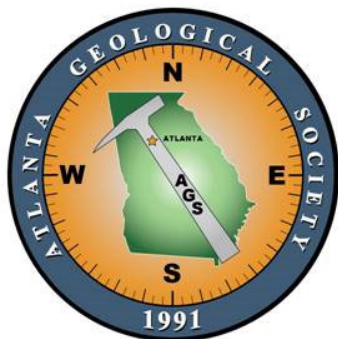




Atlanta Geological Society Newsletter

ODDS AND ENDS

Dear AGS members,

As you are on a journey, it is good to check the map every now and then to make sure you're still on the right track. This is the way felt when I recently had a reason to check the AGS By-Laws. The first item under our Aims and Objectives is: Article II – 1.a. To strengthen and advance the geologic sciences as a profession and to provide an open forum for the exchange of ideas. I'm not sure these words are exactly in the forefront of their minds when Ken Simonton is making the coffee for our Saturday morning PG Study Groups or when John Salvino is picking up our pizzas. Yes, it is glorious to stand among the dinosaurs in the Fernbank rotunda and ponder geology. It is heartwarming to see younger geologists taking notes from the lecturer all in hopes of soon passing the P.G. test. These noble activities are made possible by the work of us all putting in a little effort with the perhaps unrecognized intent of advancing the geologic sciences as a profession. So take a moment and follow the link. This is what we are here for, the greater good for geology.

<http://atlantageologicalsociety.org/wp-content/uploads/2017/06/AGS-Bylaws03-31-05.pdf>

Duty calls, so I will not be there this time. But it is good duty. I get to talk about environmental science for two days teaching a course. Until next time...

Hope to see you Tuesday!

Ben Bentkowski, President

September Meeting

Join us **Tuesday, September 24, 2019** at the Fernbank Museum of Natural History, 760 Clifton Road NE, Atlanta GA. The social starts at 6:30 pm and the meeting starts at 7:00 p.m.

This month our presentation is **“Deep Soil Core Monoliths: Artifacts of Soil Development”**

presented by Dr. Steve Fitzpatrick Please find more information about the presentation and Dr. Fitzpatrick's bio on the next page.

Please come out, enjoy a bite to eat, the camaraderie, an interesting presentation and perhaps some discussion on the importance of accurate mineral characterization. Also, the differences that can exist between mineralogical, industrial and regulatory definitions for minerals.

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Atlanta Geological Society September Speaker

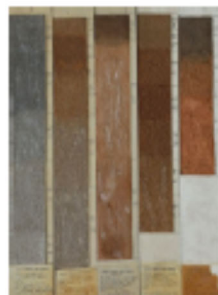
“Deep Soil Core Monoliths: Artifacts of Soil Development”

Speaker Dr. Steve Fitzpatrick's Bio:

Steve Fitzpatrick is a lecturer at Georgia State University Perimeter College. He obtained both his bachelor's and master's degree at the University of Georgia's Department of Geology. Steve is primarily a hydrogeologist having done focused work on runoff, infiltration and kinematic pressure driven throughflow, as well as imaging the subsurface utilizing ground-penetrating radar. He has led numerous field trips in the North Georgia Piedmont, often taking students to hydrologically-critical sites such as developmentally challenged urban streams and ecosystems. Currently Mr. Fitzpatrick is working on a PhD in geochemistry at Georgia State University's Geoscience Department investigating new mechanisms for characterizing sediment transport through routing methods and sediment fingerprinting analysis. He spends his spare time exercising, doing outdoors activities and playing guitar. Steve has a daughter, in high school, who has found an interest in oceanography.

Abstract:

Soil horizonation presents a visible history of soil development. There are several methods that have been used to study soils. One of those approaches, the creation of soil monoliths serves as a useful teaching aid in the study of the Earth's critical zone where rock, soil, water, air, and organisms interact. Typical monolith preparation has so far been confined to the 1- to 2-m depth of the solum. Critical ecosystem services provided by soils also occur in materials from the deeper soil profile. Soil monolith preparation needs to take this new paradigm into account. Soil cores from such depths can be obtained during site investigations for studies of various engineering and environmental problems. The complexity of soil structure makes the preservation and presentation of cores into monoliths difficult. For mobile and vertical displays, a solution of acetone and polyvinylidene chloride (PVDC) at a 5:1 mass ratio can be used to create good structurally sound deep soil core monoliths. Several soil cores were obtained during installation of monitoring wells at two sites 2.5 km apart in the Piedmont of Georgia in the southeastern United States. To reduce health and safety risk, a well-ventilated location and use of protective gear, while handling and using chemicals, is essential to the process. The finished products are in display at the Geology Department, University of Georgia, Athens, GA in the USA.



Defluorination of Perfluorooctanoic Acid (PFOA) and Perfluorooctane Sulfonate (PFOS) by *Acidimicrobium* sp. Strain A6

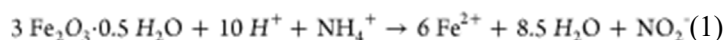
Introduction

PFAS (per- and polyfluoroalkyl substances) are known to be among the most challenging organic pollutants to remediate in aquatic and terrestrial environments. PFAS are found in a wide range of consumer products, they are ubiquitous in the environment, and are extremely recalcitrant. Among them, perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS), which have been manufactured widely and can also be formed via degradation of precursors, are the most common PFAS present in many environmental settings and are of increasing concern. Studies indicate that PFOA and PFOS pose considerable threats to the natural environment and human health because of their wide distribution, extraordinary persistence, bioaccumulation tendencies, and potential toxicological effects. Therefore, identifying methods to mineralize these PFAS is a topic of growing urgency.

The carbon–fluorine (C–F) bond is the strongest covalent bond in organic chemistry, hence biodegradation of perfluoroalkyl chemicals is difficult and usually limited to molecules, or regions of molecules, that are not fully fluorinated such as fluorobenzene, fluoroacetate, perfluorohexylethanol, and perfluorohexylsulfonate. Fluorotelomer compounds, which have an ethyl group between the perfluoroalkyl chain and the rest of the nonfluorinated functional groups, can undergo extensive transformations, resulting in a partial defluorination or shortening of the perfluoroalkyl chain. These findings on fluorotelomer transformation are consistent with those on degradations of difluoromethane sulfonate (DFMS) and 2,2,2-trifluoroethane sulfonate (TES), all of which contain C–H bonds, indicating that the lack of C–H bonds in perfluorinated compounds like PFOA and PFOS makes them more difficult to degrade.

Studies of successful PFOA and PFOS biodegradation, especially mineralization, are limited. It has been reported that PFOS and PFOA can be eliminated using activated sludge as a seed and incubated under anaerobic conditions, although the buildup of fluoride ion (F^-) was not observed. In studies by single cultures, a decrease of about 32% of PFOA was observed after a 96 h incubation with *Pseudomonas parafulva*, and 67% of PFOS was biologically decomposed by *Pseudomonas aeruginosa* over 48 h. The degradation of PFOS by *Pseudomonas plecoglossicida* was studied, which showed that this strain can use PFOS as a carbon source, transforming it to perfluoroheptanoic acid and releasing F^- . Although reductive defluorination has been shown to be energetically favorable, up to date, no bioreductive defluorination of perfluorinated compounds such as PFOA and PFOS has been reported in the literature.

Anaerobic oxidation of ammonium (NH_4^+) under iron-reducing conditions, referred to as Feammox, is a relatively novel pathway in the nitrogen cycle. Here, NH_4^+ is oxidized to nitrite (NO_2^-) coupled to the reduction of ferric iron [Fe(III)] to ferrous iron [Fe(II)]. An autotrophic microorganism responsible for this process, *Acidimicrobium* sp. strain A6 (ATCC, PTA-122488; referred to as A6 from here on), has been identified and isolated. The environmental conditions at sites where the Feammox process occurs and A6 is present have been described and show that the organism is common at sites where the pH is <7 and soils are iron rich. The Feammox process has been reported to occur by many investigators in many different environmental settings. The Feammox stoichiometry when ferrihydrite is the Fe(III) source can be written as:



For this reaction and environmental/incubation conditions described previously, the change in Gibbs free energy (ΔG_r) is 145.08 kJ/mol NH_4^+ . Although oxidation of NH_4^+ to N_2 has been reported for the Feammox process, incubations with A6 have shown that NO_2^- is the product of the NH_4^+ oxidation by this organism. It was also shown that in addition to NH_4^+ , A6 is capable of using H_2 as an electron donor while reducing Fe(III). Furthermore, it was shown that A6 is unable to utilize common organic electron donors as its carbon source, but that it does incorporate CO_2 into its biomass. Given that it has been shown that A6 can cometabolically degrade TCE and PCE, the objective of this research was to determine if PFAS, specifically PFOA and PFOS, can be biodegraded/defluorinated by either the pure A6 and/or an A6 enrichment culture while oxidizing NH_4^+ or H_2 under iron-reducing conditions.

Defluorination of Perfluorooctanoic Acid (PFOA) and Perfluorooctane Sulfonate (PFOS) by *Acidimicrobium* sp. Strain A6 (Continued)

Materials and Methods

Feammox Incubation Experiments

Two hundred milliliters of either a pure A6 culture or an A6 enrichment culture, obtained from a Feammox laboratory-scale continuous-flow membrane reactor, which has been operated for 180 days, were mixed with 500 mL of an anoxic inorganic Fe(III)–NH₄⁺ enrichment medium. This medium consisted of 7.5 mM 6-line ferrihydrite (Fe₂O₃·0.5H₂O, prepared according to Cornell and Schwertmann), 2.81 mM NH₄Cl, 0.19 mM (NH₄)₂SO₄, 0.24 mM NaHCO₃, 0.71 mM KHCO₃, 0.07 mM KH₂PO₄, 0.41 mM MgSO₄·7H₂O, and 0.40 mM CaCl₂·2H₂O, in addition to 1 mL/L of a trace element solution and 1 mL/L of a vitamin solution (ATCC MD-VS). The mixture of medium and culture was then shaken in an anaerobic chamber for 24 h to be homogenized prior to the incubations. An electron shuttling compound, 9,10-anthraquinone-2,7-disulphonic acid (AQDS), was added to the pure A6 culture at 25 µM, which was shown to be needed to grow the pure A6 culture. These mixtures were evenly distributed into multiple 10 mL serum vials in an anaerobic chamber and were sealed with butyl rubber stoppers. The headspace (2 mL) of each vial was vacuumed and then flushed with a N₂/CO₂ (80:20) mixture to achieve anoxic conditions and provide additional CO₂ to the vials, which is required by A6 for its growth. All steps for the inoculation and isolation were carried out under sterilized conditions (autoclaved vials, and the media filtered through a 0.2 µm membrane). The *E_h* in the vials was -135 ± 17 mV, and the initial pH was 4.5 ± 0.2 and increased to 5.0 ± 0.2 during the incubations.

Effects of PFOA and PFOS on the growth of A6 and its Feammox activity were evaluated via incubations at initial concentrations of 0.24 µM, 2.4 µM, 0.024 mM, and 0.24 mM PFOA and 0.20 µM, 2.0 µM, 0.02 mM, and 0.20 mM PFOS (equivalent to 0.1 mg/L, 1.0 mg/L, 10 mg/L, 100 mg/L, and 200 mg/L PFOA/PFOS).

PFOA and PFOS Incubations with NH₄⁺ as Electron Donor

Incubations as described above were conducted with initial concentrations of both 0.24 µM and 0.24 mM (0.1 mg/L and 100 mg/L) PFOA as well as 0.20 µM and 0.20 mM (0.1 mg/L and 100 mg/L) PFOS. The high concentration (0.24 mM PFOA and 0.20 mM PFOS), much higher than what is most often found in contaminated environments, was selected to allow for more accurate F[−] and sulfate (SO₄^{2−}) analyses, fluorine and carbon balance, and to evaluate the effect of defluorination on the reduction of Fe(III). For each set of experiments, several controls were prepared, including a positive control that was identical as described above but without PFAS to compare the Feammox activity in their absence. One set was prepared as described above with the PFAS and was autoclaved. One set was prepared as above with the PFAS and no NH₄⁺ to link the PFAS degradation to Feammox activity (or lack thereof in the absence of NH₄⁺). One set was prepared as described above but without adding a Fe(III) source. Finally, one set was prepared with the PFAS, but instead of seeding the vials with A6, they were seeded with *Geobacter sulfurreducens* ATCC 51573 (with an initial concentration of 0.12×10^7 copies/mL) and augmented with 0.5 mM acetate to determine if the iron reduction and buildup of Fe(II) might be responsible for the degradation of these PFAS. All vials were placed on a rotary shaker at 150 rpm at 30 °C for the incubations. On days 0, 7, 35, 60, and 100, three vials were destructively sampled for Fe(II), NH₄⁺, PFOA/PFOS, dissolved organic carbon (DOC), and microbial analyses. An additional three vials were sacrificed, filtered, and stored at 4 °C to be available if required for further analyses. Given the large time interval between analyzing the data collected on day 60 and day 100, and since data from day 100 are key to assess how much a chemical constituent has changed during the incubations, samples from three stored vials collected on day 60 were analyzed for all compounds measured at the same time as the 100 day samples to ascertain that the accuracy of the various analytical techniques had not changed over time. Hence, n = 6 for day 60.

PFOA and PFOS Incubations with H₂ as Electron Donor

Hydrogen (H₂) was tested as an alternate electron donor to NH₄⁺ for A6 to conduct PFAS degradation/ defluorination. For this purpose, pure A6 and A6 enrichment cultures were incubated with the same medium plus PFAS, but without NH₄⁺, and with H₂ in the headspace of the vials. A small amount of NH₄⁺ (0.15–0.20 mM) was still present in the vials to which no NH₄⁺ was added, which originated from the transfer of cells from the inoculum and was the nitrogen source required for

Defluorination of Perfluorooctanoic Acid (PFOA) and Perfluorooctane Sulfonate (PFOS) by *Acidimicrobium* sp. Strain A6 (Continued)

bacterial growth in these incubations. Five incubation sets were conducted in parallel for both the pure A6 and the A6 enrichment cultures including (1) PFOA/PFOS + Fe(III) + NH_4^+ , (2) PFOA/PFOS + Fe(III) + H_2 , (3) PFOA/PFOS + H_2 , (4) PFOA/PFOS + Fe(III) + NH_4^+ + H_2 , and (5) autoclaved control of PFOA/PFOS + Fe(III) + H_2 . With the exception of the samples to which no NH_4^+ was added, the concentrations of PFOA/PFOS, Fe(III), and NH_4^+ were the same as for the experiments with NH_4^+ as electron donor. The incubations with NH_4^+ instead of H_2 as electron donor were run in parallel to compare the effects of these two electron donors on the degradation of PFAS, under the exact same initial culture activity, bacterial numbers, and incubation conditions.

For each incubation, 2 mL of either a pure A6 or an A6 enrichment culture was mixed with 18 mL of the medium including 0.24 mM PFOA or 0.20 mM PFOS in a 50 mL vial. The headspace of each vial was vacuumed and then, for the incubations with H_2 as electron donor, was filled with a N_2/H_2 (80:20) mixture, while for those with NH_4^+ as electron donor vials were filled with a N_2/CO_2 mixture (80:20). Vials were then placed on a rotary shaker at 150 rpm at 30 °C for a 35 day incubation period. Three subsamples were collected destructively on day 0, 7, 21, and 35 for Fe(II), NH_4^+ , F^- , DOC, and PFOA/PFOS analyses.

Chemical and Microbiological Analyses

PFAS were analyzed commercially by the Guangdong Institute of Microbiology (China) and Eurofins (USA) via ultraperformance liquid chromatography–tandem mass spectrometry (UPLC-MS-MS: Agilent 1290-6430A) following well-established methods. All compounds were quantified with a standard curve in the range of 0.5–100 $\mu\text{g/L}$, after making appropriate dilutions with methanol. A blank control was also included in each sample sequence to ascertain that the target compounds were not detected in their absence. A Zorbax SB-C18 (10 mm $\times$ 2.1 mm, 1.7 μm) column was used at 50 °C, with an isocratic mobile phase composed of (A) (32:0.15% (v/v) acetic acid in water) and (B) (68:0.15% (v/v) acetic acid in methanol) with a flow rate of 0.4 mL/min. The eluent gradient started with 25% (B) for 0.5 min, and then was lineally increased to 95% (B) in 6 mins and held at that gradient for 5 min, and eventually returned to the initial conditions within 1 min and held for 2 mins for equilibration during the injection interval. Detection was done by negative electrospray ionization (ESI) mass spectrometry in a multiple reaction monitoring mode (MRM) (more detailed information is provided in Section S1.1 and Table S1 of the Supporting Information).

Redox potential and pH in the incubation vials were measured using a Hach HQ40d multi-probe meter (Hach, Loveland, CO, USA). DOC and POC (particulate organic carbon) were analyzed using a Shimadzu TOC-5000A analyzer for samples filtered through or retained by 0.2 μm aperture filters. Fe(II) was analyzed via the ferrozine assay method. Different ions were analyzed for filtered samples (0.2 μm) via an ion chromatograph (IC) with a conductivity detector (ICS-3000, Dionex Co., USA), with an AS18 column (4 mm i.d. $\times$ 200 mm) for anions and a CS16 column (4 mm i.d. $\times$ 200 mm) for cations.

Since precise F^- analyses are key in this research, and since they can be affected by various interferences, multiple QA precautions were taken. The analytical method for F^- was modified based on methodologies described in the literature. Two separate IC analyses were conducted. The first one used an AS-18 column with a KOH solution (20 mM) as the eluent, flow rate = 0.80 mL min^{-1} , and the suppressor current was set at 85 mA. The other one used an AS12A column (4 mm i.d. $\times$ 200 mm), with 7.5 mM NaHCO_3 /22.5 mM Na_2CO_3 as the eluent, flow rate = 1.00 mL min^{-1} , and the suppressor current was set at 50 mA. Dionex retention time standards were used as external calibration curves, which contained F^- at seven equal-increment dilutions up to a concentration of 5.2 mM. There was no significant difference ($p < 0.05$) in the measured F^- concentration between IC methods, hence the values reported here for all incubations with the higher PFAS concentrations, and used for the fluoride balances, are for the AS-18 column with KOH as the eluent. Retention times and the chromatograms of the analysis of F^- and other ions are shown in Table S2. As an additional confirmation, F^- was also analyzed using a perfectION combination electrode (Mettler-Toledo, USA). The concentrations measured with the F^- -specific electrode were within 10% of those measured via IC and were not significantly different ($p < 0.05$). F^- measurements for the low-concentration PFAS incubations were somewhat higher using the electrode, and the difference between the IC and the electrode measurements was significant.

Defluorination of Perfluorooctanoic Acid (PFOA) and Perfluorooctane Sulfonate (PFOS) by *Acidimicrobium* sp. Strain A6 (Continued)

Total DNA was extracted from samples of the 100 day incubations with 0.24 mM PFOA and 0.20 mM PFOS (Section S1.2, Supporting Information). Sequencing of the 16S rRNA genes from the A6 enrichment cultures over the incubation period was performed on an Illumina MiSeq platform (Section S1.3, Supporting Information). The 16S rRNA genes of A6 were quantified through quantitative PCR (qPCR) analyses (Section S1.4, Supporting Information).

Statistical Analysis

The normality and homoscedasticity of the data was examined. Significance for all tests was accepted at the 0.05 level. All the analyses were performed using SPSS v12.

Results and Discussion

Degradation of PFOA with NH_4^+ as Electron Donor

Effects of PFOA on the Feammox activity (in terms of NH_4^+ removed and Fe(III) produced, as well as on A6 numbers) were found to be negligible within the concentration of interest over a 2 week incubation and are discussed in [Section S2 and Figure S1](#) of the Supporting Information. [Figure 1](#) shows results for incubations with an initial PFOA concentration of 0.24 mM (100 mg/L) for the pure A6 and the A6 enrichment cultures. Comparable NH_4^+ removal, Fe(II) and NO_2^- production, and A6-16S rRNA gene numbers during the incubations ([Figure 1c, d, f and Figure S3a](#)) show that both cultures had very similar Feammox activity. While all incubations were set up without adding organic carbon, buildup of acetate ([Figure 1e](#)) was detected in both cultures during incubations with PFOA, and to higher levels than in the positive control without PFOA ([Figures S4c and S6c](#)).

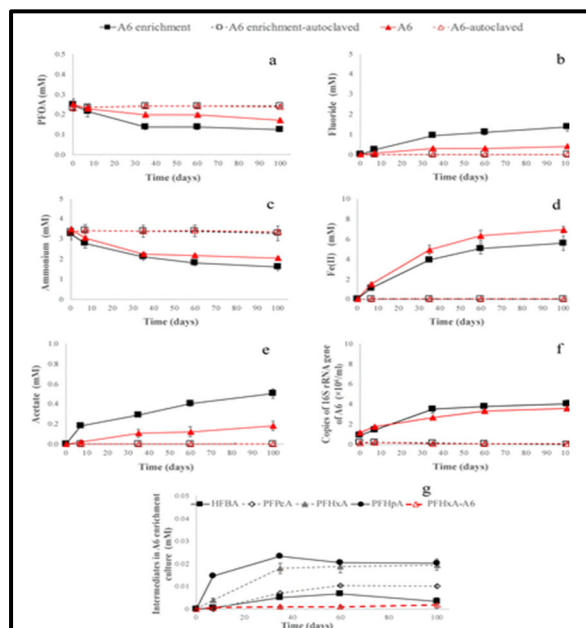


Figure 1. Results of PFOA 0.24 mM (100 mg/L) incubations with pure A6 and A6 enrichment cultures and NH_4^+ as electron donor [av. (SD), $n = 3$ for all samples, except for day 60 for which $n = 6$].

Over the 100 day incubations, a 0.12 mM (50%) decrease of PFOA was detected in the A6 enrichment culture and 0.08 mM (33%) in the pure A6 culture ([Figure 1a](#)). Four intermediate products, including perfluorobutanoic acid (HFBA), perfluoropentanoic acid (PFPeA), perfluorohexanoic acid (PFHxA), and perfluoroheptanoic acid (PFHpA) ([Figure 1g](#)) were detected in the A6 enrichment culture incubations, neither of which was present initially nor in any control. Only perfluorohexanoic acid (PFHxA) was detected in the incubation with the pure A6 culture, and at much lower concentrations ($0.12 \pm 0.05 \mu\text{M}$) than in the A6 enrichment culture. After the incubation, 1.36 mM of F^- was detected in the A6 enrichment culture, and 0.42 mM in the pure A6 culture incubations ([Figure 1b](#)). During the same period, the 16S rRNA gene numbers of A6 increased from 1.15×10^6 to 3.57×10^6 copies/mL in the pure culture and from 0.87×10^6 to 4.02×10^6 copies/mL in the enrichment culture ([Figure 1f](#)).

There were no changes in concentration of any of the chemical species monitored in the autoclaved controls, and there was no PFOA removal or F^- generation in the cultures without Fe(III) or NH_4^+ , nor in the incubations with *G. sulfurreducens* ([Figures S4 and S6](#)). Over the 100 day incubations, *Geobacter* increased from 0.12×10^7 to 2.12×10^7 copies/mL and produced 6.98 mM Fe(II) ([Figure S6](#)). Results for the incubations with an initial concentration of 0.24 μM (0.1 mg/L) show a 0.15 μM (63%) PFOA removal for both the pure A6 and the A6 enrichment cultures ([Figure S8](#)).

Defluorination of Perfluorooctanoic Acid (PFOA) and Perfluorooctane Sulfonate (PFOS) by *Acidimicrobium* sp. Strain A6 (Continued)

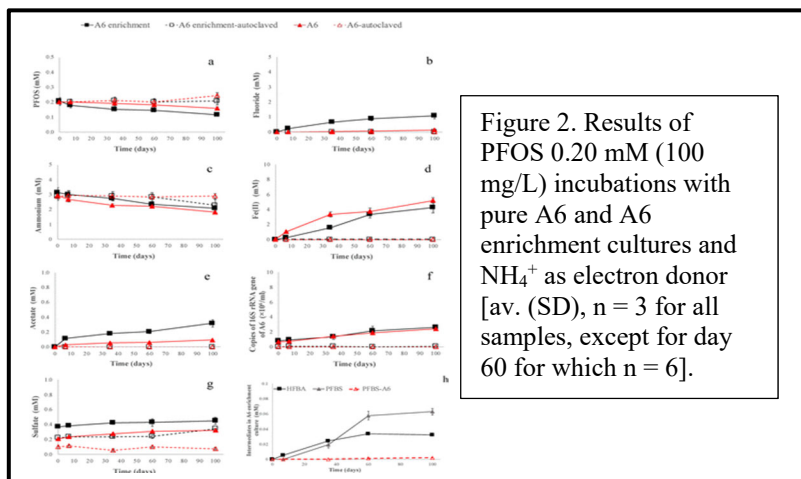
Due to the low concentrations, neither the intermediate nor end products were analyzed. The higher relative error of the F⁻ analysis at this concentration and lack of quantified intermediates does not allow for an accurate fluorine balance. Acetate concentrations in the incubations with 0.24 μM PFOA (Figure S8e) are somewhat higher than those in the positive control (Figure S4c) but not significantly different.

Degradation of PFOS with NH_4^+ as Electron Donor

Similar to the results for PFOA, effects of PFOS on Feammox activity were negligible as discussed in [Section S2](#) and [Figure S2](#) in the Supporting Information. As shown in [Figure 2](#), 0.045 mM (23%) of PFOS was removed by the pure A6 culture over 100 days of incubation, and 0.093 mM (47%) by the A6 enrichment culture. Intermediates detected in the A6 enrichment culture include HFBA and perfluorobutane sulfonate (PFBS) (Figure 2h), while the only intermediate detected in the pure A6 culture incubation, and at a much lower concentration, is PFBS.

As for the incubations with PFOA, comparable NH_4^+ oxidation, and Fe(III) and NO_2^- production were found in both cultures during these incubations (Figure 2c, d and Figure S3b). The number of A6-16S rRNA genes in the pure culture increased from 0.70×10^6 to 3.32×10^6 copies/mL, and from 0.85×10^6 to 3.51×10^6 copies/mL in the enrichment culture (Figure 2f). The F⁻ measurements show that 1.07 mM of F⁻ was produced during the 100 day incubation with the A6 enrichment culture, which is almost 10 times higher than the amount of F⁻ produced in the pure A6 culture incubation (Figure 2b). An increase of 0.13 mM SO_4^{2-} was observed in the pure A6 culture during the PFOS incubations (Figure 2g), which was not observed in the incubations with PFOA. Autoclaving the medium in the presence of ferrihydrite resulted in a decrease in the dissolved SO_4^{2-} concentration as can be seen in Figure 2g. The noisier baseline of the autoclaved control makes it harder to state conclusively that there was a significant increase in the SO_4^{2-} concentration in the A6 enrichment culture. Furthermore, the presence of sulfate reducers (see microbial community discussions below), decrease in SO_4^{2-} over time in the positive control (Figure S7g), and coupled to the decrease in DOC vs time in the A6 enrichment culture (see dissolved carbon balance section below) indicate that sulfate reduction could have occurred in the A6 enrichment culture incubations, which makes it difficult to determine if sulfate was produced from the degradation of PFOS in these incubations.

There were no changes in concentration of any of the chemical species monitored in the autoclaved controls where there was no PFOS removal or F⁻ generation in the cultures without Fe(III) or NH_4^+ and neither was there PFOS removal in the incubations with *G. sulfurreducens* (Figures S5 and S7). Over the incubation period, *G. sulfurreducens* numbers increased from 0.12×10^7 to 1.98×10^7 copies/mL, producing 6.24 mM Fe(II) (Figure S7). Results for the incubations with an initial concentration of 0.20 μM (100 $\mu\text{g/L}$) PFOS shown in Figure S9 show that the pure A6 culture removed 0.07 μM (35%) PFOS and the A6 enrichment culture removed 0.12 μM (60%) over the incubation period. It is interesting to note that, in general, the fraction of PFOA/PFOS removed by each culture was similar for the incubations with the high and the low PFOA/PFOS concentration.



Degradation of PFOA and PFOS with H_2 as Electron Donor

A comparable amount of PFOA removal was observed during 35 days of incubation in both the pure A6 and the A6 enrichment cultures when either Fe(III) + NH_4^+ or Fe(III) + H_2 were present (Figure S10a). Similar results were observed for the PFOS incubations (Figure S11a). No PFAS removal was observed in the autoclaved controls (Figures S10a and S11a), nor in any of the other controls discussed above. A noticeable increase over time of fluorinated degradation products (HBFA, PFPeA, PFHxA, and PFHxA for the PFOA incubations and HBFA and PFBS for the

Defluorination of Perfluorooctanoic Acid (PFOA) and Perfluorooctane Sulfonate (PFOS) by *Acidimicrobium* sp. Strain A6 (Continued)

PFOS incubations) was detected in the A6 enrichment culture incubations (Figures S10g,h and S11g,h). A buildup of fluorinated degradation products was not observed in the pure A6 culture incubations. Sulfate buildup in the PFOS incubations (Figure S11g) was significant for the pure A6 culture incubations when either NH_4^+ or H_2 was the electron acceptor, while for the enrichment culture the increase in sulfate was only significant when NH_4^+ was the electron donor.

Characteristics of the Microbial Community during Incubations with and without PFOA/PFOS

The microbial community analysis reveals the presence of denitrifiers (*Ralstonia* and *Bacillus*), iron reducers (*Acidimicrobium* and *Aciditerrimonas*), and sulfate reducers (*Desulfosporosinus*). These organisms might have been using the NO_2^- generated from the Feammox process, Fe(III), and SO_4^{2-} present in the medium as electron acceptors to oxidize the defluorinated or partially defluorinated products from the PFOS/PFOA defluorination, resulting in the decreasing DOC vs time in the A6 enrichment culture.

Although the short term effects of PFOA and PFOS were negligible on the Feammox activity, the microbial community analysis from the A6 enrichment culture of samples collected on day 0 and day 60 shows that the composition of the community with PFOA diverged over time from that with PFOS, while the change of the composition in samples without PFAS was much smaller (Figure S12).

It is also interesting to note that *Acidimicrobium* was dominant at the onset of the incubations (Figure S12). Although copy numbers of A6 increased during the 60 day incubations (more in the presence of PFOA than PFOS) the relative population of the *Acidimicrobium* decreased in the positive control incubations, more so in the presence of PFAS, and most in the presence of PFOS. The larger relative *Acidimicrobium* population in the PFOA incubations (22.6%) vs the PFOS incubations (10.4%) is consistent with the higher 16S rRNA gene numbers of A6 in that incubation, and a higher Feammox activity in terms of NH_4^+ removal (39% higher than in the PFOS incubation) and Fe(II) production (47% higher than in the PFOS incubation) over the same time period. The higher Feammox activity in the PFOA A6 enrichment culture incubations also corresponds to a higher PFOA removal and F^- production vs PFOS removal and F^- production in the PFOS incubations. Hence, it appears that, at these rather high concentrations, PFOS has a more detrimental effect on A6 than PFOA. Further work is needed to explore the threshold concentrations where this effect becomes less marked, and if it may have an impact on long-term PFOS bioremediation schemes with A6.

Fluorine Balance

The results for PFOA/PFOS degradation allow for a fluorine balance during each incubation, which for the A6 enrichment culture is shown in Table 1 for PFOA and in Table S3 for PFOS. Results show a good fluorine balance, which gives confidence in the accuracy of the analyses shown in Figures 1 and 2.

The same fluorine balances for incubations with the pure A6 culture are shown in Table S4 for PFOA and in Table S5 for PFOS. The fluorine balance for the pure A6 culture incubations shows a slight decreasing trend in total quantified fluorine over time for both the incubation with PFOA and with PFOS, indicating that some fluorinated intermediates might have been present but were not detected. Standards for partially fluorinated intermediates were not available and, if present, such compounds were not detected.

Effect of Defluorination on Fe(III) Reduction

As shown by Equation 1, the expected molar ratio of Fe(II) produced to NH_4^+ oxidized is 6:1. If during the defluorination process, some electrons from the oxidation of NH_4^+ are transferred to the PFAS to free F^- instead of being transferred to Fe(III) to produce Fe(II), one should expect a commensurate decrease in Fe(III) reduction. Results of the Fe(II)/ NH_4^+ ratio vs time during the A6 enrichment culture incubations with PFOA and PFOS are shown in Table 2 and in Table S6, respectively,

Defluorination of Perfluorooctanoic Acid (PFOA) and Perfluorooctane Sulfonate (PFOS) by *Acidimicrobium* sp. Strain A6 (Continued)

and in Table S7 and in Table S8 for the pure A6 culture with PFOA and PFOS, respectively. The first column in each table shows the observed $\text{Fe(II)}/\text{NH}_4^+$ ratio for incubations with PFOA/PFOS, the second column shows the ratio of $[\text{Fe(II)} + \text{F}^-]/\text{NH}_4^+$ for incubations with PFOA/PFOS, while the third column shows the $\text{Fe(II)}/\text{NH}_4^+$ ratio of the positive controls that were incubated in parallel without PFOA/PFOS. The actual $\text{Fe(II)}/\text{NH}_4^+$ ratio observed during Feammox incubations is usually less than 6:1, which is attributed to (i) a less efficient Fe(II) extraction especially early on during the incubations, (ii) when AQDS is present, the reduction of AQDS and buildup of AH_2QDS , which accumulates early on during incubations, and (iii) the possible oxidation of Fe(II) by NO_2^- , especially when the pH is >6 .

By day 100, the $\text{Fe(II)}/\text{NH}_4^+$ ratio in the controls without PFOA and PFOS was between 4.6 and 4.8 in the A6 enrichment culture and between 4.8 and 5.1 in the pure A6 culture. In contrast, the respective $\text{Fe(II)}/\text{NH}_4^+$ ratio in the presence of these PFAS was lower (3.4 to 4.0 in the A6 enrichment culture and 4.6 and 4.8 in the pure A6 culture), while the $[\text{Fe(II)} + \text{F}^-]/\text{NH}_4^+$ was closer to the positive controls. These analyses suggest that these PFAS may be acting as alternative electron acceptors to Fe(III) , and hence, that the F^- production could be due to reductive defluorination. Incubations without Fe(III) (Figures S6a and S7a) did not result in defluorination, indicating that these PFAS, at the experimental conditions described here, cannot be used as sole electron acceptors for the growth of A6 using NH_4^+ or H_2 as electron donors. Results also show that in the presence of these PFAS, even at the high concentrations used here, the large majority of electrons were transferred to Fe(III) .

Dissolved Organic Carbon Balance

DOC analyses were performed immediately after sampling during the 35 day incubations, and DOC balances were performed on these 0.24 mM PFOA and 0.20 mM PFOS incubations with both NH_4^+ and H_2 as electron donors.

As A6 numbers increased during the incubations, with CO_2 as the carbon source (Figure 1f and Figure 2f), the particulate organic carbon (POC) increased from 1.42 mM to 2.05 mM and from 1.29 mM to 1.78 mM in the 100 day PFOA and PFOS pure A6 culture incubations, respectively. In contrast, DOC remained constant over the incubation time in the pure A6 culture (Table 3 and Table S9 as well as Figures S10f and S11f). Although no organic carbon (except the PFAS) was supplied to any vials, there was a background DOC in the positive control (without PFAS), ranging from 0.18 ± 0.02 to 0.36 ± 0.03 mM over the 35 day incubations for the pure A6 and the A6 enrichment culture, respectively, which is attributed to the long-term fixation of organic carbon by this autotroph. At 0.24 mM PFOA and 0.20 mM PFOS, their contribution to the total DOC is an order of magnitude higher than that of the background DOC. Given that the DOC fixed during the 35 day incubation period is negligible in comparison to the DOC from the PFAS added, a constant DOC vs time in the pure A6 culture incubations indicates that none of the PFAS that were being degraded nor their degradation products were oxidized to CO_2 .

DOC was measured as described above as well as estimated. DOC as a function of incubation time was estimated based on the concentration and molecular formula of the initial PFAS, fluorinated intermediates, and acetate for each timepoint. The background DOC from the positive control (no PFAS) was then added to these estimated DOC values (for the pure A6 culture: 0.18 mM for PFOA and 0.17 mM for PFOS; for the A6 enrichment culture: 0.35 mM for PFOA and 0.38 mM for PFOS incubations). Hence, a close match between the measured and estimated DOC indicates that the major dissolved organic compounds, which includes the original PFAS and their degradation products (fluorinated and nonfluorinated organics), have been properly quantified.

Table 4 and Table S10 show the measured and estimated DOC vs time for the incubations with the A6 enrichment culture when either NH_4^+ or H_2 is used as electron donor, for incubations with PFOA and PFOS, respectively. Results show that the DOC decreased at a rate of $\sim 5.7 \mu\text{M day}^{-1}$, which is attributed to the presence of heterotrophic bacteria that can grow on PFOA/PFOS degradation products such as acetate while using electron acceptors such as NO_2^- (Figure S3), Fe(III) , or SO_4^{2-} . The measured and estimated DOC values are in close agreement, indicating that the key degradation intermediates contributing to the DOC have been identified and properly quantified.

Defluorination of Perfluorooctanoic Acid (PFOA) and Perfluorooctane Sulfonate (PFOS) by *Acidimicrobium* sp. Strain A6 (Continued)

Table 3 and Table S9 show the measured and estimated DOC vs time for the incubations with the pure A6 culture with NH_4^+ or H_2 as an electron donor for incubations with PFOA and PFOS, respectively. In contrast to the A6 enrichment culture, here the DOC remains constant with time, indicating that, as expected, A6 does not utilize PFOA or PFOS nor any of their degradation products as carbon source. Results again show a good agreement between measured and estimated DOC.

Production of Shorter Chain Fluorinated Compounds

The production during incubations with the A6 enrichment culture of shorter-chain fluorinated compounds such as HFBA, PFPeA, PFHxA, and PFHpA during the degradation of PFOA, and the production of PFBS and HFBA during the degradation of PFOS show that in addition to defluorination, the C–C bond of these molecules was oxidized. Production of SO_4^{2-} in the PFOS incubations indicates that the C–S bond was oxidized.

Concentrations of shorter carbon chain–perfluorinated intermediates and of acetate in the incubations with the pure A6 culture were much lower than those in the A6 enrichment culture and not detected when H_2 was the electron donor. As mentioned above, the decrease over time in total fluorine quantified (0.56 mM for PFOA and 0.58 mM for PFOS over 100 days, Tables S4 and S5) indicates the possibility of the formation and accumulation of other fluorinated organics in the pure A6 culture that were not detected. Hence, further research is needed to determine what fluorinated intermediates that have not been identified here might be produced, and when and to what degree the pure A6 culture is capable of breaking the C–C bond.

Although the Feammox activity in the pure and enriched A6 culture was similar in terms of NH_4^+ removed and Fe(II) produced as well as A6 numbers, the A6 enrichment culture had a higher overall PFOA and PFOS removal and production of smaller perfluorinated compounds, acetate, and F^- . This indicates the possibility of a synergistic interaction between A6 and other organisms in the A6 enrichment culture during the degradation of these PFAS, where once a perfluorinated compound has been partially defluorinated by A6, heterotrophs in the A6 enrichment culture are capable of further degrading these intermediates. Since A6 is an autotroph and no organic carbon was added to the incubations, the increase in acetate above that in the positive control during the incubations with the PFAS, coupled with the carbon balance, indicates that complete defluorination of PFOA and PFOS may be achieved by these cultures. Incubations with ^{13}C -labeled PFAS will have to be conducted to confirm that the acetate is a product from the PFAS degradation.

Possible Environmental Settings for PFAS Remediation via Feammox

Given that the Feammox process has been reported in many environmental settings, as long as the pH is acidic and soils are iron rich, the results presented here indicate that under the right conditions, the Feammox process could be stimulated to achieve PFAS biodegradation in contaminated sediments and groundwater systems. The Feammox process has been stimulated successfully in constructed wetland mesocosms and microbial electrolysis cell for the removal of NH_4^+ and in soil columns for the removal of TCE.

Read more about this article at: <https://pubs.acs.org/doi/full/10.1021/acs.est.9b04047>

Can the world make the chemicals it needs without oil?

Black, gooey, greasy oil is the starting material for more than just transportation fuel. It's also the source of dozens of petrochemicals that companies transform into versatile and valued materials for modern life: gleaming paints, tough and moldable plastics, pesticides, and detergents. Industrial processes produce something like beauty out of the ooze. By breaking the hydrocarbons in oil and natural gas into simpler compounds and then assembling those building blocks, scientists long ago learned to construct molecules of exquisite complexity. Fossil fuels aren't just the feedstock for those reactions; they also provide the heat and pressure that drive them. As a result, industrial chemistry's use of petroleum accounts for 14% of all greenhouse gas emissions. Now, growing numbers of scientists and, more important, companies think the same final

Can the world make the chemicals it needs without oil? (Continued)

compounds could be made by harnessing renewable energy instead of digging up and rearranging hydrocarbons and spewing waste carbon dioxide (CO₂) into the air. First, renewable electricity would split abundant molecules such as CO₂, water, oxygen (O₂), and nitrogen into reactive fragments. Then, more renewable electricity would help stitch those chemical pieces together to create the products that modern society relies on and is unlikely to give up.

"This is very much a topic at the forefront right now," says Daniel Kammen, a physicist at the University of California, Berkeley. Chemists in academia, at startups, and even at industrial giants are testing processes—even prototype plants—that use solar and wind energy, plus air and water, as feedstocks. "We're turning electrons into chemicals," says Nicholas Flanders, CEO of one contender, a startup called Opus 12. The company, located in a low-slung office park in Berkeley, has designed a washing machine-size device that uses electricity to convert water and CO₂ from the air into fuels and other molecules, with no need for oil. At the other end of the commercial scale is Siemens, the manufacturing conglomerate based in Munich, Germany. That company is selling large-scale electrolyzers that use electricity to split water into O₂ and hydrogen (H₂), which can serve as a fuel or chemical feedstock. Even petroleum companies such as Shell and Chevron are looking for ways to turn renewable power into fuels.

Changing the lifeblood of industrial chemistry from fossil fuels to renewable electricity "will not happen in 1 to 2 years," says Maximilian Fleischer, chief expert in energy technology at Siemens. Renewable energy is still too scarce and intermittent for now. However, he adds, "It's a general trend that is accepted by everybody" in the chemical industry.

A SHARP RISE in supplies of solar, wind, and other forms of renewable electricity lies behind the trend. In 2018, the world surpassed 1 terawatt (TW) of installed solar and wind capacity. The second TW is expected by mid-2023, at just half the cost of the first, and the pace is likely to accelerate. One recent analysis suggests lower prices for renewable generation could prompt the development of 30 to 70 TW of solar energy capacity alone by 2050, enough to cover a majority of global energy needs. "In the near future there will be a bunch of renewable electrons around," says Edward Sargent, a chemist at the University of Toronto in Canada. "And a lot of them are going to be cheap." According to the National Renewable Energy Laboratory, the cost of utility-scale solar power should drop by 50% by 2050 and the cost of wind power by 30%.

That surge in renewables has already led to brief periods when electricity supplies exceed demand, such as midday in sunny Southern California. The result is dramatic price drops. At times, utilities even pay customers to take electricity so that excess supply doesn't melt transmission lines. "This gives us an opportunity to make something valuable with these electrons," Sargent says.

One potential role for those electrons is to displace the fossil fuels that now provide the heat needed to drive industrial reactions. In the 24 May issue of *Science*, Sebastian Wismann and Ib Chorkendorff of the Technical University of Denmark in Kongens Lyngby and colleagues reported redesigning a conventional fossil fuel-powered reactor that makes H₂ from methane and steam to run on electricity. In their new reactor, electricity flowing through an iron alloy tube encounters resistance, pushing temperatures as high as 800°C. The heat causes methane and steam flowing through the tube to react, stripping H₂ from methane more efficiently than traditional methods and potentially offering both cost savings and reduced climate impact.

But even if the heat comes from electricity, reactions such as those that generate fuel from methane still emit waste CO₂. Chemists want to go further, harnessing electrons not just as a source of heat, but as a direct input to the reactions. Industrial chemists already use electricity to smelt aluminum from bauxite ore and generate chlorine from salt—electron-adding reactions for which electrically driven chemistry is ideally suited. But as with H₂, most commodity chemicals are made from fossil fuels, transformed with heat and pressure generated by more fossil fuels.

Giving up those fuels doesn't involve chemical magic. Key industrial chemicals such as carbon monoxide (CO) and ethylene can already be made by adding electrons to abundant starting materials such as CO₂ and water, if efficiency is no object. The trick is to do so economically.

Can the world make the chemicals it needs without oil? (Continued)

That process requires a cheap source of renewable electricity. But according to an analysis in the 26 April issue of *Science* led by Sargent and Thomas Jaramillo, a chemical engineer at Stanford University in Palo Alto, California, that's not the only prerequisite. Sargent, Jaramillo, and colleagues compared the costs of making a variety of simple industrial compounds with fossil fuels or renewable electricity. They found that electrosynthesis would be competitive for producing chemical staples such as CO, H₂, ethanol, and ethylene if electricity cost 4 cents per kilowatt hour (kWh) or less—and if the conversion of electrical energy to energy stored in chemical bonds was at least 60% efficient.

If electricity's cost fell further, more compounds would be within reach. In a May 2018 analysis in *Joule*, Sargent and colleagues found that under stricter market assumptions, including an electricity price of 2 cents/kWh, synthesizing formic acid, ethylene glycol, and propanol would all be feasible. "This gives us a clear set of targets," says chemist Phil De Luna, a Sargent collaborator at National Research Council Canada in Toronto.

Sargent's papers are "right on the mark," says Harry Gray, a chemist at the California Institute of Technology (Caltech) in Pasadena, who has analyzed what's needed to displace fossil fuels with electrosynthesis. Of making commodities by electrosynthesis, he says, "I think we'll be there within 10 years."

Kammen notes that several utility-scale solar and wind projects already meet one benchmark, delivering power at or below 4 cents/kWh, and the cost of renewables continues to decline. But reaching 60% conversion efficiency of electrical to chemical energy is a bigger challenge, and that's where researchers are focusing their efforts.

The simplest processes, those that make H₂ and CO, are already reaching that second benchmark. According to Fleischer, commercial electrolyzers from Siemens and other companies already do better than 60% efficiency in splitting water to produce H₂. Siemens uses an established technology called proton-exchange membrane (PEM) electrolyzers, which apply a voltage between two electrodes, one on each side of a polymer membrane. The voltage splits water molecules at a catalyst-coated anode into O₂, hydrogen ions, and electrons. The membrane only allows hydrogen ions to pass to the other catalyst-coated electrode, the cathode, where they meet up with electrons to generate H₂ gas. The cost of the H₂ produced has fallen dramatically in recent years as the size of electrolyzers has increased to industrial scale. Still, Bill Tumas, an associate lab director at the National Renewable Energy Laboratory in Golden, Colorado, noted last month at a meeting of the American Chemical Society that the cost of the electrolyzers, as well as their component electrode materials and catalysts, needs to drop further to generate H₂ at a price competitive with massive thermal plants that break apart methane.

Opus 12 and other companies also rely on PEM electrolyzers but add a supplementary catalyst to the cathode to split piped-in CO₂ into CO and O₂. The CO can be captured and sold for use in chemical manufacturing. Or it can be combined with hydrogen ions and electrons generated at the anode to construct a range of other building blocks for industrial chemistry, including gases such as ethylene—the raw material for certain plastics—and liquids such as ethanol and methanol. According to Etosha Cave, Opus 12's chief scientific officer, the company has already produced 16 commodity chemicals. And it is working to scale up its reactors over the next few years to process tons of CO₂ per day, most likely captured from flue gas from power plants and other industrial sources.

The growing supply of renewable energy has some chemists thinking about ways to generate carbon-neutral fuels. Last month, in Dresden, Germany, a company called Sunfire completed a test run of a high-temperature electrolysis reactor, known as a solid-oxide fuel cell, that promises even higher efficiency than PEM electrolyzers. The reactor is at the heart of a four-stage test plant that generates fuel from water, CO₂, and electricity. The first stage of the boxcar-size plant separates CO₂ from air and then feeds the CO₂ to Sunfire's fuel cell. It works a bit differently from its PEM counterparts: It uses electricity to split both water and CO₂ at the cathode, generating a mix of CO, H₂, and negatively charged oxygen atoms, or oxide ions. Those ions travel through an oxygen-permeable solid membrane to the anode, where they give up electrons and combine to produce O₂. The mix of CO and H₂, known as synthesis gas, then moves to a third reactor, which assembles them into more complex hydrocarbons. At the fourth stage, those hydrocarbons are combined with more H₂ and refashioned into the mix of hydrocarbons in gasoline, diesel, and jet fuel. Because the plant works at high temperatures, the water- and CO₂-splitting reactions convert electrical energy to chemical bonds at nearly 80% efficiency, the company says.

Can the world make the chemicals it needs without oil? (Continued)

Sunfire's test plant now makes about 10 liters of fuel per day. The company is already scaling up the technology and plans to open its first commercial plant, in Norway, next year. The setup will be part of a larger plant that will use 20 megawatts of hydropower to produce 8000 tons of transportation fuel per year, enough to supply 13,000 cars. Its method will avoid producing 28,600 tons of CO₂ annually from fossil fuels.

Another advance could also boost efficiency: using industrial waste as the source of electrons needed to split off CO from CO₂. Oxygen's formation at the anode, producing electrons, is normally so sluggish that 90% of the overall process's electrical energy goes to this reaction. In the 22 April issue of *Nature Energy*, chemist Paul Kenis of the University of Illinois in Urbana and colleagues reported spiking the anode with glycerol—a clear, viscous liquid that's a byproduct of biodiesel production—which gives up its electrons more readily. By doing so, the technique could reduce the energy requirement for splitting CO₂ by 53%. And as a bonus, when glycerol loses electrons, it produces a combination of formic acid and lactic acid, two common industrial compounds used as preservatives and in cleaning products and cosmetics. "You take a waste and turn it into something of value," Kenis says.

THOUGH SIMPLE INDUSTRIAL chemicals may be poised for greening, directly synthesizing most complex hydrocarbons with electricity remains too inefficient and costly. Even making compounds with just two carbons, such as ethylene and ethanol, typically captures only about 35% of the input of electrical energy in the final compound. With three-carbon compounds and beyond, the efficiency can drop below 10%. The problems are twofold: First, every time new bonds are forged, some energy is lost. And generating more-complex hydrocarbons inevitably means making more side products. That outcome forces producers to separate their desired compound, at extra cost.

But innovations are starting to help there, too, including better catalysts. In the 21 August online issue of *Joule*, for example, Sargent and his colleagues report creating a device that uses a membrane coated with a copper catalyst to convert CO₂ and steam to a mix of two-carbon compounds, including ethylene and ethanol, with 80% efficiency. They achieved that efficiency by pressing one electrode directly onto the membrane, thereby eliminating a fluid-filled gap that was sapping energy and was causing the device to break down quickly.

One class of complex molecules that could prove easier to make with electricity is carbon nanotubes. Those long, hollow, strawlike molecules—prized for their strength and electronic capabilities—are commonly made through chemical vapor deposition: In a heated quartz tube, cobalt and iron catalysts strip away carbon atoms from pumped-in acetylene gas and add them to growing nanotubes that take seed on the metal particles. That process is energy intensive and expensive, typically costing about \$100,000 to produce 1 ton of nanotubes. But in 2015 in *Nano Letters*, Stuart Licht, a chemist at George Washington University in Washington, D.C., and colleagues reported an electrolysis approach calculated to cost one-100th as much.

Licht's setup starts with molten lithium carbonate spiked with metal catalysts. An electric current strips carbon atoms from the lithium carbonate and adds heat that sustains the reaction. The catalysts pick up the carbons and insert them into growing nanotubes. Bubbling CO₂ into the mix then regenerates the lithium carbonate. The process is 97.5% efficient. Because it uses waste CO₂, Licht notes it is carbon negative: Making each ton of carbon nanotubes uses 4 tons of CO₂.

The nanotubes can then be mixed into cement to create a high-strength composite that sequesters the carbon, keeping it from oxidizing and returning to the atmosphere. The tubes can also be mixed with metals such as aluminum, titanium, and stainless steel to strengthen them. C2CNT, a company Licht formed to commercialize the technology, is one of 10 finalists for the Carbon XPrize, which will award \$20 million for successful technologies for turning CO₂ into products.

HOW QUICKLY THE VAST chemical plants sprawling over the world's industrial zones will shift from fossil fuels to green power is a matter of debate. Nate Lewis, a chemical engineer at Caltech, says the transition will be slow. One major hurdle, he notes, is that renewables are intermittent, meaning chemical plants relying on them will be inefficient. Economists capture the idea with a measure called the capacity factor, a ratio of a plant's output over time compared with what's theoretically possible. Fossil fuel-powered chemical plants can run around the clock, although downtime for maintenance and for other issues typically reduces their capacity factor to about 60%. But the inputs to a plant powered by

Can the world make the chemicals it needs without oil? (Continued)

renewables themselves have low capacity factors: Wind and hydropower typically come in just under 50%, and solar drops to below 25% because of nighttime and cloudy days. "Your full capacity is only being used for a few hours a day," says Harry Atwater, a chemist at Caltech and head of the Joint Center for Artificial Photosynthesis, a solar fuel collaboration among Caltech, Lawrence Berkeley National Laboratory, and other institutions. The upshot, Lewis notes, is that any plant powered by renewables would take longer to make a profit, making investors reluctant to back such projects.

Plants driven by renewables could stay online longer if they drew on multiple power sources or had a steadier power supply thanks to batteries or another form of energy storage, Kammen notes. But those solutions can add cost, Lewis says. "We're still a long way away" from generating most commodity chemicals profitably from renewables. Producing enough renewable electricity to remake the chemical industry is also a challenge. In an analysis in the 4 June issue of the *Proceedings of the National Academy of Sciences*, for example, researchers concluded that running the global chemical industry on renewables would require more than 18 petawatt hours of electricity, or 18,000 terawatt hours, every year. That's 55% of the total global electricity production expected from all sources in 2030.

Perhaps the most likely outlook for industrial chemistry is a gradual greening. Until chemists can find catalysts able to make complex hydrocarbons with high efficiency, companies may use renewable electricity to produce simple molecules such as H_2 and CO and then fall back on fossil fuels to drive the reactions to stitch those together into more complex hydrocarbons.

But as chemists develop new reactors and find ever-more-chaired combinations of catalysts—and as renewable energy continues to surge—the plants that churn out chemical staples will inevitably become more like the green variety, fully sustained by sun, air, and water.

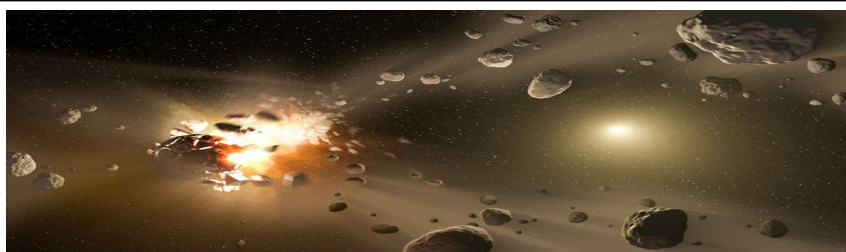
Read more about this article at: <https://www.sciencemag.org/news/2019/09/can-world-make-chemicals-it-needs-without-oil>

Veil of dust from ancient asteroid breakup may have cooled Earth

Faced with a dangerously warming world, would-be geoengineers have dreamed up ways to quickly turn down the heat. One proposed technique: spreading a veil of dust that would sit in space or Earth's atmosphere and reflect sunlight. Researchers say they have now found evidence for a similar experiment that played out naturally, 466 million years ago, when an asteroid out in space exploded into bits. Dust from the breakup blanketed the planet, says Birger Schmitz, a geologist at Lund University in Sweden, plunging it into an ice age that was soon followed by an explosion in animal life.

The ancient episode offers both encouragement and caution for geoengineers. If Schmitz is right, it dramatically demonstrates how dust can cool the planet. But the deep freeze is a lesson in potential unintended consequences. "Maybe our study will trigger a big academic controversy," says Schmitz, who leads a study published this week in *Science Advances*.

All over the world, the ratio of decaying isotopes in a common meteorite type suggests the space rocks formed in a singular shock event 466 million years ago. Models based on how long they took to cool suggest they came from a 150-kilometer-wide parent body, which broke up in a collision in the asteroid belt beyond Mars, sending a stream of fragments into the inner solar system. Bits from the breakup still fall to Earth today.



An asteroid collision 466 million years ago created meteorites that still fall to Earth.

Schmitz's team has found a rich source of the debris: a limestone quarry in southern Sweden. Since the 1990s, it has yielded more than 100 fossil meteorites, found in rock layers that date to soon after the asteroid breakup. "The flux had to be enormous at this time," says Bill Bottke, a planetary scientist at the Southwest Research Institute in Boulder, Colorado,

Veil of dust from ancient asteroid breakup may have cooled Earth (Continued)

who has studied the breakup.

The meteorites fell about the time early animal life boomed. Major animal groups had already evolved, but during this Great Ordovician Biodiversification Event (GOBE), ocean animals doubled or even tripled in biodiversity. Reefs built by microbes gave way to some of the first coral reefs, trilobites grew larger, and tentacled predators such as nautiloids diversified and swarmed the mostly fishless seas. In 2008, Schmitz argued that the asteroid breakup might be responsible. Perhaps, he and colleagues proposed, large fragments striking Earth spurred the GOBE by shaking up ecosystems, clearing out ecological niches for new species to evolve into.

But the idea didn't catch on, in part because there was no sign of large impact craters from just after the collision. Instead, some paleontologists offered a different trigger for the GOBE: a succession of ice ages that took place at the same time. Colder water can hold more dissolved oxygen, fueling life. And as water froze into glaciers, sea levels dropped, isolating shallow seas and creating niches for speciation.

Schmitz's team now thinks the asteroid breakup brought on those ice ages, by creating a cloud of dust that hung in space and in the atmosphere, reflecting sunlight away from Earth and allowing the ice to build up. In layers of limestone spanning just a few million years, from the original quarry and other sites in Sweden and Russia, the team found a surge in both small extraterrestrial grains and in chemical isotopes that trace even finer extraterrestrial dust. "All this dust floated in, just when the sea level fall started," Schmitz says. "Suddenly it clicked."

Rebecca Freeman, a paleontologist at the University of Kentucky in Lexington, says the timing is "perfect." "It isn't necessarily the answer to every question, but it certainly ties together a lot of observations," she says.

Peter Reiners, a geochemist at the University of Arizona in Tucson, argues that the falling asteroid dust would have also delivered iron to the world's oceans, chilling the climate a different way. The dust would have nourished photosynthetic microbes at the sea surface, drawing carbon dioxide out of the atmosphere. When they died and sank, much of the carbon they absorbed would be buried with them, further cooling the planet.

The ancient events are eerily similar to modern-day geoengineering schemes. A study in 2012 evaluated the idea of towing an asteroid to a gravitationally stable point between Earth and the sun and grinding off dust that would remain in space and shade Earth. Researchers found that a 32-kilometer-wide near-Earth asteroid called 1036 Ganymed could make a dust cloud big enough to remain in place and block 6.6% of the sun's light, well over the 1.7% reduction the authors say could offset 2°C of expected warming. Fertilizing the ocean with iron has also been proposed to combat climate change.

Seth Finnegan, a paleontologist at the University of California, Berkeley, is not yet convinced about the ancient geoengineering event. He wants to see global evidence for extraterrestrial dust, alongside signals for cooling and biodiversification. He also urges researchers to model how much dust the asteroid breakup would have made, and how it would have affected climate. Schmitz says he's searching for dust at a third site in central China.

If it turns out that a powdered asteroid really did have such a profound effect on the Ordovician, Finnegan adds, then the episode also delivers a warning: It "shows that the consequences of messing around in that way could be pretty severe."

Read more about this article at: <https://www.sciencemag.org/news/2019/09/veil-dust-ancient-asteroid-breakup-may-have-cooled-earth>

This sulfur-spewing Russian volcano is turning sunsets purple

Sunrise and sunset chasers discovered something odd this summer: In rural Colorado and the rest of the Northern Hemisphere, Earth's daily light shows were turning purple. Now, weather balloons probing the stratosphere have traced the mysterious purple light to a volcanic eruption in Russia.

This sulfur-spewing Russian volcano is turning sunsets purple (Continued)

On 22 June, Russia's Raikoke volcano blasted ash and sulfuric gas 17 kilometers into the stratosphere. Eruptions that violent are rare—the last to spew gases that high was in 1991, when Mount Pinatubo in the Philippines blew its top. Researchers monitoring the stratosphere with high-altitude balloons soon found a layer of sulfur particles 20 times thicker than normal. This was enough to explain the purple sunsets and sunrises and to pin them on the Raikoke eruption, they report this week.



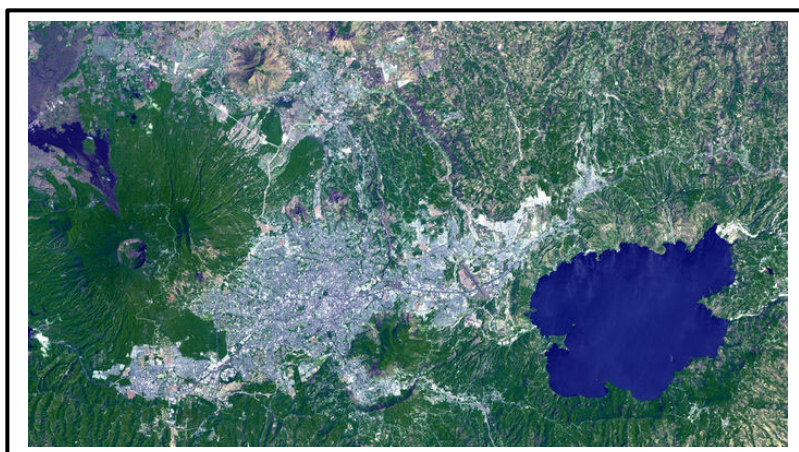
When the sun rises or sets, its rays strike the atmosphere at an angle—forcing the light to travel farther and filter through more particles known as aerosols. Those aerosols, including the high-flying sulfur particles, act like disco balls—scattering the light in all directions. If a volcanic eruption launches enough sulfur into the stratosphere, this scattering of light can cause the entire planet to cool temporarily by diverting more sunlight into space.

Raikoke was powerful, but it didn't deliver enough aerosols to significantly alter Earth's climate, researchers say. But this same light-scattering effect is what's responsible for the recent violet sunrises and sunsets. The effect won't last forever, researchers say—maybe another month or two. Until then, clear skies and low air pollution will improve your chances of catching the fleeting purple haze.

Read more about this article at: <https://www.sciencemag.org/news/2019/09/sulfur-spewing-russian-volcano-turning-sunsets-purple>

'Mystery' volcano that cooled the ancient world traced to El Salvador

The sixth century was a rough time to be alive: Lower-than-average temperatures in the Northern Hemisphere triggered crop failure, famine, and maybe even the onset of bubonic plague. The ultimate culprit, scientists say, were two back-to-back volcanic eruptions—one in 536 C.E. and another around 540 C.E. The first likely happened in Iceland or North America. But the location of the second one has remained a mystery—until now.



‘Mystery’ volcano that cooled the ancient world traced to El Salvador (Continued)

Researchers studying ancient deposits from El Salvador’s Ilopango volcano knew that a massive eruption had taken place there sometime between the third and sixth centuries. That event, dubbed Tierra Blanca Joven (TBJ), or “white young earth,” sent a volcanic plume towering nearly 50 kilometers into the atmosphere.

To better pin down the date of this eruption, the scientists collected slices from three tree trunks embedded in TBJ volcanic ash 25 to 30 kilometers from the present-day lake that covers the caldera (above). The tropical hardwood trees likely died after being engulfed by the searing hot, gale-force winds containing the volcanic gases, ash, and pumice that would have swept outward after the eruption.

Back in the lab, the researchers estimated the ages of different parts of the slices by counting their rings and using carbon-14 dating. The multiple measurements yielded much more precise dates than could have been gotten from single measurements.

The three trees all died between 500 and 545 C.E., dates that suggest the TBJ eruption was the mysterious 540 C.E. volcanic event, the researchers report today in *Quaternary Science Reviews*. In fact, their dating may be even more precise than that: Based on atmospheric circulation patterns, the researchers estimate that the eruption actually occurred in the fall of 539 C.E. That would help explain the era’s ongoing global cooling and famine—and could even shed light on a mysterious, temporary break in monument building by the Maya.

Read more about this article at: <https://www.sciencemag.org/news/2019/08/mystery-volcano-cooled-ancient-world-traced-el-salvador>

Crystalline nets harvest water from desert air, turn carbon dioxide into liquid fuel

SAN DIEGO, CALIFORNIA—When Omar Yaghi was growing up in Jordan, outside of Amman, his neighborhood received water for only about 5 hours once every 2 weeks. If Yaghi wasn’t up at dawn to turn on the spigots to store water, his family, their cow, and their garden had to go without. At a meeting last week here, in an-other area thirsting for freshwater, Yaghi, a chemist at the University of California, Berkeley, reported that he and his colleagues have created a solar-powered device that could provide water for millions in water-stressed regions. At its heart is a porous crystalline material, known as a metal-organic framework (MOF), that acts like a sponge: It sucks water vapor out of air, even in the desert, and then releases it as liquid water.

“This is fantastic work that addresses a real problem,” says Jorge Andrés Rodríguez Navarro, a MOF chemist at the University of Granada in Spain. It’s also just one example of how MOFs may finally be entering their prime. Yaghi and his colleagues synthesized the first MOF in 1995, and chemists have created tens of thousands of the structures since. Each is made up of metal atoms that act like hubs in a Tinkertoy set, connected into a porous network by organic linkers designed to hold fast to the hubs and create openings to house molecular guests. By mixing and matching the metals and linkers, researchers found they could tailor the pores to capture gas molecules, such as water vapor and carbon dioxide (CO₂). “We can play games with modifying these and know exactly where every atom is,” says Amanda Morris, a MOF researcher at Virginia Polytechnic Institute and State University in Blacksburg. But because many of the early MOFs were expensive to make and degraded quickly, they did not live up to initial excitement.

In recent years, Yaghi and other MOF-makers have figured out a broad set of design rules to make MOFs more robust. More highly charged metals, for example, create stronger bonds that stand up to heat. That has opened up functions such as housing catalysts, which typically work faster at high temperatures. Another stability boost came when researchers learned to tailor the architecture to shield less-stable bonds in a MOF from attack by trapped molecules.

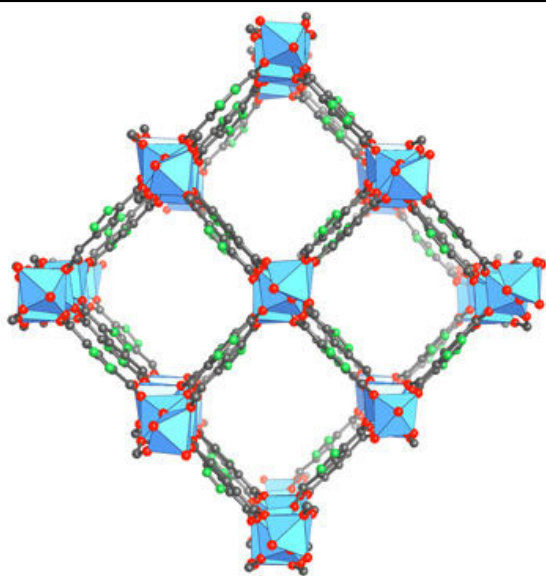
As a result, commercial applications are starting to take off. One recent market report predicted that sales of MOFs for applications including storing and detecting gases will balloon to \$410 million annually over the next 5 years, up from \$70 million this year. “Ten years ago, MOFs showed promise for a lot of applications,” says Omar Farha, a MOF chemist at Northwestern University in Evanston, Illinois. “Now, that promise has become a reality.”

Crystalline nets harvest water from desert air, turn carbon dioxide into liquid fuel (Continued)

One application is Yaghi's, which he hopes will help provide drinking water for the estimated one-third of the world's population living in water-stressed regions. Yaghi and his colleagues first developed a zirconium-based MOF in 2014 that could harvest and release water. But at \$160 per kilogram, zirconium is too expensive for bulk use. So, last year, his team came up with an alternative called MOF-303, based on aluminum, which costs just \$3 per kilogram. In the desert of Arizona, Yaghi and his team placed their MOF in a small, clear plastic container. They kept it open to the air at night, allowing the MOF to absorb water vapor. They then closed the container and exposed the MOF to sunlight, which drove liquid water from it—but the harvest was only about 0.2 liters per kilogram of MOF per day.

At last week's meeting of the American Chemical Society and in the 27 August issue of *ACS Central Science*, Yaghi reported that his team has devised a new and far more productive water harvester. By exploiting MOF-303's ability to fill and empty its pores in just minutes, the team can make the new device complete dozens of cycles daily. Supported by a solar panel to power a fan and heater, which speed the cycles, the device produces up to 1.3 liters of water per kilogram of MOF per day from desert air. Yaghi expects further improvements to boost that number to 8 to 10 liters per day. Last year, he formed a company called Water Harvesting that this fall plans to release a microwave-size device able to provide up to 8 liters per day. The company promises a scaled-up version next year that will produce 22,500 liters per day, enough to supply a small village. "We're making water mobile," Yaghi says. "It's like taking a wired phone and making a wireless phone."

Other MOF applications are showing promise as well. In the 25 January issue of *ACS Applied Nano Materials*, Farha and his colleagues reported using a MOF to detoxify chemical weapons. The MOF consists of a lanthanum-based framework linked to ring-shaped organic compounds. The compounds, called porphyrins, had previously been shown to be adept at absorbing light and using that energy to convert oxygen molecules in the air to a reactive form known as singlet oxygen. In the study, the singlet oxygen in turn could break down molecules of a lab-safe molecular cousin of mustard gas both inside and outside the pores. At the meeting here, Farha's Northwestern colleague Joseph Hupp reported that he and his colleagues have extended the idea with a series of zirconium-, hafnium-, and cerium-based MOFs that can detoxify nerve agents such as sarin gas. A thin coating of MOFs on gas masks and uniforms could help protect soldiers from exposure to chemical weapons, Hupp says.



Pores in MOF-303, an aluminum-based metal-organic framework, can capture water vapor and release it as liquid.

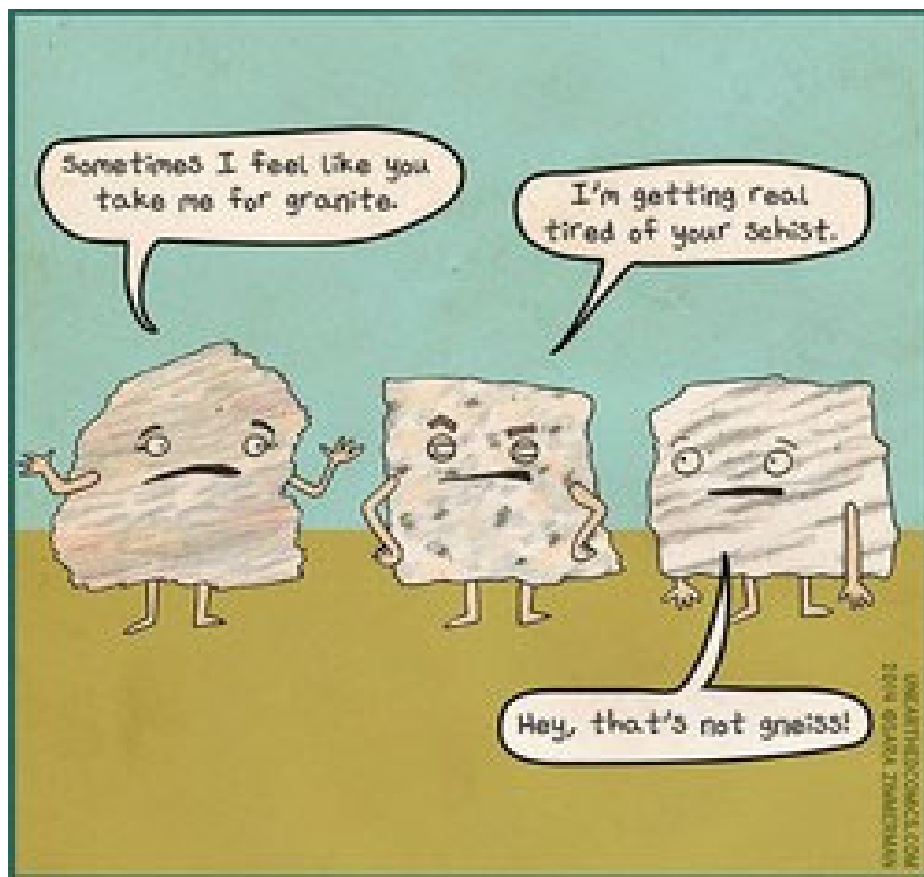
Farha and others have also encapsulated enzymes inside MOFs, protecting the fragile molecules from harsh environments and enabling them to carry out industrial reactions outside cells. In one example, Farha's team reported in the 26 March issue of *Angewandte Chemie* that a MOF-caged enzyme called formate dehydrogenase can convert CO_2 to formic acid, a common industrial chemical, at more than three times the rate of the uncaged enzyme, and under greener conditions than formic acid is normally made. At the meeting, Thomas Rayder, a graduate student at Boston College, reported building on the idea. He encapsulated a pair of enzymelike catalysts in a zirconium-based MOF to drive a series of reactions that convert gaseous CO_2 to methanol, a liquid fuel.

When they were unprotected by the MOFs, Rayder found, the two catalysts didn't produce any methanol because they were quickly deactivated, likely by reacting with each other. But safely ensconced in the MOFs, they could make methanol at temperatures and pressures far below those used in existing methanol plants, offering a potentially cheaper and greener way to make the fuel.

Crystalline nets harvest water from desert air, turn carbon dioxide into liquid fuel (Continued)

Rayder and others still need to show that these and other MOFs can be manufactured cheaply on a large scale. Each potential commercial MOF needs to prove itself in stability, efficiency, and life span. But if MOFs can pass those tests, they could offer a framework for tackling some of the world's most pressing problems.

Read more about this article at: <https://www.sciencemag.org/news/2019/09/crystalline-nets-harvest-water-desert-air-turn-carbon-dioxide-liquid-fuel>



September 2019 Atlanta Geological Society PG Cansisate Workshop

Date: Saturday, **September 28, 2019**
Time: 10:00 am to 12:00 pm
Venue: Fernbank Science Center
(check-in with the receptionist for the specific classroom location)
156 Heaton Park Drive, N.E.
Atlanta, GA 30307
678-874-7102
<http://fsc.fernbank.edu/>

Speaker: Jim Kennedy, PhD, PG

Subject: **Geohydrology & Engineering Geology**

Jim is the Georgia State Geologist and holds B.S. and M.S. degrees in physics and geophysical sciences from the Georgia Tech and a Ph.D. in geology from Texas A&M where he did research on reclaimed lignite mines. As State Geologist, he has worked on the Coastal Sound Science Initiative to manage salt-water intrusion into the Upper Floridan aquifer, permitting of coastal groundwater supply wells, and the State Water Plan. He also has provided expert testimony at the Office of State Administrative Hearings in support of landfill, quarry, and water withdrawal permits issued by the Georgia Environmental Protection Division. Prior to joining the EPD, Dr. Kennedy worked as a consultant and conducted engineering geology, groundwater supply, and environmental remediation projects in various areas of the United States and Europe.

Please join us and **forward this message** to anyone interested in becoming a Georgia Registered Professional Geologist, or anyone who might be interested in the topic. Two Professional Development Hours are available for attendees of the class. The classes are open to all, membership in the AGS is not required; if you would like to join an application form is attached.

For more information on becoming a member, visit www.atlantageologicalsociety.org. Contact us at the addresses below if you have questions about the workshop or the exams.

Atlanta Geological Society
Professional Registration/Career Development Committee
Ken Simonton, P. G., kws876@gmail.com
Ginny Mauldin-Kenney, ginny.mauldin@gmail.com

Fernbank Events & Activities

Weekday Wonders

Monday, September 23, 2019 11:30 AM

Drop in for a variety of science-themed hands-on activities. Recommended for ages 4 – 12

Discover Zoology

Monday, September 23, 2019 2:30 PM

Explore the different ways animals survive and thrive as you solve a science mystery. Recommended for ages 8+

Little Lessons

Tuesday, September 24, 2019 11:30 AM

Our littlest visitors will enjoy a special story time with a Fernbank storyteller. Recommended for ages 1 – 4

Geology Rocks

Tuesday, September 24, 2019 2:30 PM

Discover how the rocks of Georgia formed with hands-on experiments and touchable specimens. Recommended for ages 8+

Folk Tales

Wednesday, September 25, 2019 11:30 AM

Hear a story for young visitors from cultures around the world, with a fun activity. Recommended for ages 1+

Cosmic Quest

Wednesday, September 25, 2019 2:30 PM

Blast off for an exploration of space that will take you from Earth through the universe. Recommended for ages 8+

Little Lessons

Thursday, September 26, 2019 11:30 AM

Our littlest visitors will enjoy a special story time with a Fernbank storyteller. Recommended for ages 1 – 4

Geology Rocks

Thursday, September 26, 2019 2:30 PM

Discover how the rocks of Georgia formed with hands-on experiments and touchable specimens. Recommended for ages 8+

Tadpole Tales

Friday, September 27, 2019 11:30 AM

Preschoolers will enjoy a story and special activity with a Fernbank educator. Recommended for ages 1 – 6

Live Animal Encounter

Friday, September 27, 2019 1:00 PM

Get up close and personal with a member of Fernbank's animal collection. Recommended for ages 4+

Discover Zoology

Friday, September 27, 2019 2:30 PM

Explore the different ways animals survive and thrive as you solve a science mystery. Recommended for ages 8+

Fernbank Events & Activities

Latin Dance Night

Friday, September 27, 2019 8:00 PM

Spice things up with sassy Latin rhythms as you dance the night away to Salsa, Bachata, Cumbia and Merengue.

Traveling the Silk Road Opening Day

Saturday, September 28, 2019 10:00 AM

Enjoy Fernbank's newest special exhibit, featuring the peoples and cultures who benefited from trade on the silk road.

Field Trip Preview Day

Saturday, September 28, 2019 10:00 AM

Fernbank invites educators to enjoy a free event featuring museum explorations, special activities and more.

Silk Road Folk Tales

Saturday, September 28, 2019 11:00 AM

Celebrate the opening of the new special exhibit, Traveling the Silk Road, with a special story from South Asia for young visitors.

Ranger Explorations

Saturday, September 28, 2019 1:30 PM

Join a Fernbank Ranger for fun and informative outdoor activities in WildWoods. Recommended for ages 6+

Live Animal Encounter

Saturday, September 28, 2019 2:00 PM

Get up close and personal with a member of Fernbank's animal collection. Recommended for ages 4+

Incredible Weather

Saturday, September 28, 2019 3:00 PM

Delve into the dynamic world of weather, climate, and atmospheric science with live experiments and demonstrations. Recommended for ages 8+

Folk Tales

Sunday, September 29, 2019 11:00 AM

Hear a story for young visitors from cultures around the world, with a fun activity. Recommended for ages 1+

Nature Walk

Sunday, September 29, 2019 11:00 AM

Get a closer look at nature in WildWoods and Fernbank Forest with a Fernbank educator.

Recommended for ages 8+

Live Animal Encounter

Sunday, September 29, 2019 12:00 PM

Get up close and personal with a member of Fernbank's animal collection. Recommended for ages 4+

Incredible Weather

Sunday, September 29, 2019 3:00 PM

Delve into the dynamic world of weather, climate, and atmospheric science with live experiments and demonstrations. Recommended for ages 8+

Geology Rocks

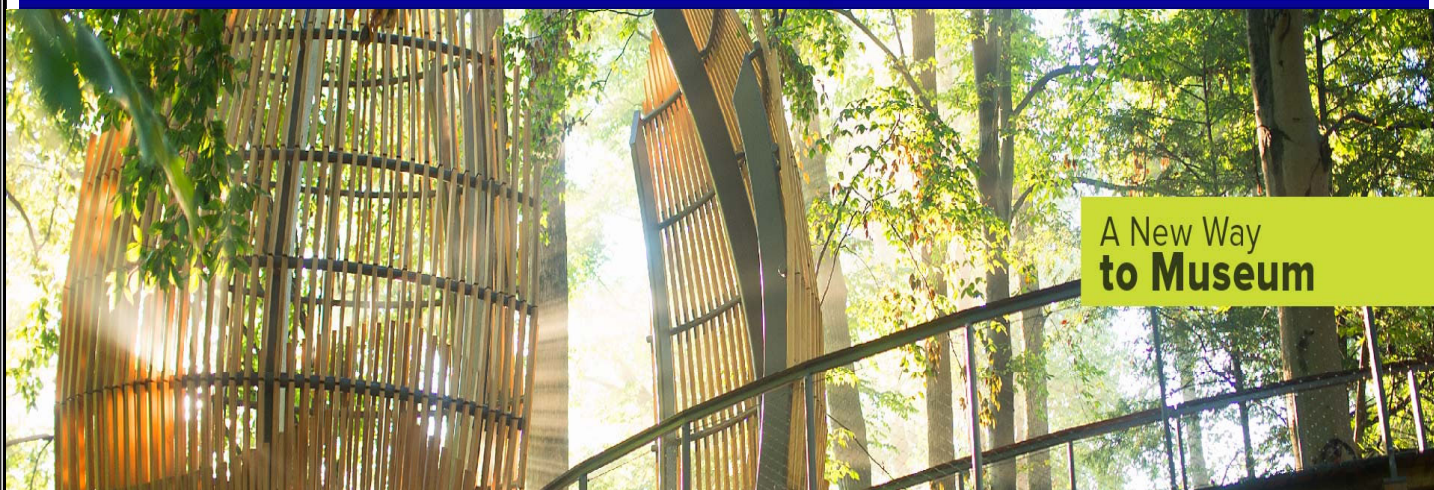
Monday, September 30, 2019 2:30 PM

Discover how the rocks of Georgia formed with hands-on experiments and touchable specimens.



FERNBANK MUSEUM

of NATURAL HISTORY



A New Way
to Museum



A New Way to Museum

Take a walk on the wild side as you explore 75 acres of new outdoor nature adventures. WildWoods and Fernbank Forest combine to highlight the natural world through immersive trails, educational programming, hands-on exhibits and beautiful scenery.

New for Summer! Experience the wonders of nature on Fernbank's giant 4-story screen with Backyard Wilderness 2D, and enjoy hands-on nature adventures outside in WildWoods.



Apollo 11 First Steps Edition 2D

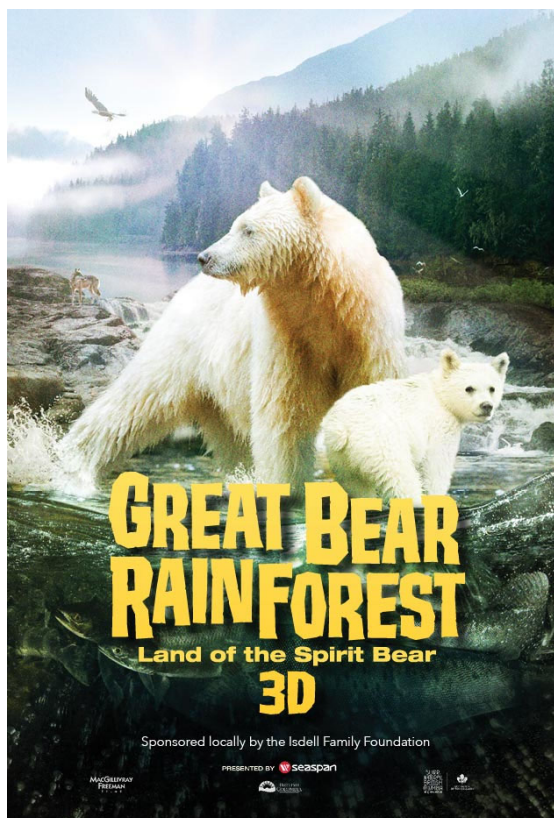
Showing May 31 through December 31, 2019

In this special giant-screen edition created exclusively for science centers and museum theaters of Todd Douglas Miller's critically acclaimed Apollo 11 documentary, the filmmakers reconstruct the exhilarating final moments of preparation, liftoff, landing and return of this historic mission—one of humanity's greatest achievements and the first to put men on the moon.



Fernbank Museum of Natural History
 (All programs require reservations, including free programs)

Now showing in the Fernbank IMAX movie theater:



Great Bear Rainforest 3D

Showing May 3 through October 31, 2019

Hidden from the outside world, the Great Bear Rainforest is one of the planet's most exquisite and secluded wildernesses. Found on Canada's rugged Pacific coast, it is the largest temperate coastal rainforest in the world and is home to indigenous First Nations peoples, who have provided stewardship of the forest for millennia. Embark on a remarkable journey into a land of grizzlies, coastal wolves, sea otters, and humpback whales—and discover the secret world of the Spirit Bear. Narrated by Ryan Reynolds.

Volcanoes: The Fires of Creation 3D

Showing September 13 through January 16, 2019

From the air we breathe to the water we drink, volcanoes have helped shape the Earth's landscape for billions of years. Between eruptions and cooling magma, over 500 volcanoes ignite the fires of creation on Earth today, continuing to form environmentally significant ecosystems and wildlife habitats on the planet. Journey around the globe from Hawaii to Ethiopia, Vanatu to Pompeii to explore the fascinating world of lava lakes, acid ponds and geysers. Dodge boulders and descend into hot lava with adventurer and photographer Carsten Peter.

AGS Officers

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Secretary: Rob White

Phone (770) 891-0519

robeth@bellsouth.net

Treasurer: John Salvino, P.G.

Phone: 678-237-7329

johnsalvino@bellsouth.net

Past President

Shannon Star George

shannonsgeorge@gmail.com

AGS 2019 Meeting Dates

Listed below are the planned meeting dates for 2019 and 2020. Please mark your calendar and make plans to attend.

2019 Meeting Schedule

October 29

November 26

December No meeting

January 28

February 25

PG Study Group meetings

October 26

November 30

December No Meeting

January 25

February 29

AGS Committees

AGS Publications: Open

Career Networking/Advertising: Todd Roach

Phone (770) 242-9040, Fax (770) 242-8388

tdr@piedmontdrilling.com

Continuing Education: Open

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Phone (404) 929-6341

miranda.Shealy@FernbankMuseum.org

Doug John

Phone (404) 929-6342

doug.John@FernbankMuseum.org

Georgia PG Registration: Ken Simonton

Phone: 404-825-3439

kws876@gmail.com

Ginny Mauldin-Kenney,

ginny.mauldin@gmail.com

Teacher Grants: Bill Waggener

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Web Master: Javan Zeito

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www.atlantageologicalsociety.org

ATLANTA GEOLOGICAL SOCIETY

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ANNUAL MEMBERSHIP FORM

Please print the required details and check the appropriate membership box.

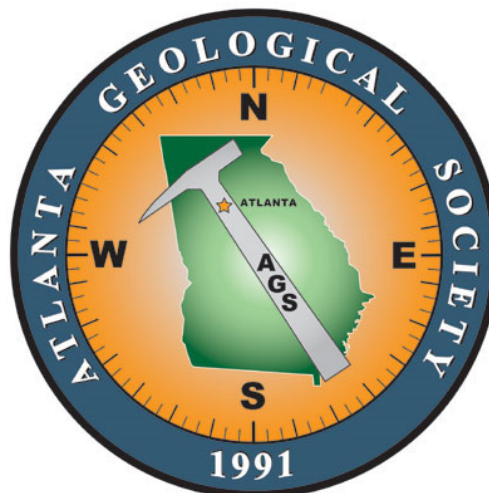
DATE: _____

NAME: _____

ORGANIZATION: _____

TELEPHONE (1): _____ TELEPHONE (2): _____

EMAIL (1): _____ EMAIL (2): _____



STUDENT \$10 ☐

PROFESSIONAL MEMBERSHIP \$25 ☐

CORPORATE MEMBERSHIP \$100 ☐

(Includes 4 professional members, please list names and emails below)

NAME: _____ EMAIL: _____

NAME: _____ EMAIL: _____

NAME: _____ EMAIL: _____

NAME: _____ EMAIL: _____

For further details, contact the AGS Treasurer:
John Salvino johnsalvino@bellsouth.net

Please make checks payable to the “Atlanta Geological Society” and bring them to the next meeting or remit with the completed form to:

Atlanta Geological Society, Attn: John Salvino
3073 Lexington Avenue
Woodstock, Georgia 30189

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