Mechanically Triggered Carbon Monoxide Release with Turn-On Aggregation-Induced Emission

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ABSTRACT: Polymers that release functional small molecules under mechanical stress potentially serve as next-generation materials for catalysis, sensing, and mechanochemical dynamic therapy. To further expand the function of mechanoresponsive materials, the discovery of chemistries capable of small molecule release are highly desirable. In this report, we detail a non-scissile bifunctional mechanophore (i.e., dual mechano-activated properties) based on a unique mechanochemical reaction involving norborn-2-en-7-one (NEO). One property is the release of carbon monoxide (CO) upon pulsed solution ultrasonication. A release efficiency of 58% is observed at high molecular weights ($M_n = 158.8$ kDa), equating to ~ 154 molecules of CO released per chain. The second property is the bright cyan emission from the macromolecular product in its aggregated state, resulting in a turn-on fluorescence readout coincident with CO release. This report not only demonstrates a unique strategy for the release of small molecule in a non-scissile way, but also guides future design of force-responsive aggregation-induced emission (AIE) luminogens.

Carbon monoxide (CO) is one of the deadliest chemicals in the world, sending nearly 50,000 people to the hospital per year in the US.¹ In contrast, it is also widely acknowledged as an important signaling molecule akin to hydrogen sulfide (H₂S) and nitric oxide (NO) with essential physiological roles.² Moreover, CO has been developed as a potential therapeutic agent due to its cytoprotective,³ antibacterial,⁴ anti-inflammatory,⁵ and anticancer effects.⁶ As early clinical trials that administer CO through inhalators reported safety concerns and difficulties in delivering precise amounts of CO to patients, the development of safer alternatives for CO delivery are needed.⁷ CO-releasing molecules (CO-RMs) serve as a promising strategy to overcome these limitations, as they allow for the controlled release of CO under external stimuli such as light,⁸ reactive oxygen species (ROS),⁹ and enzymes.¹⁰ Although ongoing research in organic based CO-RMs have eliminated the use of potentially toxic metals while providing improved synthetic tunability,¹¹ the discovery of alternative chemistries and stimuli for the release of CO will further help advance CO-associated biological studies and therapeutics.

Polymer mechanochemistry is a potentially useful platform for the controlled release of small molecules for therapeutic applications,^{12–14} as ultrasound has the unique ability to penetrate deep within biological tissues to achieve mechanochemical transformations noninvasively with precise spatial and temporal control.¹⁵ On top of this, multimechanophore (MMP) materials that release large amounts of cargo in a highly tunable fashion are particularly attractive.^{16–21} We envisioned that bench-stable norborn-2-en-7-one (NEO)²² typically used for the cheletropic extrusion of CO,^{9,23} is a putative mechanophore for the release of CO when tethered to a polymer at the 5, 6 positions (**Scheme 1**). As

illustrated in **Scheme 1**, mechanical force transduced from the polymer backbone is hypothesized to selectively cleave the C₅–C₆ bond, resulting in a diradical intermediate. A subsequent β -elimination leads to the release of CO without backbone scission, thus allowing for multiple activations (i.e., multiple CO-release) to occur per chain. Herein, we report our findings of a CO-releasing mechanophore with concomitant turn-on aggregation-induced emission (AIE) via a fundamentally unique mechanochemical transformation.

Scheme 1. Known and Postulated CO Release Pathways from the Norborn-2-En-7-One (NEO) Scaffold^a

^aRed bonds indicate bonds broken upon applied mechanical stimuli. Blue bonds indicate the small molecule released.

Scheme 2. Synthesis of P1 and P2 Containing NEO Mechanophores

a) (3E)-di(but-3-en-1-yl) fumarate (2 equiv), reflux in toluene, 12 h (76%); b) maleic acid (2 equiv), toluene, reflux, 12 h; c) 3-buten-1-ol (3 equiv), EDC (2.2 equiv), DMAP (0.1 equiv) THF, rt, 18 h (52% over 2 steps); d) second generation Grubbs catalyst (0.05 equiv), DCM (5mM), reflux, 12h (**5** was isolated from mixture with 44% yield; **3** was obtained as E/Z mixture with 57% yield); e) Polymerizations performed in CHCl_3 at 60 °C for 20 h at $[\text{NEO}]:[\text{COE}] = 1:1$; $[\text{olefin}]_0/[\text{G2}]_0 = 4000$; $[\text{olefin}]_0 = 1.5 \text{ M}$.

Ring opening metathesis polymerization (ROMP) was chosen as our polymerization strategy for the incorporation of NEO into a MMP system. As described in previous reports, mechanophores with different isomeric configurations lead to unique products and exhibit large difference in activation percentages (Φ).²⁴⁻²⁶ Thus, we individually designed and prepared *cis*- and *trans*-NEO containing isomers (Scheme 2). Starting from cyclopentadienone dimer **1**, Diels-Alder cycloreversion/cycloaddition in the presence of a fumarate derivative followed by ring-closing metathesis (RCM) afforded macrocycle **3** (E:Z = 9:1) in 43% yield. Following a similar strategy but using maleic acid in place of the fumarate derivative, **5** was obtained in 23% yield over 3 steps. Surprisingly, epimerization was observed during esterification leading to a mixture of *cis*- and *trans*- product (*cis*: *trans* = 5:1). Following the RCM reaction, macrocycle **5** was isolated (confirmed by single crystal X-ray diffraction) from other diastereomers in moderate yield (44%). Subsequent ROMP of **3** or **5** with comonomer (Z)-cyclooctene (COE) and chain transfer agent (Z)-oct-4-ene produced **P1** and **P2**, respectively, with molecular weights (M_n) ranging from 6.2 to 158.8 kDa and NEO incorporations of 44.1–52.6 mol%.

The mechanochemical reactivity of **P2** ($M_n = 158.8 \text{ kDa}$) was evaluated in dilute THF solutions using pulsed ultrasonication (1 s on/1 s off, -10 °C, 20 kHz, 8.8 W/cm²). After 240 min of sonication, ¹H NMR of the resulting material **SP2** showed the appearance of six new resonance peaks at $\delta = 6.9, 5.8, 5.6, 4.3, 2.4$, and 2.2 ppm with a concomitant decrease of all corresponding NEO resonances (Figure 1). The microstructure of **SP2** was determined via 2D NMR analysis (Figure S10–12) and was consistent with the formation of a single isomer, as evidenced by the two sharp singlet resonances around $\delta = 5.9$ and 2.2 ppm. While multiple isomers are conceivable based on the hypothesized diradical intermediate and its presumed isomerization pathways,^{24,25,27} formation of the sole (E,Z,E) isomer was confirmed from ROESY and ¹³C-gated decoupling experiments (Figure S14–17). From peak

assignments, it was determined that 58% of the NEO mechanophores were activated after 240 min of ultrasonication based on integration in ¹H NMR (Figure S7), which is in good agreement with quantitative ¹³C NMR analysis (Figure S9). Low molecular weight **P2** ($M_n = 6.2 \text{ kDa}$) showed no activation under the same sonication conditions, indicating the mechanical nature of this transformation (Figure S13).

Figure 1: Stacked ¹H NMR transformation of **P2** to **SP2** in CDCl_3 upon sonication. NMR assignments of resonances in **SP2** are color coded in the lower spectrum.

Figure 2: (a) Fluorescence spectra of **SP2** in water/THF mixtures at different water fractions, f_w , ($\lambda_{\text{ex}} = 350 \text{ nm}$). (b) Fluorescence spectra change during the sonication of **P2** ($M_n = 158.8 \text{ kDa}$, polymer suspension was prepared in THF-water mixture with $f_w = 90\%$ at 0.05 mg/mL , $\lambda_{\text{ex}} = 350 \text{ nm}$). Control experiments were done using pure THF solution of **P2** at 0.05 mg/mL . (c) Photograph of polymer suspension before and after ultrasonication under 365 nm UV. Purple color was from the scattering light of the UV-lamp. (d) Solid-state mechanoactivation of **P2**. Photographs were taken under 365 nm UV irradiation. The emission peak labeled * originated from light-scattering effects.

Figure 3: a) GC detection of **P2** ($M_n = 129.7 \text{ kDa}$) and control polymer ($M_n = 6.2 \text{ kDa}$) upon sonication using GC-TCD. b) IR spectra of **P2** and **SP2** ($\Phi = 58\%$). c) TGA analysis of **P2** and **SP2**. d) Activation% (Φ) of **P2** with different M_n upon sonication. Φ was determined from the average of two trials.

Significantly lower mechanochemical activation ($\Phi = 12\%$) was observed for **P1** of a similar molecular weight ($M_n = 143.7 \text{ kDa}$, 46.8% NEO incorporation) after 240 min of sonication. While the main product obtained matched with that of **P2**, two smaller resonances appeared in the conjugated olefin region around $\delta = 5.9 \text{ ppm}$, indicating the generation of other stereoisomers (Figure S18). Due to the overall low Φ , these minor products were unable to be properly identified. Studies to determine the structure of these isomers as well as the origin of stereoselectivity and mechanosensitivity between the *cis*- and *trans*-NEO are ongoing.

Based on the determined structure of **SP2**, we reasoned by analogy to tetraphenylethene (TPE), one of the most common

AIE luminogens, that the diphenylethene motif in the macromolecular product exhibits similar photophysical properties.²⁸ Different from typical aromatic luminophores that suffer from aggregation-caused quenching (ACQ) effects, AIE luminogens show dramatically enhanced emission profiles in the aggregated state.²⁹ To our delight, under 365 nm UV irradiation, **SP2** showed cyan fluorescence when aggregated in THF-water mixtures (Figure 2c). Comparatively, in pure THF solutions, minimal emissions were observed (Figure S25). To gain a better understanding of the photoluminescence property of **SP2**, the water fraction (f_w , vol% water) in these THF-water suspensions were varied. Rising of the baseline and tailing of the spectra were observed

in the emission spectrum when increasing f_w from 0 to 70% due to the light-scattering effect of the formed nanoaggregates (**Figure 2a**).³⁰ Maximum emission intensities were observed at $f_w = 95\%$ with a maximum emission wavelength (λ_{max}) of 466 nm. Aliquots from sonication experiments showed a continuous increase of emission when monitored over 240 min, indicating an accumulation of activated *cis*-NEO with time (**Figure 2b**). Fluorescence of **SP2** was also measured at different concentrations and in the solid state, giving a similar λ_{max} (**Figure S22**). Solid state activation of **P2** was also achieved by compression and shear of **P2** ($M_n = 120.0$ kDa) in a mortar by a pestle for 2 minutes and showed a similar cyan emission upon 365nm UV irradiation (**Figure 2d**).

To confirm the release of CO from **P2**, gas chromatography (GC), infrared spectroscopy (IR) and thermal gravimetric analysis (TGA) were conducted (**Figure 3**). A GC equipped with a thermal conductivity detector (TCD) was first injected with a CO standard, as shown in **Figure S26**, and the retention time (t_R) of CO was determined to be around 3.1 min. After sonication of **P2** ($M_n = 129.7$ kDa) for 30 min, an aliquot of the headspace was injected and showed the appearance of a peak with $t_R = 3.1$ min, confirming the release of CO. Contrary, negligible CO was detected when low molecular weight **P2** ($M_n = 6.2$ kDa) was sonicated. Infrared (IR) spectroscopy analysis of **SP2** vs **P2** revealed a new band (1631 cm^{-1}) and a small shift of the ester carbonyl band (from 1734 to 1717 cm^{-1}) due to the generated conjugated alkenes as well as the unsaturated esters. Reduction of the bridge carbonyl stretching band (1779 cm^{-1})²² intensity after 240 min of sonication further validated the CO release. Lastly, differences in the weight loss between **P2** and **SP2** (6.8 and 3.6 wt%, respectively) at the first onset of degradation ($T_D = 206\text{ }^\circ\text{C}$), were in relatively good agreement with predicted values (4.7 and 2.9 %, respectively) for the mass loss of CO at 43.2 mol% incorporation and $\Phi = 38\%$.

As the ability to control the amount of CO released in a tunable fashion is an important characteristic of CO-RMs, various molecular weight **P2** were synthesized and the kinetics of activation were investigated. Sonication experiments were monitored by ^1H NMR and size-exclusion chromatography (SEC) analysis (**Table S3**) and showed an increase of Φ from 16% to 58% over the molecular weight range after 240 min (**Figure 3d**). This molecular weight dependent activation profile is in good agreement with other MMPs^{31,32} and provides further proof of the mechanical nature of the mechanophore. SEC analysis showed a continuous decrease in molecular weight during sonication, indicating the competition between NEO activation and random backbone scission (**Figure S29**). For **P2** of 55.9 kDa, 110.5 kDa, and 158.8 kDa, it was determined that about 19, 83, and 154 CO molecules are released on average per chain, respectively (See SI for more details).

In summary, we have demonstrated a new non-scissile MMP system that releases CO with turn-on AIE. A triene motif was generated upon mechanical force from a NEO scaffold as a distinctive product that has never been accessed before under other stimuli (heat, light, etc.). In addition, the NEO mechanophore represents the first example of mechanically induced AIE *via* covalent polymer mechanochemistry. We foresee that the NEO mechanophore will not only open exciting biological and biomedical opportunities, but also guide the design of novel force-responsive AIE luminogens for damage detection and bioimaging applications.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website.

Synthesis and characterization of compounds (PDF)

Crystallographic data for compound **3** (*E*-isomer) and **5** (CIF)

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Notes

The authors declare no competing financial interest.

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Supporting Information

Mechanically Triggered Carbon Monoxide Release with Turn-on Aggregation-Induced Emission

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Materials:

Reagents from commercial sources were used without further purification unless otherwise noted. Anhydrous dichloromethane (CH_2Cl_2), tetrahydrofuran (THF), triethylamine, and toluene were obtained from a solvent purification system equipped with activated alumina columns. Anhydrous chloroform (CHCl_3) was obtained by distillation over P_2O_5 . Column chromatography was performed on Biotage Isolera using Silicycle SiliaSep HP flash cartridges. Deuterated solvents were purchased from Cambridge Isotope Laboratories, Inc. and used as received. TLC plates with fluorescent indicator F254 were used and visualized with UV lamps.

Characterization:

^1H -NMR spectra were recorded using a Varian Inova 400 MHz and 500 MHz spectrometers. ^{13}C -NMR, and 2D spectra were recorded with a Bruker Avance III HD 500 MHz spectrometer equipped with a BBFO cryoprobe and are reported in parts per million (ppm) relative to their respective solvent ($(\text{CDCl}_3) \delta = 7.26$ or TMS. Hi-Res mass spectra were obtained on a Waters Synapt G2-Si ESI mass spectrometer. Size exclusion chromatography (SEC) was performed on an Agilent 1260 Infinity system equipped with an isocratic pump, degasser, autosampler, and a series of 4 Waters HR Styragel columns (7.8×300 mm, HR1, HR3, HR4, and HR5) in THF at 25°C and a flow rate of $1\text{ mL}\cdot\text{min}^{-1}$. The system is equipped with a triple detection system that includes an Agilent 1200 series G1362A Infinity Refractive Index Detector (RID), a Wyatt Viscostar II viscometer detector, and a Wyatt MiniDAWN Treos 3-angle light-scattering detector. Molecular weights and dispersities ($\bar{M}_w/\bar{M}_n$) were determined by a 12-point conventional column calibration with narrow dispersity polystyrene standards ranging from 980 to 1,013,000 Da. Absorption spectroscopy was performed using a UV-2501PC UV-Vis recording spectrophotometer (SHIMADZU). Emission spectroscopy was performed using a Fluoromax-4 fluorometer (Horiba). Thermal gravimetric analysis (TGA) was conducted on a TA Instruments Q50 Thermogravimetric Analysis under N_2 at $10^\circ\text{C}\cdot\text{min}^{-1}$. Differential scanning calorimetry (DSC) was conducted on a TA Instruments Discovery 250 at a ramp / cooling rate of $10^\circ\text{C}\cdot\text{min}^{-1}$ under nitrogen in an aluminum hermetic DSC pan. Glass transition temperatures were taken from the second heating cycle. Ultrasound experiments were performed using a Vibra Cell 505 liquid processor equipped with a 0.5" diameter solid probe from Sonics and Materials. Suslick cells¹² were fabricated by the School of Chemical Sciences Glass Shop at the University of Illinois. A Neslab CC 100 immersion cooler equipped with a Cryotrol temperature controller was used to maintain a constant- temperature bath for sonication experiments. Typical sonication experiments were performed using pulsed ultrasound (1.0 s on, 2.0 s off) at 20 kHz under N_2 with an output ultrasound intensity of $8.8\text{ W}/\text{cm}^2$ at -10°C . Ultrasonic intensity was calibrated using the method described by Berkowski et al.¹ Gas chromatography (GC) experiments were performed using Agilent 7820A instrument equipped with a thermal conductivity detector and a 5 Å molecular sieves (80-100 mesh) column with helium being used as the carrier gas. Geometry optimizations were performed in the Gaussian 09 software,² using the B3LYP density functional theory (DFT) and the 6-31G* basis set.

Synthetic Procedure:

(1): The synthesis of compound **1** was performed using reported protocol.³

To a stirred solution of benzil (10.0 g, 47.6 mmol) and 3-pentanone (4.08 g, 47.4 mmol) in isopropanol (200 mL), a solution of KOH (2.40 g, 42.7 mmol) dissolved in 100 mL of isopropanol was added and allowed to stir for 3 h at rt. The solution was concentrated, and the residue was diluted with EtOAc. The organic layer was washed with water, brine, dried over anhydrous Na₂SO₄, filtered, and concentrated under vacuum. To the crude product, 40 mL of acetic anhydride and 0.5 mL of concentrated H₂SO₄ were added to the flask and allowed to stir for 5 h at rt. The solution was then added to water (450 mL) with stirring and the precipitate was collected, washed with water, and dried in vacuum to afford the dimer of **1** (10.1 g, 81%) as a grey powder. **1**: ¹H NMR (500 MHz, CDCl₃) δ 7.57 – 7.30 (m, 2H), 7.25 – 7.18 (m, 4H), 7.14 – 7.08 (m, 4H), 7.06 (t, J = 7.3 Hz, 1H), 6.96 (td, J = 8.1, 6.2 Hz, 5H), 6.90 (dd, J = 6.7, 2.8 Hz, 2H), 6.74 – 6.63 (m, 2H), 2.25 (s, 3H), 1.64 (s, 3H), 1.25 (s, 3H), 0.58 (s, 3H), ¹³C NMR (126 MHz, CDCl₃) δ 209.60, 203.30, 166.06, 144.48, 143.33, 142.98, 140.23, 134.21, 134.13, 133.51, 131.97, 130.94, 130.27, 129.46, 128.02, 127.43, 127.36, 127.15, 127.04, 127.00, 66.86, 61.15, 59.84, 58.62, 18.18, 12.53, 12.43, 9.95. HRMS-ESI (*m/z*): found [M+H]⁺ for C₃₈H₃₃O₂ 521.2457 (calcd. 521.2481)

di(but-3-en-1-yl)-1,4-dimethyl-7-oxo-5,6-diphenylbicyclo [2.2.1] hept-5-ene-2,3-dicarboxylate (2): To an oven-dried round bottom flask equipped with a stir bar, dimer **1** (8.06 g, 0.16 mmol, 1 equiv) and maleic acid (3.61 g, 0.31 mmol, 2 equiv) were refluxed in toluene (70 mL) under nitrogen for 12 h. After cooling to rt, the mixture was concentrated and the residue (10.0 g, 86%) was used without purification. The crude reaction mixture (5.0 g, 10.3 mmol, 1 equiv) and 4-dimethylaminopyridine (DMAP) (0.13 g, 1.0 mmol, 0.1 equiv) were then dissolved in anhydrous THF (50 mL) and cooled to 0 °C before EDC (4.4 g, 22.7 mmol, 2.2 equiv) was added. The mixture was allowed to stir for 10 min and at this time, 3-buten-1-ol (2.2 g, 31.0 mmol, 3 equiv) was injected and the reaction mixture was allowed to stir at rt overnight. After removal of volatiles, the reaction mixture was diluted with EtOAc (200 mL) and subsequently washed with water (200 mL), 0.1 M HCl (200 mL), water (200 mL), saturated NaHCO₃ aqueous solution (200 mL), and brine (200 mL). The material was dried over Na₂SO₄, filtered, and concentrated *in vacuo*.

The crude product was purified by column chromatography (15% ethyl acetate in hexanes) to afford **2** as a yellow solid (2.6 g, 52%). Undesired isomerization was observed during esterification to afford an inseparable mixture of *cis* and *trans* isomer (*cis/trans* = 5:1). **2** (*cis* isomer): ^1H NMR (500 MHz, CDCl_3) δ 7.18 – 7.08 (m, 10H), 5.64 (ddt, J = 16.7, 9.7, 6.7 Hz, 2H), 5.04 – 4.97 (m, 4H), 4.06 (q, J = 6.7 Hz, 4H), 3.32 (s, 2H), 2.25 – 2.18 (m, 4H), 1.45 (s, 6H). ^{13}C NMR (126 MHz, CDCl_3) δ 200.04, 170.28, 141.74, 134.69, 133.95, 130.30, 127.72, 127.22, 117.32, 64.13, 56.66, 51.12, 32.78, 12.01. HRMS-ESI (m/z): found $[\text{M}+\text{H}]^+$ for $\text{C}_{31}\text{H}_{33}\text{O}_5$ 485.2312 (calcd. 485.2328)

(3): Compound **2** (mixture of *cis* and *trans* isomers, 1.0 g, 2.0 mmol) was dissolved in anhydrous CH_2Cl_2 (400 mL, 5.0 mM) and the solution was sparged with argon for 15 min. Second generation Grubbs catalyst (44.5 mg, 0.05 mmol, 0.025 equiv) was then added under a positive argon flow and the solution was refluxed for 12 h. At this time, the solution was concentrated and purified by column chromatography (12% ethyl acetate in hexanes) to afford **3** as a white solid. Further purification of **3** was done by recrystallization in 50% DCM in hexanes to remove residual **(Z)-cis-3** and **trans-3** macrocycles and afforded colorless crystals of **3** (0.41g, 44%). The structure of **3** was confirmed by single crystal X-ray diffraction. **3**: ^1H NMR (400 MHz, CDCl_3) δ 7.13 (q, J = 4.3, 3.4 Hz, 6H), 7.09 – 7.03 (m, 4H), 5.49 (s, 2H), 4.54 – 4.41 (m, 2H), 3.89 (d, J = 10.2 Hz, 2H), 3.29 (s, 2H), 2.29 (s, 4H), 1.41 (s, 6H). ^{13}C NMR (126 MHz, CDCl_3) δ 199.66, 169.86, 141.50, 134.83, 130.08, 128.59, 127.79, 127.26, 64.21, 56.96, 51.89, 27.14, 11.83. HRMS-ESI (m/z): found $[\text{M}+\text{H}]^+$ for $\text{C}_{29}\text{H}_{29}\text{O}_5$ 457.2008 (calcd. 457.2015)

Di(but-3-en-1-yl) fumarate (4): To a stirred solution of fumaryl chloride (1.0 g, 6.5 mmol, 1 equiv) in anhydrous CH_2Cl_2 (18 mL), 3-buten-1-ol (1.4 g, 19.6 mmol, 3.0 equiv) was added under a nitrogen atmosphere. Anhydrous triethylamine (1.3 g, 13.1 mmol, 2 equiv) was then added dropwise at 0 °C. The reaction mixture was then allowed to warm to rt and was stirred overnight. After completion, the reaction mixture was diluted with DCM (100 mL) and the organic layer was washed with saturated NH_4Cl (100 mL), water (100 mL), brine (100 mL), dried over Na_2SO_4 , filtered, and concentrated *in vacuo*. The crude product was further purified by column chromatography (10% ethyl acetate in hexanes) to afford **4** as colorless oil (1.4 g, 96%). ^1H NMR (500 MHz, CDCl_3) δ 6.84 (d, J = 2.1 Hz, 2H), 5.78 (ddt, J = 17.1, 10.2, 6.7 Hz, 2H), 5.18 – 5.06 (m, 4H), 4.25 (td, J = 6.7, 2.2 Hz, 4H), 2.43 (qt, J = 6.7, 1.4 Hz, 4H). ^{13}C NMR (126 MHz, CDCl_3) δ 165.03, 133.71, 133.70, 117.70, 64.47, 33.03. HRMS-ESI (m/z): found $[\text{M}+\text{H}]^+$ for $\text{C}_{12}\text{H}_{17}\text{O}_4$ 225.1124 (calcd. 225.1127)

Trans-di(but-3-en-1-yl)-1,4-dimethyl-7-oxo-5,6-diphenylbicyclo [2.2.1]hept-5-ene-2,3-dicarboxylate (5): To a stirred solution of dimer **1** (1.16 g, 2.2 mmol, 1 equiv) in toluene (10 mL), compound **4** (1.0 g, 4.5 mmol, 2 equiv) was added and refluxed under nitrogen for 12 h. After cooling to rt, the solvent was evaporated under vacuum and the crude product was purified by column chromatography (12% ethyl acetate in hexanes) to afford **5** as white solid (0.82g, 76%). **5**: ^1H NMR (500 MHz, CDCl_3) δ 7.23 – 7.18 (m, 3H), 7.15 (tt, J = 5.1, 2.5 Hz, 3H), 7.04 (dt, J = 6.7, 1.5 Hz, 2H), 6.93 – 6.86 (m, 2H), 5.79 (ddd, J = 17.2, 10.3, 1.2 Hz, 1H), 5.55 – 5.44 (m, 1H), 5.19 – 5.07 (m, 2H), 4.99 – 4.88 (m, 2H), 4.26 – 4.13 (m, 2H), 4.01 – 3.85 (m, 2H), 3.52 (dd, J = 4.7, 1.3 Hz, 1H), 3.30 (dd, J = 4.9, 1.3 Hz, 1H), 2.43 (q, J = 6.8 Hz, 2H), 2.06 (qd, J = 6.7, 1.5 Hz, 2H), 1.57 (d, J = 1.4 Hz, 3H), 1.22 (d, J = 1.3 Hz, 3H). ^{13}C NMR (126 MHz, CDCl_3) δ 201.60, 172.23, 171.41, 143.50, 140.88, 133.79, 133.77, 133.64, 129.64, 129.26, 128.24, 127.99, 127.74, 127.49, 117.72, 117.42, 64.56, 64.51, 56.42, 55.97, 51.62, 50.22, 33.10, 32.66, 12.38, 9.71. HRMS-ESI (m/z): found $[\text{M}+\text{H}]^+$ for $\text{C}_{31}\text{H}_{33}\text{O}_5$ 485.2313 (calcd. 485.2328)

(6): Compound **5** (0.5 g, 1.0 mmol) was first dissolved in anhydrous DCM (90 mL, 5.0 mM), and the solution sparged with argon for 15 min. Second generation Grubbs catalyst (21 mg, 0.026 mmol, 0.025 equiv) was then added under a positive argon atmosphere and was refluxed for 12h. After completion, the solution was concentrated and the crude product was purified by column chromatography (12% ethyl acetate in hexanes) to afford **6** as a white solid (0.26 g, 57%, *E:Z* = 9:1). The major product of **6** (*E* isomer) was confirmed by single crystal X-ray diffraction. **6**: ^1H NMR (500 MHz, CDCl_3) δ 7.24 – 7.19 (m, 3H), 7.18 – 7.13 (m, 3H), 7.06 (ddd, J = 10.0, 5.5, 2.4 Hz, 4H), 5.41 – 5.26 (m, 2H), 4.68 (ddd, J = 12.9, 11.0, 2.6 Hz, 1H), 4.58 (td, J = 11.4, 3.3 Hz, 1H), 3.96 (ddd, J = 10.9, 4.6, 2.2 Hz, 1H), 3.81 (ddd, J = 11.0, 4.5, 2.1 Hz, 1H), 3.11 (d, J = 7.8 Hz, 1H), 3.01 (d, J = 7.9 Hz, 1H), 2.34 (ddt, J = 24.3, 11.6, 7.9 Hz, 4H), 1.38 (s, 3H), 1.33 (s, 3H). ^{13}C NMR (126 MHz, CDCl_3) δ 201.00, 172.40, 172.16, 143.50, 142.28, 134.34, 133.72, 130.10, 130.06, 129.73, 129.70, 128.30, 128.27, 127.92, 127.88, 127.69, 127.39, 62.79, 62.67, 56.20, 54.39, 53.76, 52.91, 33.46, 33.30, 11.45, 9.20. HRMS-ESI (m/z): found $[\text{M}+\text{H}]^+$ for $\text{C}_{29}\text{H}_{29}\text{O}_5$ 457.2025 (calcd. 457.2015)

General Polymerization Procedure:

As an example, to a 2 mL oven dried vial equipped with a stir bar, 100 mg (0.22 mmol) of **3** was added and purged with argon for 10 minutes. To the vial, 28.5 μL (0.22 mmol) of *cis*-cyclooctene that was run through neutral alumina and was also injected. Stock solutions of G2 and the CTA agent were made as follows. To a 10 mL volumetric flask, 7.1 mg of G2 was added and purged with argon for 10 min before diluting to the mark with CHCl_3 . To a separate 10 mL volumetric flask, 5.6 μL of *cis*-4-octene was added and diluted to the mark with CHCl_3 . To the 2 mL vial, 131.9 μL of both the CTA and G2 solutions were added and quickly allowed to stir at rt until **3** was fully solubilized. At this time, the vial was heated to 60 $^\circ\text{C}$ and allowed to stir overnight. At this time, 0.1 mL of ethyl vinyl ether and 1 mL of DCM were added and allowed to stir at rt for 30 min before precipitating into 20 mL of MeOH to give a white solid.

General Sonication Procedure:

To an oven-dried Suslick cell,¹² 12 mL of a 1 $\text{mg}\cdot\text{mL}^{-1}$ solution of P2 in THF was filtered through a cotton plug and added. The solution was sparged for 10 min with argon before being placed in a cooling bath at -10 $^\circ\text{C}$. At this time, sonication was initiated with a constant flow of argon, and 1 mL aliquots were taken at predetermined times. Aliquots were concentrated and dried before SEC and ^1H -NMR analysis.

Figure S1. Representative ^1H NMR of **P2** upon sonication (500 MHz, CDCl_3). Growth of new peaks from activated *cis*-NEO were color-coded.

Figure S2. Representative ^1H NMR of **P2** (500 MHz, CDCl_3). *cis*-NEO incorporation% was calculated from the integrated intensity ratio of the olefin resonances (H_4 and H_5).

Figure S3. 2D ^1H - ^1H COSY NMR of **P2** (500 MHz, CDCl_3). Correlations are highlighted.

Figure S4. Representative ^{13}C NMR of **P2** (500 MHz, CDCl_3).

Figure S5. 2D ^1H - ^{13}C HSQC NMR of **P2** (500 MHz, CDCl_3).

Figure S6. 2D ^1H - ^{13}C HMBC NMR of **P2** (500 MHz, CDCl_3).

Figure S7. Representative ^1H NMR of **SP2** (500 MHz, CDCl_3), Activation% (Φ) was calculated from the integrated intensity ratio of H_1 to H_a .

Figure S8. Representative ^{13}C NMR of SP2 (500 MHz, CDCl_3). Carbons in the activated motif were assigned.

Figure S9. Partial quantitative ^{13}C NMR of SP2 (500 MHz, CDCl_3). Activation% (Φ) was calculated from the integrated intensity ratio between carbonyl C_a and C_b .

Figure S10. 2D ^1H - ^1H COSY NMR of **SP2** (500 MHz, CDCl_3). Protons in activated *cis*-NEO structure were highlighted.

Figure S11. 2D ^1H - ^{13}C HSQC NMR of **SP2** (500 MHz, CDCl_3). Correlations in activated *cis*-NEO structure were highlighted.

Figure S12. 2D ^1H - ^{13}C HMBC NMR of **SP2** (500 MHz, CDCl_3). Correlations in activated *cis*-NEO structure was highlighted.

Figure S13. ^1H -NMR of control **P2** ($M_n = 6.2$ kDa) upon sonication (500 MHz, CDCl_3). No new peaks were observed upon 240 min of sonication.

Stereochemistry Determination after Activation

Figure S14. Potential stereoisomers of NEO mechanophore after activation. Only most extended conformation was drawn for each isomer. Black curved arrows indicate potentially rotatable bonds.

Figure S15. Stacked ¹³C NMR of selected peaks of **SP2** (500 MHz, CDCl₃)

The sharp singlet peaks around 5.9 ppm and 2.2 ppm in ¹H-NMR strongly indicated a single symmetrical product, excluding the (Z,Z,E) and (Z,E,E) isomers. While a doublet of quartets (coupling from H_a as well as the 3 methyl protons) was observed for C_α in proton-coupled ¹³C NMR, only broadening of peaks was seen for C_β (both ³J_{C-H} coupling between H_a/C_β and methyl proton/C_β are expected), indication relatively small coupling constant. Although the ³J_{C-H} (8.0 Hz) between H_a and C_α was at the borderline between *cis* and *trans*,⁴ the significantly lower ³J_{C-H} between H_a and C_β was strongly indicative of the *cis* configuration between H_a and C_β, further excluding (Z,Z,Z) and (Z,E,Z) isomers. (E,Z,E) and (E,E,E) isomers were differentiated from detailed NOE analysis.

Figure S16. 2D ^1H - ^1H ROESY NMR of **SP2** (500MHz, CDCl_3). Relative NOE intensity was determined by integration between H_1 , H_2 , and H_6 .

Figure S17. Optimized structures of (*E,Z,E*) and (*E,E,E*) isomers at the B3LYP/6-31G* level of theory.

The relative NOE intensity from 2D-ROESY NMR was 9.72/2 : 10.00/6 : 19.50/3 = 4.86 : 1.67 : 6.50 between H_1/H_2 , H_2/H_6 , and H_1/H_6 after normalization, suggesting the interproton distance on average to be $d_{26} > d_{12} > d_{16}$. In the optimized structure, the close proximity between H_2 and H_6 in the (*E,E,E*) isomer is inconsistent with the observed NOE signal, while the H_2 and H_6 are relatively far away from each other in the (*E,Z,E*) optimized structure, consistent with NOE observations. Since the smallest NOE value was observed between H_2 and H_6 experimentally, the (*E,Z,E*) configuration is more consistent with the ROESY data.

Figure S18. Stacked ^1H NMR **P2** ($M_n = 158.8$ kDa, 47.1% incorporation, $\Phi = 58.8\%$) and **P1** ($M_n = 143.7$ kDa, 46.8% incorporation, $\Phi = 12.0\%$) upon 240 min sonication (500 MHz, CDCl_3). Two small resonances at $\delta \sim 5.9$ ppm indicated the generation of other isomers in **SP1**.

Figure S19. ^1H NMR (500 MHz, CDCl_3) of **P1** ($M_n = 143.7$ kDa, 46.8% incorporation) (500 MHz, CDCl_3).

Figure S20. ^{13}C NMR (126 MHz, CDCl_3) of **P1** ($M_n = 143.7$ kDa, 46.8% incorporation).

X-Ray Single Crystal Structures

Crystal Structure of **3** and **6** (*E*-isomer)

Figure S21. Crystal structure of **3** and **6** (*E* isomer).

Single crystals suitable for X-ray diffraction analysis for both **3** and **6** (*E* isomer) were obtained by slow diffusion of hexanes into CHCl_3 solution.

Intensity data were collected on a Bruker D8 Venture kappa diffractometer equipped with a Photon II CPAD detector. An $\text{I}\mu\text{s}$ microfocus Mo source ($\lambda = 0.71073 \text{ \AA}$) (ed83k) or Cu source ($\lambda = 1.54178 \text{ \AA}$) (ed63L) coupled with a multi-layer mirror monochromator provided the incident beam. The sample was mounted on a 0.3 mm nylon loop with the minimal amount of Paratone-N oil. Data was collected as a series of φ and/or ω scans. Data was collected at 100 K (ed83k) or 120 K (ed63L) using a cold stream of N_2 (g). The collection, cell refinement, and integration of intensity data was carried out with the APEX3 software.⁸ A multi-scan absorption corrections was performed with SADABS.⁹ The structures were phased with intrinsic methods using SHELXT¹⁰ and refined with the full-matrix least-squares program SHELXL.¹¹

Table S1. Crystal data and structure refinement for **3**

Empirical formula	C ₂₉ H ₂₈ O ₅	
Formula weight	456.51	
Temperature	100(2) K	
Wavelength	0.71073 Å	
Crystal system	Tetragonal	
Space group	P4 ₂ /n	
Unit cell dimensions	a = 17.1769(3) Å	a = 90°
	b = 17.1769(3) Å	b = 90°
	c = 15.6999(3) Å	g = 90°
Volume	4632.19(18) Å ³	
Z	8	
Density (calculated)	1.309 Mg/m ³	
Absorption coefficient	0.089 mm ⁻¹	
F(000)	1936	
Crystal size	0.248 x 0.236 x 0.230 mm ³	
Theta range for data collection	2.371 to 27.109°.	
Index ranges	-22<=h<=22, -22<=k<=22, -20<=l<=20	
Reflections collected	124615	
Independent reflections	5109 [R(int) = 0.0548]	
Completeness to theta = 25.242°	99.9 %	
Absorption correction	Semi-empirical from equivalents	
Max. and min. transmission	0.7455 and 0.7214	
Refinement method	Full-matrix least-squares on F ²	
Data / restraints / parameters	5109 / 43 / 329	
Goodness-of-fit on F ²	1.061	
Final R indices [I>2sigma(I)]	R1 = 0.0389, wR2 = 0.0934	
R indices (all data)	R1 = 0.0457, wR2 = 0.0991	
Extinction coefficient	0.0026(3)	
Largest diff. peak and hole	0.396 and -0.219 e.Å ⁻³	

Table S2. Crystal data and structure refinement for **6** (*E* isomer)

Empirical formula	C ₂₉ H ₂₈ O ₅	
Formula weight	456.51	
Temperature	120(2) K	
Wavelength	1.54178 Å	
Crystal system	Orthorhombic	
Space group	Pna2 ₁	
Unit cell dimensions	a = 14.2847(3) Å	a = 90°
	b = 14.0329(3) Å	b = 90°
	c = 11.6373(2) Å	g = 90°
Volume	2332.76(8) Å ³	
Z	4	
Density (calculated)	1.300 Mg/m ³	
Absorption coefficient	0.711 mm ⁻¹	
F(000)	968	
Crystal size	0.454 x 0.222 x 0.098 mm ³	
Theta range for data collection	4.417 to 74.531°.	
Index ranges	-17<= <i>h</i> <=17, -17<= <i>k</i> <=17, -14<= <i>l</i> <=14	
Reflections collected	40267	
Independent reflections	4745 [R(int) = 0.0298]	
Completeness to theta = 67.679°	100.0 %	
Absorption correction	Semi-empirical from equivalents	
Max. and min. transmission	0.7538 and 0.6755	
Refinement method	Full-matrix least-squares on F ²	
Data / restraints / parameters	4745 / 1 / 310	
Goodness-of-fit on F ²	1.025	
Final R indices [I>2sigma(I)]	R1 = 0.0257, wR2 = 0.0672	
R indices (all data)	R1 = 0.0259, wR2 = 0.0673	
Absolute structure parameter	0.05(3)	
Extinction coefficient	0.0012(2)	
Largest diff. peak and hole	0.268 and -0.143 e.Å ⁻³	

Photophysical Characterizations:

Figure S22. Photoluminescence characterization of **P2** in THF-water mixture ($f_w = 90\%$) upon sonication ($\lambda_{\text{ex}} = 350$ nm). Control experiments were measured in pure THF at $50 \mu\text{g mL}^{-1}$. (a) Fluorescence emission spectra of **P2** ($M_n = 158.8$ kDa) upon 240 min sonication at various concentrations. Solid state fluorescence emission spectra was measured from polymer thin film deposited on a glass substrate. (b) Fluorescence emission spectra of **P2** ($M_n = 55.9$ kDa) upon sonication. (c) Fluorescence emission spectra of **P2** ($M_n = 110.5$ kDa) upon sonication. (d) Fluorescence emission spectra of **P2** ($M_n = 158.8$ kDa) upon sonication.

Figure S23. Fluorescent emission spectra of control **P2** ($M_n = 6.2$ kDa) upon sonication

Figure S24. UV-Vis spectra of **P2** ($M_n = 158.8$ kDa) before and after 240 min sonication in THF or THF and water mixtures at 0.10 mg mL^{-1}

Figure S25. Aggregation-Induced Emission turn on of **P2** upon sonication. Photos taken under 365nm UV. (a) **P2** in pure THF before sonication. (b) **P2** suspension before sonication in THF and water mixture ($f_w = 90\%$) The purple color is from light scattering. (c) **SP2** in pure THF upon 240 min sonication. (d) **SP2** suspension generated upon 240 min sonication followed by the addition of water into THF ($f_w = 90\%$) upon 240 min sonication.

General GC-TCD CO detection procedure:

To an oven-dried two arm cell, 35 mL of a 1.8 mg·mL⁻¹ solution of **P2** in THF was added, and the solution was sparged with N₂ for 30 min at -10 °C. Then the N₂ flow was stopped and the system was closed before the sonication was initiated. An air-tight Hamilton SampleLock syringe was used to extract 300 µL of the gas headspace, which was then injected into GC at predetermined times.

Figure S26. GC-TCD trace of model CO gas. CO gas was prepared from reported procedures.⁵

Figure S27. SEC traces of **P2** and **SP2** in THF. A) All **P2** used for CO release kinetic trials and low molecular weight **P2** control. B) Sonication trial of 55.9 kDa **P2** C) Sonication trial of 110.5 kDa **P2** D) Sonication trial of 158.8 kDa **P2**.

Figure S28. DSC of **P2** ($M_n = 129.7$ kDa) and **SP2** ($M_n = 72.5$ kDa, $\Phi = 38.1$ %). Glass transition temperatures (T_g) were taken from the second heating curve with a heating rate of $10\text{ }^\circ\text{C}\cdot\text{min}^{-1}$.

Figure S29. P2 activation vs. scission cycle at different molecular weights. Decrease in slope with increasing molecular weight is in good accord with prior reports.^{6,7}

Calculations

*Amount of CO released per chain for P2
(158.8 kDa, 47.1% NEO incorporation, $\Phi = 56.2\%$):*

Weight percent of NEO in copolymer =

$$\frac{(456.24 \text{ (NEO)} \text{ g} \cdot \text{mol}^{-1} * 0.471)}{(456.24 \text{ g} \cdot \text{mol}^{-1} * 0.471) + (110.2 \text{ (COE comonomer)} \text{ g} \cdot \text{mol}^{-1} * 0.529)} * 100 = 78.7 \%$$

$$DP_{\text{NEO}} = \frac{(158,800 \text{ g} \cdot \text{mol}^{-1} * 0.787)}{456.24 \text{ g} \cdot \text{mol}^{-1}} = 274$$

$$\text{Activation per chain} = 274 * 0.562 = \mathbf{154}$$

*Expected amount of CO released (TGA) for P2 (129.7 kDa, 43.2% NEO incorporation)
and SP2 ($\Phi = 38.1\%$):*

Weight percent of NEO in copolymer =

$$\frac{(456.24 \text{ (NEO)} \text{ g} \cdot \text{mol}^{-1} * 0.432)}{(456.24 \text{ g} \cdot \text{mol}^{-1} * 0.432) + (110.2 \text{ (COE comonomer)} \text{ g} \cdot \text{mol}^{-1} * 0.568)} * 100 = 75.9 \%$$

Weight percent of NEO in copolymer after 240 min sonication =

$$\frac{(456.24 \text{ (NEO)} \text{ g} \cdot \text{mol}^{-1} * 0.432 * 0.619)}{(456.24 \text{ g} \cdot \text{mol}^{-1} * 0.432 * 0.619) + (428.23 \text{ (activated NEO)} \text{ g} \cdot \text{mol}^{-1} * 0.432 * 0.381) + (110.2 \text{ (COE comonomer)} \text{ g} \cdot \text{mol}^{-1} * 0.568)} * 100 = 47.8 \%$$

For 1 g of P2, 0.759 g is attributed to NEO. $FW_{\text{CO}} = 28.01 \text{ g} \cdot \text{mol}^{-1}$ which is 6.14% the mass of NEO. Therefore predicted weight loss % =

$$0.759 * 6.14\% = \mathbf{4.7\%}$$

For SP2, only 0.478 g is attributed to NEO. Therefore predicted weight loss % =

$$0.478 * 6.14\% = \mathbf{2.9\%}$$

*Scission Cycle:*⁶

$$SC = \ln(M_0) - \ln(M_t)/\ln(2)$$

Table S3. Characterization of **P2** upon sonication

Time (min)	M_n (kDa) ^{a)}	NEO (%)	$\bar{D}$ ^{a)}	SC	Φ (%) ^{b)}
0	55.9	44.1	1.6	-	-
30	49	-	1.5	0.19	5.1
60	47.8	-	1.4	0.23	10.9
120	42.2	-	1.4	0.41	14.6
240	38.5	-	1.3	0.54	20.6
Time (min)	M_n (kDa) ^{a)}	NEO (%)	$\bar{D}$ ^{a)}	SC	Φ (%) ^{b)}
0	110.5	47.7	1.7	-	-
30	76	-	1.6	0.54	15.2
60	68.6	-	1.4	0.69	24.4
120	53.5	-	1.4	1.05	34.8
240	41.8	-	1.3	1.40	43.8
Time (min)	M_n (kDa) ^{a)}	NEO (%)	$\bar{D}$ ^{a)}	SC	Φ (%) ^{b)}
0	158.8	47.1	1.7	-	-
30	94.1	-	1.6	0.75	29.6
60	78.1	-	1.5	1.02	40.5
120	59.6	-	1.4	1.41	48.5
240	44.7	-	1.4	1.83	57.6

a) M_n and $\bar{D}$ determined by SEC (RI) analysis in THF compared to a 12 pt. conventional calibration using narrow dispersity polystyrene standards. b) activation (%) determined by ¹H-NMR analysis (CDCl₃).

NMR Spectra

Figure S30. ¹H NMR spectrum of **1** (500 MHz, CDCl₃).

Figure S31. ¹³C NMR spectrum of **1** (126 MHz, CDCl₃).

Figure S32. ^1H NMR spectrum of the mixture **2** and **5** (500 MHz, CDCl_3).

Figure S33. ^{13}C NMR spectrum of the mixture **2** and **5** (126 MHz, CDCl_3).

Figure S34. ^1H NMR spectrum of **3** (500 MHz, CDCl_3).

Figure S35. ^{13}C NMR spectrum of the **3** (126 MHz, CDCl_3).

Figure S36. ^1H NMR spectrum of **4** (500 MHz, CDCl_3).

Figure S37. ^{13}C NMR spectrum of **4** (126 MHz, CDCl_3).

Figure S38. ¹H NMR spectrum of **5** (500 MHz, CDCl₃).

Figure S39. ¹³C NMR spectrum of **5** (126 MHz, CDCl₃).

Figure S40. ^1H NMR spectrum of **6** (500 MHz, CDCl_3).

Figure S41. ^{13}C NMR spectrum of **6** (126 MHz, CDCl_3).

Optimized Geometry Coordinates

EZE-isomer

C	0.000218383	0.00025998	0.000539047
C	-0.000375899	-0.00035617	-0.000371134
C	-0.000256493	-0.000347245	-0.000069266
C	0.000374249	0.000181473	0.000049327
C	-0.000029642	0.000028592	-0.000417021
C	-0.000057735	0.000155732	0.000405016
C	-0.000305227	-0.000149396	0.000033479
C	0.000118833	0.000159472	0.000028745
C	-0.000071383	-0.000041534	0.000012218
C	0.000000323	-0.000049554	-0.000020357
C	-0.000041118	0.000050791	0.000018745
C	0.000109433	0.000078229	-0.000007013
C	0.000029058	-0.000069657	-0.000186563
C	-0.000016081	-0.000011719	0.000081036
C	-0.000006881	0.000045383	0.00002732
C	0.000017167	-0.000065263	0.000006829
C	0.000021675	0.000001663	-0.000132959
C	-0.000039078	-0.000060073	0.000333665
C	0.000001819	0.000061929	0.000016253
C	0.000015873	-0.000050776	-0.000034844
C	0.000156643	0.000070414	-0.000303571
O	-0.000017395	0.000025816	0.000142153
O	-0.000062365	-0.000065348	0.000020716
C	0.000051118	-0.00000353	-0.000130892
C	0.000260549	0.000183537	-0.000142323
O	-0.000104587	-0.000100116	-0.000011401
O	-0.000036804	0.000005018	0.000085198
C	0.00009892	0.000095037	-0.000029432
H	0.000003559	0.000032785	0.000035806
H	-0.000023476	0.00001457	-0.000029652
H	0.000008893	0.000022029	0.000007543
H	0.000014522	0.000012116	0.000006291
H	0.000009652	-0.000016229	-0.000010882
H	-0.000000631	-0.000022229	-0.000001453
H	0.00003703	-0.000006149	0.000015097
H	0.000002489	-0.000015014	-0.000019624
H	-0.000002381	-0.000004717	-0.000019158
H	-0.000000661	0.000021677	0.000001241
H	-0.000009387	0.000016113	0.00001222
H	-0.000015173	-0.000039878	-0.000023344
H	-0.000004332	-0.000003814	-0.000016121
H	0.000014953	-0.000016299	0.000008288

H	0.000007262	-0.000018124	0.000022884
H	0.000012706	0.000008853	0.000007106
H	-0.000017874	0.000014369	-0.000005107
H	-0.000029783	0.000004306	0.000001018
H	0.000006706	-0.000002759	0.000013894
H	-0.000023373	-0.000014108	0.00001523
H	-0.00001111	0.000020264	0.000018324
H	-0.000014477	-0.000001998	-0.000005579
H	-0.000015011	-0.000009288	0.000025749
H	-0.000003458	-0.000029162	-0.000002742

EEE-isomer

C	-0.295827	2.199712	0.317868
C	-1.468785	2.203143	0.989051
C	-2.190617	3.320008	1.172845
C	-1.762791	4.488021	0.675853
C	-0.61087	4.516694	-0.007017
C	0.099874	3.390892	-0.178952
C	0.414135	1.054194	0.134384
C	1.771831	1.055814	0.00459
C	-0.267183	-0.126379	0.121379
C	0.252634	-1.183822	0.802731
C	1.062756	-1.005812	1.86967
C	1.602144	-2.033373	2.544207
C	1.353953	-3.293479	2.163696
C	0.56633	-3.504641	1.101012
C	0.032937	-2.466019	0.438489
C	-1.436547	-0.201488	-0.575404
C	-2.405994	-1.067486	-0.197587
C	-1.670917	0.747548	-1.743397
C	2.378126	0.034721	-0.647249
C	2.604739	2.180947	0.600702
C	3.701675	-0.192518	-0.896624
C	-3.642932	-1.292221	-0.731312
O	-4.448215	-2.231894	-0.127833
O	4.042432	-1.329102	-1.595383
O	4.581861	0.559543	-0.532353
C	5.404509	-1.581497	-1.849352
O	-4.058189	-0.701103	-1.70674
C	-5.728002	-2.468931	-0.665955
H	-1.870586	1.287231	1.454444
H	-3.136296	3.281379	1.739843
H	-2.353633	5.407915	0.818036
H	-0.259725	5.46628	-0.445381
H	1.002569	3.479342	-0.804629

H	1.288892	0.000617	2.260902
H	2.247377	-1.844346	3.418898
H	1.798455	-4.141882	2.709642
H	0.375375	-4.536424	0.760081
H	-0.551903	-2.717385	-0.462526
H	-2.257206	-1.685818	0.705434
H	-0.773193	1.327934	-2.046106
H	-1.897961	0.169736	-2.667304
H	-2.492206	1.470832	-1.537927
H	1.762241	-0.758816	-1.106863
H	2.038837	2.852414	1.281591
H	3.369583	1.76198	1.29258
H	3.10886	2.795046	-0.179245
H	5.474403	-2.538178	-2.413812
H	5.836357	-0.768417	-2.474817
H	5.95993	-1.693877	-0.891363
H	-6.219261	-3.251462	-0.045602
H	-6.342552	-1.542013	-0.619426
H	-5.642533	-2.845807	-1.70975

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