, US Department of State
Addis Ababa and Dire Dawa, Ethiopia; Sheffield, UK; Johannesburg and Cape Town South Africa; Roma, Lesotho
2010-2014 Director, NanoPower Africa, US Department of State
Cincinnati OH
2010 Visiting Professor, Department of Physics
University of Cape Town, Cape Town, South Africa
2008-Present Professor, Chemical and Materials Engineering
University of Cincinnati, Cincinnati OH
2000-2007 Associate Professor, Chemical and Materials Engineering
University of Cincinnati, Cincinnati OH
2003-2004 Visiting Professor, Department of Mechanical and Process Engineering
ETH Zürich, Zürich, Switzerland
1994-2000 Assistant Professor, Chemical and Materials Engineering
University of Cincinnati, Cincinnati OH
1993-1994 Staff Member, Organic Materials Group 1815, Sandia National Laboratory
Albuquerque, NM
1982-1986 Patent Examiner, Biomedical Materials, US Patent and Trademark Office
Arlington, VA

E. Contributions to field (peer-reviewed citations, lectures, exhibits, conference papers, etc.)
h-index 36 (from Web of Science) for 188 total publications

1) Approximations leading to a unified exponential/power-law approach to small-angle scattering. Beaucage, G; J. of Appl. Cryst. 28 717-728 (1995). 1067 citations
2) Small-angle scattering from polymeric mass fractals of arbitrary mass-fractal dimension. Beaucage, G; J. of Appl. Cryst. 29 134-146 (1996). 750 citations
3) Disposable Smart lab on a chip for point-of-care clinical diagnostics Ahn, CH; Choi, JW; Beaucage, G; Nevin, JH; Lee, JB; Puntambekar, A; Lee, JY Proc. IEEE 92 154-173. 381 citations
4) Structural studies of complex systems using small-angle scattering: a unified Guinier/power-law approach. Beaucage, G; Schaefer, DW; J. Non-Cryst. Solids 172 797-805 (1994). 231 citations
5) Ellipsometric study of the glass transition and thermal expansion coefficients of thin polymer films. Beaucage, G; Composto, R; Stein, RS; J. Polym. Sci. Part B: Polym. Phys. 31 319-326 (1993). 154 citations
6) Rational Design of Reinforced Rubber Kohls, D; Beaucage, G; Curr. Opin. Solid State & Mat. Sci. 6 183-194 (2002). 151 citations
7) Probing the dynamics of nanoparticle growth in a flame using synchrotron radiation. Beaucage G, Kammler HK, Agashe N, Pratsinis SE and Narayanan T, Nature Mater. 3, 370-373 (2004). 94 citations
8) Determination of branch fraction and minimum dimension of mass-fractal aggregates. Beaucage G, Phys. Rev. E, 70, 031401 (2004). 102 citations
9) Particle size distributions from small-angle scattering using global scattering functions. Beaucage, G; Kammler, HK; Pratsinis, SE; Journal of Applied Crystallography 37 523-535 (2004). 256 citations
10) 3D Hierarchical orientation in polymer–clay nanocomposite films. Bafna, A; Beaucage, G; Mirabella, F; Mehta, S; Polymer 44 1103-1115 (2003). 143 citations.
11) Fractal analysis of flame-synthesized nanostructured silica and titania powders using small-angle X-ray scattering Hyeon-Lee, J; Beaucage, G; Pratsinis, SE; Vemury, S; Langmuir 14 5751-5756 (1998). 115 citations
12) A structural model for equilibrium swollen networks. Sukumaran SK, Beaucage G Europhysics Letters 59 714-720 (2002).
13) Towards resolution of ambiguity for the unfolded state. Beaucage G Biophysical J. 95 503-509 (2008).
14) Multiple Size Scale Structures in Silica-Siloxane Composites Studied by Small-Angle Scattering Beaucage, G; Ulibarri, TA; Black, EP; Schaefer, DW; in Hybrid Organic-Inorganic Composites eds. Mark, JE; Lee, CYC; Bianconi, PA; ACS Symposium Series 585 97-111 (1995). 96 citations
15) Structure of flame-made silica nanoparticles by ultra-small-angle X-ray scattering Kammler, HK;; Beaucage, G; Mueller, R; Pratsinis, SE Langmuir 20 1915-1921 (2004). 91 citations
16) Monitoring simultaneously the growth of nanoparticles and aggregates by in situ ultra-small-angle x-ray scattering Kammler, HK; Beaucage, G; Kohls, DJ; Agashe, N; Ilavsky, J; J. Appl. Phys. 97 054309 (2005). 86 citations
17) Aero-sol-gel synthesis of nanostructured silica powders HyeonLee, J; Beaucage, G; Pratsinis, SE; Chem. Mat. 9 2400-2403 (1997).
18) Impact of an Emergent Hierarchical Filler Network on Nanocomposite Dynamics Rishi, K; Beaucage, G; Kuppa, V; et al.; Macromolecules 51 7893-7904 (2018).

Current & Pending Funding for all faculty and external collaborators (as appropriate). Identify any externally funded research that may overlap with aspects of this project. Given the applied research focus of this program, the applicant(s) may be supported by external funding for basic research relevant to the proposed project. Such funding could include corporations, foundations, or government sources. (No page limit – any format acceptable)

The project will involve interaction with organizations in the value-chain for PO recycling.

A Materials Science PhD student, Ugo Ukoli, will work on this project funded by Sun Chemical, a major organic pigment manufacturer with research and production facilities in Cincinnati. Ugo is already working with Sun and is available immediately. A second Chemical Engineering PhD student from LyondellBasell, Mike Camara, will spend part time on this project. The equipment will be setup in 552 Mantei Center (ERC) in a hood that is already equipped with gas handling equipment. The experimental setup will be reviewed for safety by high-pressure chemists from LyondelBasell, Dr. Sandor Nagy, and Dr. Chuck Holland who routinely work with 1,000-2,000 bar 250°C conditions for LDPE synthesis on the lab scale.

Participants in the proposal are listed in Table 1. These include LyondellBasell, the largest manufacturer of polyethylene with research labs in Cincinnati, Sun Chemical a major organic pigment manufacturer for PO with research and production facilities in Ivorydale, Procter & Gamble, a major end-user of POs and a partner in PureCycle Incorporated which is also local to Cincinnati. Avient, formerly known as PolyOne, a large formulation and compounding company headquartered in Cleveland producing PO color concentrates. Rumpke Recycling a regional recycler of POs. Cincinnati EPA Research Lab and their regulatory affiliates in Washington DC. This team was assembled for a DOE concept paper on PO recycling in Fall 2021. DOE requested a demonstration of preliminary work which will be provided by this funding for further DOE, NSF, DOD, EPA and industry funded proposals. A funding source for filing of IP resulting from this work exists among this team of research partners. The partners will also be consulted concerning appropriate research directions.

The current contacts at participating organizations for the DOE concept paper (and future proposals based on this work) are:

LyondellBasell	Harry Mavridis	Director of Research
	Currently funding one Ph.D. Student working on polyolefins: Mike Camara (Ch. E.)	
Sun Chemical	Russell Schwartz	Vice President for Research and Development
	Currently funding one Ph.D. Student working on polyolefins: Ugo Okoli (Mat. Sci.)	
Procter & Gamble	Paula Ray	Vice President for Research and Development
Avient (PolyOne)	Amit Kulkarni	Director of Research and Development
Rumpke Recycling	Steve Sargent	Director of Business Development
Cincinnati EPA	E. Sahle-Demessie	Sr. Chemical Engineer