Technical Report

August 1999 • NREL/TP-570-26797

Bibliography of Work on the Heterogeneous Photocatalytic Removal of Hazardous Compounds from Water and Air

Update Number 3 to January 1999

Daniel M. Blake

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1617 Cole Boulevard
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Summary

The subject of this report is chemistry and engineering for the application of heterogeneous photocatalysis. The state of the art in catalysts are forms of titanium dioxide or modifications thereof, but work on other heterogeneous catalysts is included in this compilation.

This report is a continuation the bibliographies of work on the photocatalytic oxidation of organic or inorganic compounds in air or water and on the photocatalytic reduction of inorganic compounds in water that were published in May 1994, October 1995, and January 1997. The previous reports included 663, 574, and 518 citations, respectively. This update contains 1,517 new references. These were published between October 1996 and January 1999, or are references from prior years that were not included in the previous reports. The general focus of the work is removing hazardous chemical or biological contaminants from air, water, and surfaces. This report also references work on properties of semiconductor photocatalysts and the application of photocatalytic chemistry in organic synthesis. The organization is the same as in the previous reports in this series except that patents are included as a separate list because of the large number that have appeared since the last report. The first part of the report gives citations for work done in a few broad categories that are generic to the process. Three tables provide references to work on specific substances. The first covers organic compounds that are included in various lists of hazardous substances identified by the U.S. Environmental Protection Agency (EPA). The second lists compounds not included in that table, but that have been treated in a photocatalytic process. The third covers inorganic compounds that have been treated by a photocatalytic process.

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1.0 Introduction

This update in combination with the previous reports[1,2,3] provides a comprehensive bibliography of the work on photocatalytic chemistry and processes that are available in the open literature. It will be of most use to scientists and engineers interested in the use of heterogeneous photocatalytic oxidation or reduction processes in environmental remediation, process emission control, indoor air quality, or other applications in which oxidation or reduction chemistry on illuminated semiconductor surfaces can occur. Because of the large number of documents, no attempt has been made to critically assess the information in the cited literature. The combined reports include more than 3,300 citations to work published between 1970 and the beginning of 1999. The literature cited includes U.S. and foreign patents. Information was compiled by manually scanning the literature and by searching commercial databases. This update includes about 100 citations to work done before 1996 that were not included in the previous reports. Some citations have doubtless been missed and topics covered in some papers may not have been identified and covered in every appropriate category. The author is grateful to the many people who sent references and reprints of their work. Coverage is limited to heterogeneous processes, except in a few cases where review material for homogeneous processes is relevant to heterogeneous photocatalytic chemistry. The author invites readers to send references to relevant work that appeared before 1999 that has been missed to the mailing or e-mail address included in Section 5.3.

The number of new publications, including patents, continues to grow each year, as shown in the plot in the figure. The growth in patents is primarily due to the high level of commercial interest in applications being developed in Japan. The number of papers, reports, and conference proceedings has leveled off at about 300 per year, with an increasing fraction coming from outside the United States.

The photocatalytic oxidation of organic compounds in water has received the most attention, but there is a rapidly increasing amount of work on the oxidation of volatile organic or inorganic compounds in the gas phase. Photocatalytic reduction of organic compounds and metal-containing ions has also received increasing attention. Studies of cell killing and disinfection by illuminated titanium dioxide (TiO_2) have also been increasing in number. Nearly 1,000 substances have been tested to date.

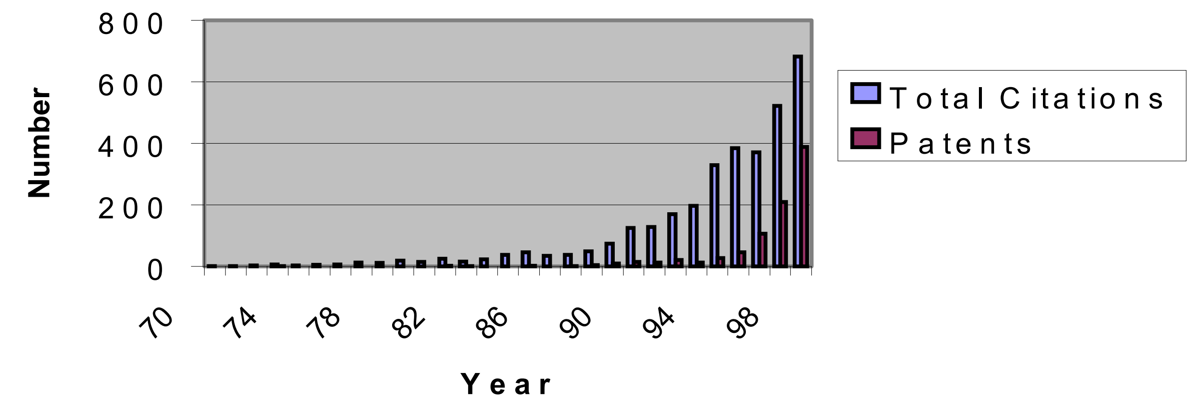
Intermediates and by-products have been widely observed to form and persist in the treated medium. These can include a variety of mineral acids, oxygenated organic compounds, and carbon monoxide. The nature of the intermediates can be used as a tool for revealing details of the chemical mechanism for the photocatalytic process. The net process involves oxidizing the organic compound to an intermediate stage of oxygen content or to carbon dioxide, water, and a mineral acid (if a heteroatom such as nitrogen

[1] Blake, Daniel M. (1994). *Bibliography of Work on the Photocatalytic Removal of Hazardous Compounds from Water and Air*. NREL/TP-430-6084. Golden, CO: National Renewable Energy Laboratory. 75 pp. [DE94006906]. Available from the National Technical Information Service, Springfield, VA 22161.

[2] Blake, Daniel M. (1995). *Bibliography of Work on the Photocatalytic Removal of Hazardous Compounds from Water and Air. Update Number 1, to June 1995*. NREL/TP-473-20300. Golden, CO: National Renewable Energy Laboratory. 102 pp. Available from the National Technical Information Service, Springfield, VA 22161.

[3] Blake, Daniel M. (1997). *Bibliography of Work on the Photocatalytic Removal of Hazardous Compounds from Water and Air. Update Number 2, to October 1996*. NREL/TP-430-22197. Golden, CO: National Renewable Energy Laboratory. 88 pp. Available from the National Technical Information Service, Springfield, VA 22161.

Figure. Total Citations and Patents Related to Photocatalytic Chemistry by Year



or chlorine is present). Other oxidizing agents may be substituted for oxygen. Certain metal ions from water can be modified or removed when the ions replace oxygen as the electron acceptor in the process and are deposited as lower oxidation state oxides or metals on the surface of the photocatalyst. These processes are more efficient when sacrificial electron donor compounds are provided.

Reference to new test work on about 375 compounds is included in the tables in Section 3. The most-studied compounds are phenol derivatives, BTEX (benzene, toluene, ethyl benzene, and xylene) components found in fuel spills, oxides of nitrogen, and chlorinated solvents such as tri- and per-chloroethylene and chloroform. A significant number of pesticides, dye compounds, and surfactants has been shown to be mineralized and a variety of bacteria, viruses, cancer cells, and other cell types has been found to be killed by irradiation with near-ultraviolet light in the presence of titanium dioxide. The breadth of work attests to the very wide range of applications that are being considered for the technology. The self-cleaning and wetting properties of irradiated titanium dioxide surfaces are now the subjects of a high level of interest because of the potential for commercial applications.

The section on companies active in the field was not updated for this report because little new information was available to the author. The high level of R&D activity by Japanese companies is indicated by the large number of patents assigned to them (see the patent list in Section 5.2). However, the author has little information on the individual Japanese companies that actively commercialize products.

The following sections cover reviews written on various aspects of the technology, work in developing and testing photocatalysts and oxidants, engineering issues, other topics, and patents. These sections include information that can apply to a range of applications. They are followed by tables listing references to work performed on specific substances. References to work on systems in which the compound to be treated is carried in the gas phase or on a surface exposed to air are indicated by the prefix “g” in the citation number.

2.0 Generic Information

This section references work that spans the field of photocatalytic processes.

2.1 Reviews and Articles

Reviews have been written covering many aspects of photocatalytic chemistry and technology. This section also includes reviews written before 1999 that were not cited in the previous reports. Reviews covering the broad topics given can be found in the following:

> Semiconductors and supports – 104, 232, 326, 407, 542, 604, 800, 834, 840, 841; methodology for comparing reaction systems – 56, 90, 235, 236, 669, 670; mechanisms/activity – 33, 55, 57, 164, 165, 222, 255, 256, 299, 368, 405, 407, 802, 854, 857; nanocrystalline semiconductors – 19, 371; photoelectrochemical systems – 75, 106, 255, 256, 433, 490; solar – 13, 15, 16, 28, 29, 31, 32, 56, 75, 77, 153, 164, 165, 235, 236, 237, 242; companies active in the field – 591, 760, 816, 817; adsorption – 104; self-cleaning surfaces – 217, 218, 222, 256, 257, 565, 640, 645, 751, 810, 817; disinfection, cell killing, and toxicology – 79, 104, 217, 220, 221, 222, 252, 256, 257, 490, 514, 550, 565, 640, 650, 738, 748, 792, 793, 806, 810, 826; water treatment – 54, 56, 57, 118, 219, 220, 252, 373, 433, 445, 490, 581, 592, 729, 730; indoor air quality – 22, 220, 221, 222, 256, 257, 323, 372, 514, 518, 549, 550, 565, 640, 792, 793, 821; environmental applications – 26, 54, 57, 222, 224, 232, 234, 235, 236, 252, 330, 376, 405, 485, 490, 500, 514, 539, 565, 575, 591, 679, 745, 783, 854, 857; energy storage – no new reports; preparation and applications of semiconductor thin films and coatings – 26, 29, 31, 48, 223, 224, 314, 565, 592, 834; iron doped titanium dioxide as photocatalysts – 425; organic synthesis – 560; intercalation compounds – no new reports; oxidation of chlorophenols – 105; comparison of advanced oxidation processes – 118, 485; issues and questions in application of photocatalysis – 77; reactors – 56, 77, 235, 236, 242, 336; problems of immobilization of catalyst – 433, 592; supported photocatalysts – 592, 680; fate of organic nitrogen – 667; photocatalytic ammonia synthesis – no new reports; activation of oxygen – 317; surfactant removal – 445, 540; charge injection into semiconductor particles – ; activating titanium dioxide with visible light – 28, 29, 31, 32, 75; specialty grades of titanium dioxide – 19, 371, 372, 373, 518, 559, 728, 840, 841; photochemistry on surfaces – 33, 407; comparison of advanced pollution control methods – 126, 252; mechanisms of polymer degradation – 286; photography and imaging – 426, 481, 641; analytical chemistry applications – 430, 581.

2.2 Photocatalysts

The nature of the photocatalyst determines the rate and efficiency of the process. The anatase form of titanium dioxide has the desirable properties of being chemically stable, readily available, and active as a catalyst for oxidation processes. The 3.2 eV band gap matches the output of a wide variety of readily available lamps but is not ideal for solar applications. Rutile has a smaller band gap, 3.0 eV, but only a few reports observe photocatalytic activity for this form. The photo efficiency for reaction of target molecules is generally rather low, particularly for the aqueous phase processes. A major body of work has been directed toward modifying titanium dioxide and testing other semiconductors to identify ways to increase process efficiency and to improve the overlap of the absorption spectrum of the photocatalyst with the solar spectrum. This work is broken down into a few broad categories and covered in the references cited.

2.2.1 Modified Titanium Dioxide

Titanium dioxide and modified forms, including commercially available forms, heat-treated materials, and materials prepared by a range of techniques:

sol-gel – 14, 51, 74, 100, 207, 208, 209, 210, 243, 253, 258, 279, 284, 314, 343, 369, 392, 440, 441, 474, 499, 535, 551, 577, 578, 579, 613, 658, 693, 703, 733, 734, 815, 824, 829, 830, 835; controlled hydrolysis of $TiCl_4$ or $Ti(OR)_4$ – 315, 369, 808, 809, 851; heat treatment – 306, 343, 517, 550, 552, 631, 655, 703, 822, 830; colloidal, quantized or nano-crystalline – 4, 51, 59, 60, 61, 89, 90, 245, 246, 306, 307, 345, 360, 375, 386, 706, 707, 714, 775, 835; nanotubules – 392, 393; xerogel/aerogel – 172; mesoporous – 156, 179, 211, 472, 473; electrophoretic coating – 107, 108; flame synthesis – 40, 197, 841; titanium dioxide from different vendors – 90, 109, 110, 127, 128, 151, 175, 197, 355, 369, 371, 372, 421, 422, 497, 518, 543, 559, 600, 622, 643, 668, 684, 753, 760, 786, 816, 817; spray pyrolysis – 37, 107, 360, 527, 800; plasma enhanced chemical vapor deposition – 117, 503; sputtered – 144, 568, 176, 655, 677; epitaxial growth – 125; anodized titanium metal – 277, 550; electrocomposite deposition – 814; impregnation – 831, 832, 833; co-precipitation – ; microemulsion – 678; microroughened – 158, 711; reduction – ; dip or spin coating – 251, 440, 441, 510, 520, 528, 550, 645, 829; thermal spraying – 41, 650; screen printing – 631; rutile – 51, 125, 296, 368, 380, 438, 487, 502, 517, 555, 556, 711, 753; pillared and layered titanates – 753; cysteine – 486, 746; surface modification – 132, 133, 610, 746, 848, 849; ion implantation – 28, 29, 30, 31, 311; fluoride effect on crystallinity – 258, 363; macropores formed using latex spheres as templates – 279.

2.2.2 Hydrophobic/Hydrophilic Surface Treatment

Several approaches have been taken to modify the surface of titanium dioxide to modify the hydrophobicity:

Silica gel – 403, 499, 535, 720, 721; amphiphilic microfine titanium dioxide – 127; superhydrophilicity – 222, 733, 782; sunscreens – 269, 368; tethered organic compounds – 610; Langmuir-Blodgett films – 659; silicones – 665, 715, 721, 722.

2.2.3 Dye Sensitized Titanium Dioxide

Sensitizers have been used in conjunction with titanium dioxide to improve the response to visible light:

ruthenium complexes – 68, 75, 141, 183, 334, 386, 435, 567, 682 ; vanadium(+5) complexes – 69, 70, 71, 226, 227, 501; cobalt(+2) complexes – no new reports; nickel(+2) complexes – no new reports; copper(+2) complexes – no new reports; cobalt(+3) complexes – 69, 70, 226, 227; iron(+2 or +3) – 227, 614, 674; metal phthalocyanine – 278, 389, 614, 718; porphyrins – 131, 450, 451; and organic dyes – 68, 259, 675, 697.

2.2.4 Metal Ion Doping of Titanium Dioxide or Mixed Oxides

Other metal ions have been introduced into the titanium dioxide lattice to modify the properties. They are covered in the following:

Li – 100, 408; Mg – 611; Al – 14, 100; Si – 14, 197, 343, 479, 820; V – 46, 838; Cr – 30, 100, 247, 611, 723; Mn – 4; Fe – 89, 90, 100, 139, 140, 425, 526, 544, 578, 611, 613, 638, 658; Co – 100, 611; Zn – 100, 139; La – 418; Zr – 179, 839; Nb – 125, 357; Mo – no new reports; Ru – 686; Ba – 408; La – 418; Ce – 100, 316, 418; W – 402, 463 ; Pb – 790; Cd – 100.

2.2.5 Metallized Titanium Dioxide

Noble metals have been deposited on the titanium dioxide surface to enhance catalytic activity:

Ni – 160, 480; Cu – 383, 480; Rh – no new reports; Pd – 361; Pt – 34, 46, 90, 100, 151, 174, 184, 206, 324, 361, 422, 437, 464, 489, 496, 510, 543, 544, 561, 562, 638, 655, 660, 681, 723, 744, 759, 771, 823; Ag – 50, 139, 207, 262, 383, 438, 650, 744; Au – 181, 402, 774. Addition of metal powders (Cu, Ag, Ni, or Co) enhances some photocatalytic reactions – 276.

2.2.6 Other Semiconductors

A wide range of semiconductors and other materials has been tested for photocatalytic activity. They are generally less active than titanium dioxide. Relevant work is cited in the following:

MgO – 603; Al_2O_3 – 590; SiC – 450; V_2O_5 – 46, 313, 833; Mn_2O_3 – 130; Fe_2O_3 – 59, 61, 187, 325, 500, 590, 836, 856; $FeTiO_3$ – 590; CO_3O_4 – 393; ZnO – 88, 142, 157, 325, 355, 368, 374, 391, 392, 460, 461, 583, 603, 713, 754, 836, 856; Zn- or CdS – 47, 345, 391, 563, 627, 686, 754, 836, 856; Pt/CdS – ; ZnTe – ; ZrO_2 – 279; $ZrTiO_4$ – 525 ; MoS_2 – ; SnO_2 – 59, 310 ; Sb_2O_4 – no new reports; SnO_2 – 275, 322, 386; $BaTiO_4O_9$ – 408; CeO_2 – no new reports; WO_3 – 355, 392, 402, 523, 825; Nb_2O_5 – 357, 703, 833; RuS_2 - 664; $Cs_3PW_{12}O_{40}$; fly ash – 196, 590; furnace slag or core sands – 590; polyaniline – no new reports; poly(p-phenylene) – no new reports; polythiocyanogen – no new reports; clays – 193, 590; mica – 590; atmospheric aerosols – 325, 327; desert sand – 325, 374, 590; volcanic ash – 325; sea salt – 325; chalk – 325; or soot – 325.

2.2.7 Immobilized Photocatalysts

Most experimental work on aqueous systems has been performed using the photocatalyst in the form of fine particles suspended in the liquid phase. In a waste treatment application it would be simpler if the catalyst were immobilized in the photo reactor so the material would not have to be separated from the treated fluid in a subsequent process step. Most work for treating gases has been done with immobilized catalysts. Titanium dioxide has been affixed to a variety of surfaces:

glass (including fibers, Pyrex, quartz, Vicor) – 85, 100, 134, 135, 137, 176, 185, 186, 222, 253, 262, 294, 304, 311, 314, 315, 358, 412, 413, 469, 478, 496, 498, 509, 535, 545, 549, 551, 577, 578, 579, 600, 601, 602, 620, 621, 622,623, 624, 655, 658, 681, 693, 707, 708, 722, 739, 752, 778, 780, 781, 790, 791, 829; silica gel – 6,7, 198, 410, 464, 472, 473, 474, 484, 535, 653, 674, 698, 699, 726, 783, 831, 832, 833; metal – 48, 107, 108, 251, 310, 314, 326, 478, 788; clays – no new reports; crysotile fibers – 765; organic polymer – 41, 223, 224, 296, 314, 522, 534, 650, 692, 759; thin films – 207, 208, 209, 210, 440, 441, 519, 520, 655, 713, 808, 809; internal light guide – no new reports; zeolite – 27, 34, 35, 36, 39, 143, 312, 313, 726, 727, 783, 811, 812, 813, 818, 819, 847; alumina – 176, 410, 436, 726, 783; alumite – 470; carbon – 284, 468, 499, 609, 725, 726, 748, 750, 783, 828; membranes – 501; paper – 740; textiles – 751; Ambersorb – no new reports; PHOTOPERM™ – 227; metal oxides and ceramics – 46, 74, 107, 295, 310, 469, 503, 515, 519, 520, 521, 658, 710, 717, 727, 770, 815; vesicles and micelles – 386; slag – 289, 291, 292, 293; pellets – 822; or unspecified – 511, 512.

2.3 Hydrogen Peroxide and Other Oxidants

Oxygen is most common oxidant for photocatalytic reactions, but other oxidants have been found to improve reaction rates with a variety of organic substrates under some conditions. This work is covered in the following:

hydrogen peroxide – 59, 91, 137, 166, 236, 356, 374, 384, 508, 536, 538, 571, 573, 574, 590, 603; superoxide – ; peroxydisulfate – 453, 454, 508; chlorite – no new reports; chlorate – no new reports; bromate – 422, 423, 589, 508; periodate – no new reports; nitrous oxide – 713; or ozone – 226, 460, 461, 584.

2.4 Engineering Issues

In recent years the success of laboratory work has led to interest in applying the technology to environmental remediation and treatment of process waste streams. Work in the literature addresses issues related to the scale-up of the process and resolution of engineering problems. Progress has been signifi- cant and some companies now provide turnkey systems for treating contaminated water and air. The largest market is for room air cleaners that are produced by companies in Japan exclusively for the Japanese market.

2.4.1 Reactor and System Design

Numerous papers have addressed topics relevant to the design of reactors for photocatalytic processes:

photochemical reactors – 11; non-concentrating reactor – 24, 52, 53, 56, 78, 91, 99, 240, 545, 572, 573, 596, 764, 784, 787; parabolic trough – 23, 56, 59, 91, 96, 97, 228, 229, 346, 453, 454, 462, 570, 571, 572, 574, 607, 767, 768; compound parabolic concentrator – 263, 453, 454, 462, 478; kinetic modeling – 8, 9, 10, 71, 72, 228, 229, 498, 531, 532, 547, 579, 587, 630, 671, 757, 762, 763; packed bed – 531; filtration – 691; controlled periodic illumination – 195, 377, 762; light scattering model – 8, 9,10, 99, 109, 110, 579, 619, 635, 672; flat plate reactor – 52, 53, 56, 59, 78, 99; ceramic monolith – 295, 532, 547, 717, 770; annular packed bed reactor – 619; mass transfer limitations – 577; photocatalytic membrane reactor – 69, 71, 226, 227; fiber optic cable reactor – 535, 549, 577, 578, 579; cocurrent downflow bubble column contactor – 98, 676, 798; two phase, swirl flow monolith reactor – 128, 622; ring roughened annular reactor – 303, 305; laminar falling film slurry reactor – 411, 572, 573; shell and tube reactor – 620, 623; water bell reactor – 673; air lift loop reactor – 687, 688; field tests – 53, 97, 151, 240, 263, 280, 462, 570, 571, 572, 573, 574, 591, 756; materials for solar reactors – 336, 388, 477, 478, 545, 577, 578, 579, 607, 797, 801; solar resource assessment – 483; or treatment system design – 23, 24, 77, 78, 97, 237, 336, 346, 482, 656, 719.

2.4.2 Systems Analysis

As the technology for photocatalytically treating contaminated air and water has progressed, some work on economic evaluation has appeared in the literature. New work is limited:

photon costs from lamps and sunlight – 80, 755; marketing study – 25; solar processes – 230, 238, 346, 478, 596, 755, 797; comparison of activated carbon with photocatalytic removal of air contaminants – 260, 261, 755; process for controlling solvent emissions – 446.

2.5 Miscellaneous Topics

This category includes papers of interest that do not fall into the preceding headings:

actinometry – no new reports; adsorption – 47, 102, 103, 151, 173, 174, 385, 394, 484, 566, 637, 671, 694, 720, 725, 726, 769, 783, 799, 813; combined photocatalytic and biological treatment – 93, 94, 120, 163, 167, 168, 249, 264, 265, 415, 601, 602; combined photocatalytic and ultrafiltration treatment – 342; effect of applied voltage bias on photocatalytic reactions – 4, 108, 160, 310, 318, 322, 351, 352, 353, 354, 382, 419, 509, 606, 707, 708, 749; non-aqueous solvent systems – 1, 49, 50, 87, 101, 121, 147, 513; applications in chemical analysis – 344, 535; polymer aging – 2, 12, 62, 391, 569; photo initiators – ; "inert" ion or molecule effect – 88, 203, 212, 243, 308, 322, 397, 420, 421, 447, 494, 533, 547, 548, 575, 586, 599, 600, 603, 606, 626, 663, 668, 712, 756, 766, 778, 781, 845; dissolved metal ion effect – 384, 422, 423, 538, 555, 556, 590, 804, 845; comparison with other advanced oxidation processes – 169, 170, 249, 350, 580, 603, 605, 636, 648, 662, 696, 709, 789; purification of ultrapure water for recirculation – 129; clean room application – 213, 214, 215, 521, 747; purification of drinking water – 350, 412, 413, 795; municipal wastewater – 414; process wastewater – 81, 82, 83, 84, 199, 455, 456, 462, 492, 538, 596, 601, 602, 830, 853; paper mill effluent – 460, 461, 583, 584, 585; organic synthesis – 1, 49, 50, 87, 101, 121, 557, 558, 563, 564, 666, 690, 706, 754, 777, 833; surface science of TiO_2 – 131, 161, 194, 487, 504, 505, 506, 512, 637, 659; solid state NMR – 309, 608; quantum yield as a function of particle size and/or light intensity – 109, 111, 552, 553, 554, 671, 693, 703, 775; indoor air quality applications – 239, 328, 329, 656, 698, 699; light flux dependence – 11, 45, 64, 111, 151, 195, 246, 283, 552, 553, 554, 571, 572, 574, 594, 624, 685, 763; light source effects – 286, 400, 488, 603, 620, 621, 624, 643, 649, 652, 705, 784, 794, 814; temperature effects on photocatalytic oxidation – 46, 347, 348, 496, 564, 572; photoconductivity/ electrical conductivity – 370; imaging applications – 406, 479, 480, 481, 642; Dember effect – 404; self-cleaning surface – 280, 335, 782; ultrasound enhancement – 44, 337, 657, 700; mixed waste – 593, 594, 595, 596; catalyst lifetime – 43, 138, 151, 169, 484, 582, 586, 627, 752; treatment of photographic processing effluents – 724; point of zero charge determination – 189, 586; electrorheology – 618; computer modeling – 246, 288; mechanism and intermediates – 275, 466, 467, 484, 533, 541, 554, 561, 562, 563, 580, 583, 584, 585, 626, 638, 646, 659, 686, 701, 741, 742, 749, 752, 757, 762, 772, 773, 811, 812, 850; formation of hydroxyl radicals over metal oxides – 266, 517, 536, 638, 664, 757; formulation of photocatalytic paint – 296, 569, 692.

2.6 Patents

The number of patents that cover aspects of photocatalytic technology is increasing rapidly. This report includes 660 that have appeared since the last update. They cover a range of aqueous, gas-phase, and surface cleaning applications. The new patents are listed separately in Section 5.2.

2.7. Companies Active in the Field

R&D and market assessment activities are underway at many companies in the United States, but there is little change in the list of companies that have started business lines that use photocatalytic processes.[3] Japanese companies are very aggressively commercializing applications of titanium dioxide catalysts, films, and coatings. These products have not yet begun to appear in the U.S. market.

3.0 Compounds Studied

The tables in this section have the same format as in the first two reports. No compounds have been removed from the tables, but new compounds have been added to the second table to incorporate new work. The list of the compounds included in various lists of priority pollutants, air toxics, and the toxic release inventory compiled by the EPA[4] provided the starting point for these tables. Table 1 lists compounds in the EPA categories; Table 2 lists organic compounds that are not in Table 1; and Table 3 covers inorganic compounds that have been treated by a photocatalytic process. The inorganic compounds are arranged by element unless a significant number of citations referred to work on a specific ion or compound. A few broad categories are included in Table 2 that reflect new applications: bacteria, algae, and viruses; coal or carbon; adsorbable organic halides (AOX); color or chemical oxygen demand (COD); and oil or petroleum, for example. In these tables the citation suffix "g" indicates a gas-phase study. The treatability of compounds that have not been tested can usually be inferred from results for related compounds in the tables.

Table 1. Organic Compounds in EPA Lists of Priority Pollutants, Air Toxics, or Toxic Release Inventory

Substance	Formula	Reference
1,1,1-Trichloroethane	$CHCl_2CH_2Cl$	g154,g155,g325,466,467, 571,574
1,1,2,2-Tetrachloroethane	$CHCl_2CHCl_2$	
1,1,2-Trichloroethane	$CHCl_2CH_2Cl$	
1,1,2-Trichloro-1,2,2-trifluoroethane	CCl_2FCClF_2	
1,1-Dichloroethane	CH_3CHCl_2	
1,1-Dimethyl hydrazine	$(CH_3)_2NNH_2$	
1,2,3-Trichloropropane	$CH_2ClCHClCH_2Cl$	
1,2,4-Trichlorobenzene	$C_6H_3C_{l3}$	759
1,2,4-Trimethylbenzene	$C_6H_3(CH_3)_3$	
1,2-Butylene oxide	$H_2COCHCH_2CH_3$	
1,2-Dibromoethane	$BrCH_2CH_2Br$	
1,2-Dibromo-3-chloropropane (DBCP)	$CH_2BrCHBrCH_2Cl$	
1,2-Dichlorobenzene	$C_6H_4Cl_2$	705
1,2-Dichloroethane	$ClCH_2CH_2Cl$	657
1,2-Dichloroethylene	ClHC:CHCl	
1,2-Dichloropropane	$CH_3CHClCH_2Cl$	
1,2-Dinitrotoluene	$C_6H_3CH_3(NO_2)_2$	
1,2-Diphenylhydrazine	$C_{12}H_{12}N_2$	
1,2-Trans-dichloroethene	$C_2H_2Cl_2$	
1,3,5-Trinitrobenzene	$C_6H_3(NO_2)_3$	
1,3-Butadiene	H_2C:CHHC:CH_2	
1,3-Dichlorobenzene	C_6H_4Cl	
1,3-Dichloropropene	CHCl:$CHCH_2Cl$	
1,4-Dichlorobenzene	$C_6H_4Cl_2$	150

[4] "Notice of the Second Priority List of Hazardous Substances Commonly Found at Superfund Sites," *Environmental Reporter*, October 28, 1988, pp. 1255–1260.

Table 1. Organic Compounds in EPA Lists of Priority Pollutants, Air Toxics, or Toxic Release Inventory

Substance	Formula	Reference
1,4-Dioxane	$OCH_2CH_2OCH_2CH_2$	g154,g155,272
1-Amino-2-methylanthraquinone	$C_6H_4[C(O)]_2C_6H_2NH_2CH_3$	
1-Bromo-4-phenyoxybenzene	$p\text{-}BrC_6H_4OC_6H_5$	
2,2,4-Trimethylpentane	$(CH_3)_3C_5H_9$	
2,3,7,8-Tetrachlorodibenzo-p-dioxin	$C_{12}H_4Cl_4O_2$	
2,4,5-Trichlorophenoxyacetic acid	$C_6H_2Cl_3OCH_2CO_2H$	
2,4,5-TP acid (silvex)	$Cl_3C_6H_2OCH(CH_3)CO_2H$	
2,4,5-Trichlorophenol	$C_6H_2Cl_3OH$	
2,4,6-Trichlorophenol	$C_6H_2Cl_3OH$	156,335,753
2,4,6-Trinitrotoluene	$CH_3C_6H_2(NO_2)_3$	162,166,264,265,366,516, 597,628,654,662,663,683, 764
2,4-Diaminoanisole	$(NH_2)_2C_6H_3OCH_3$	
2,4-Dichlorophenoxyacetic acid (2,4-D)	$Cl_2C_6H_3OCH_2COOH$	263,498,g590,752
2,4-Diaminoanisole sulfate	$(NH_2)_2C_6H_3OCH_3.H_2SO_4$	
2,4-Dichlorophenol	$Cl_2C_6H_3OH$	247,333,403,453,454,501, 752
2,4-Dimethylphenol	$(CH_3)_2C_6H_3OH$	
2,4-Dinitrophenol	$C_6H_3OH(NO_2)_2$	298,315,503
2,4-Dinitrotoluene	$C_6H_3CH_3(NO_2)_2$	384
2,4-Toluene diamine	$CH_3(NH_2)_2C_6H_3$	
2,6-Dinitrotoluene	$C_6H_3CH_3(NO_2)_2$	384
2,6-Xylidine	$(CH_3)_2C_6H_3NH_2$	
2-Acetylaminofluorene	$CH_3C(O)NHC_6H_3CH_2C_6H_4$	
2-Aminoanthraquinone	$C_6H_4(CO)_2C_6H_3NH_2$	
2-Butanone	$CH_3COCH_2CH_3$	
2-Chloroacetophenone	$C_6H_5COCH_2Cl$	
2-Chloroethyl vinyl ether	$CH_2ClCH_2OCHCH_2$	
2-Chlorophenol	C_6H_4OHCl	380,630
2-Ethoxyethanol	$H_3CCH_2OCH_2CH_2CH_2OH$	
2-Methoxyethanol	$MeOCH_2CH_2OH$	
2-Methylnaphthalene	$C_{10}H_7CH_3$	
2-Nitrophenol	$NO_2C_6H_4OH$	250,476
2-Nitropropane	$CH_3CHNO_2CH_3$	
2-Pentanone, 4-Methyl	$CH_3(CH_2)_2COCH_3$	
2-Phenylphenol	$C_6H_5C_6H_4OH$	
3,3'-Dichlorobenzidine	$C_6H_3ClNH_2C_6H_3ClNH_2$	
3,3'-Dimethoxybenzidine	$[C_6H_3(OCH_3)NH_2]_2$	
3,3'-Dimethylbenzidine (o-Tolidine)	$[C_6H_3(CH_3)NH_2]_2$	
4,4'-Dichlorodiphenyldichloroethylene	$(ClC_6H_4)_2CCCl_2$	
4,4'-Diaminodiphenyl ether	$NH_2(C_6H_4)_2NH_2$	
4,4'-Isopropylidenediphenol	$(CH_3)_2C(C_6H_4OH)_2$	
4,4'-Methylenebis(N,N-dimethyl) benzenamine	$C_{17}H_{22}N_2$	
4,4'-Methylenedianiline	$H_2NC_6H_4CH_2C_6H_4NH_2$	

Table 1. Organic Compounds in EPA Lists of Priority Pollutants, Air Toxics, or Toxic Release Inventory

Substance	Formula	Reference
4,4'-Methylene-bis-(2-chloroaniline)	$CH_2(C_6H_4ClNH_2)_2$	
4,4'-Thiodianiline	$C_{12}H_{12}N_2S$	
4,6-Dinitro-o-cresol	$CH_3C_6H_2(NO_2)_2OH$	
4,6-Dinitro-2-methylphenol	$C_7H_6N_2O_5$	
4-Aminoazobenzene	$C_6H_5NNC_6H_4NH_2$	
4-Aminobiphenyl	$C_6H_5C_6H_4NH_2$	
4-Chloroaniline	$ClC_6H_4NH_2$	275
4-Chlorophenyl phenyl ether	p-$ClC_6H_4OC_6H_5$	
4-Dimethylaminoazobenzene	$(CH_3)_2C_6H_3NH_2$	
4-Methylphenol	p-$CH_3C_6H_4OH$	
4-Nitrobiphenyl	$C_6H_5C_6H_4NO_2$	
4-Nitrophenol	$NO_2C_6H_4OH$	101,128,190,191,192,436, 463,476,625,761,779
5-Nitro-o-anisidine	$NO_2C_6H_3(NH_2)(OCH_3)$	
Acenaphthene	$C_{10}H_6(CH_2)_2$	
Acenaphthylene	$C_{12}H_8$	
Acetaldehyde	CH_3CHO	g41,g154,g155,g184,318, g363,g470,g504,g505, g506,g537,g554,g645, 649,g692,g693,g698, g699,g717,g737,g770, g771,g832,g841
Acetamide	CH_3CNOH_2	
Acetone	CH_3COCH_3	g17,g154,g155,g172, g418,g511,g512,g698, g699, g737,g770,g771, g832, 838,g839
Acetonitrile	CH_3CN	
Acetophenone	$CH_3C(O)C_6H_5$	
Acrolein	CH_2CHCHO	
Acrylamide	$CH_2CHCONH_2$	
Acrylic acid	H_2C:CHCOOH	
Acrylonitrile	H_2C:CHCN	
Aldrin	$C_{12}H_8Cl_6$	
Allyl chloride	H_2CCHCH_2Cl	
Aniline	$C_6H_5NH_2$	275,588,589,600,614,651
Anthracene	$C_6H_4(CH)_2C_6H_4$	741
Aramite	$(CH_3)_3CC_6H_4OCH_2CH(CH_3)$-$SO_3C_2H_4Cl$	
Atrazine	$C_{18}H_{14}ClN_5$	226,307,462,501
Benzal chloride	$C_6H_5CHCl_2$	
Benzamide	$C_6H_5CONH_2$	
Benzene	C_6H_6	149,151,g154,g155,240, g244,g325,g329,g394, g417,g639,756,g824

Table 1. Organic Compounds in EPA Lists of Priority Pollutants, Air Toxics, or Toxic Release Inventory

Substance	Formula	Reference
Benzidine	$NH_2(C_6H_4)_2NH_2$	
Benzoic acid	C_6H_5COOH	
Benzoic trichloride	$C_6H_5CCl_3$	
Benzoyl chloride	C_6H_5COCl	
Benzoyl peroxide	$(C_6H_5CO)_2O_2$	
Benzo(a)anthracene	$C_{22}H_{14}$	
Benzo(a)pyrene	$C_{20}H_{12}$	
Benzo(b)fluoranthene	$C_{20}H_{12}$	
Benzo(g,h,i) perylene	$C_{22}H_{12}$	
Benzyl alcohol	$C_6H_5CH_2OH$	g394
Benzyl chloride	$C_6H_5CH_2Cl$	
BHC (Benzenehexachloride)	$C_6H_6Cl_6$	
Biphenyl	$C_6H_5C_6H_5$	
Bis(2-Chloroethoxy)methane	$CH_2(2\text{-}ClC_2H_5O)_2$	
Bis(2-chloroethyl) ether	$ClCH_2CH_2OCH_2CH_2Cl$	
Bis(2-chloro-1-methylethyl) ether	$[ClCH_2(CH_3)CH]_2O$	
Bis(2-ethylhexyl) adipate	$(C_7H_{13})_2C_4H_8(CO_2)_2$	
Bis(2-ethylhexyl)phthalate	$(C_4H_9CH(CH_2))_2OOC$	
Bis(chloromethyl)ether	$(CH_2Cl)O(CH_2Cl)$	
Bromochloromethane	$BrCH_2Cl$	
Bromodichloromethane	$CHCl_2Br$	
Bromoethane	C_2H_5Br	
Bromoform (Tribromomethane)	$CHBr_3$	145,146
Bromomethane (Methyl bromide)	CH_3Br	
Butyl acrylate	$CH_2{:}CHCOOC_4H_9$	
Butylbenzyl phthalate	$C_4H_9OOCC_6H_4COOC_7H_7$	
Butyraldehyde	$CH_3(CH_2)_2CHO$	g154,g155
Calcium cyanamide	NCNCa	
Caprolactam	$CH_2(CH_2)_4NHCO$	
Captan (N-Trichloromethylmercapto-tetrahydrophthalimide)	$C_9H_8Cl_3NO_2S$	
Carbaryl [1-Naphthalenol, methylcarbamate]	$C_{10}H_7OOCNHCH_3$	598
Carbon disulfide	CS_2	
Carbon tetrachloride	CCl_4	116,141,145,146,271, g325,465,570,574,791
Carbonyl sulfide	COS	
Catechol	$C_6H_4(OH)_2$	
Chloramben (Benzoic acid, 3-amino-2, 5-dichloro-)	$C_6H(CO_2H)(NH_2)Cl_2$	
Chlordane	$C_{10}H_6Cl_8$	
Chloroacetic acid	$CH_2ClCOOH$	227,731
Chlorobenzene	C_6H_5Cl	g464
Chlorobenzilate (Benzeneacetic acid, 4-chloro-alpha-(4-chlorophenyl)-)	$(C_6H_4Cl)_2C(OH)COOC_2H_5$	

Table 1. Organic Compounds in EPA Lists of Priority Pollutants, Air Toxics, or Toxic Release Inventory

Substance	Formula	Reference
Chlorodibenzodioxins, various	$C_{12}O_2H_{8-x}Cl_x$	
Chlorodibenzofurans	$C_{12}OH_{8-x}Cl_x$	
Chlorodibromomethane	$ClBr_2CH$	
Chlorodifluoromethane	$CHClF_2$	
Chloroethane	C_2H_5Cl	
Chloroform	$CHCl_3$	g5,116,139,145,146,g154, g155,g305,g325,465,493, 570,574,736,775,791
Chloromethane	CH_3Cl	
Chloromethyl methyl ether	C_2H_5ClO	
Chloroprene	$H_2C{:}CHCCl{:}CH_2$	
Chlorothalonil (1,3-Benzendedicarbonitrile, 2,4,5,6-tetrachloro-)	$C_6Cl_4(CN)_2$	
Chrysene	$C_{18}H_{12}$	
cis-1,2-Dichloroethylene	$ClHC{:}CHCl$	
cis-1,3-Dichloropropene	$CHCl{:}CHCH_2Cl$	
o-,m-,p-Cresols	$CH_3C_6H_4OH$	g395,601,602,761,779
Cumene	$C_6H_5CH(CH_3)_2$	g325,799
Cumene hydroperoxide	$C_6H_5C(CH_3)_2OOH$	
Cupferron (Benzeneamine, N-hydroxy-N-nitrose, ammonium salt)	$C_6H_5N(NO)ONH_4$	
Cyclohexane	C_6H_{12}	409, 706
Cyclohexanone	C_6H10O	
Cyclonite (RDX)	$(CH_2)_3(NNO_2)_3$	597,683
Decabromodiphenyl oxide	$(C_6Br_5)_2O$	
Dialate [Carbamothioic acid, bis (1-methylethyl)-, S-(2,3-dichloro-2-propenyl) ester]	$[(CH_3)_2CH]_2NCOSCH_2CClCHCl$	
Diaminotoluene (mixed isomers)	$CH_3C_6H_3(NH_2)_2$	
Diazomethane	CH_2N_2	
Dibenzofuran	$C_{12}H_8O$	
Dibenzo(a,h)anthracene	$C_{22}H_{14}$	
Dibromochloropropane	$CH_2BrCHBrCH_2Cl$	
Dibutyl phthalate	$C_6H_4(COOC_4H_9)_2$	
Dichlorobenzene (mixed isomers)	$C_6H_4Cl_2$	
Dichlorobromomethane	$CHBrCl_2$	
Dichlorodifluoromethane	CCl_2F_2	
Dichlorvos (Phosphoric acid, 2-dichloroethenyl dimethyl ester)	$(CH_3O)_2P(O)OCH{:}CCl_2$	135,136,137,138,254,790
Dicofol (4,4'-Dichloro-alpha-trichloro-Methylbenzhydrol)	$C_{14}H_9Cl_5O$	
Dieldrin/aldrin	$C_{12}H_{10}OPCl_6$	
Diepoxybutane	$C_4H_6O_2$	
Diethanolamine	$(HOCH_2CH_2)_2NH$	
Diethyl phthalate	$C_6H_4(CO_2C_2H_5)_2$	508

Table 1. Organic Compounds in EPA Lists of Priority Pollutants, Air Toxics, or Toxic Release Inventory

Substance	Formula	Reference
Diethyl sulfate	$(C_2H_5)_2SO_4$	
Dimethyl aminoazobenzene	$C_6H_5NNC_6H_4N(CH_3)_2$	
Dimethyl formamide (DMF)	$HCON(CH_3)_2$	
Dimethyl phthalate	$C_6H_4(COOCH_3)_2$	
Dimethyl sulfate	$(CH_3)_2SO_4$	
Dimethylcarbamyl chloride	$(CH_3)_2NCOCl$	
Disulfoton	$(C_2H_5O)_2P(S)SCH_2CH_2SCH_2CH_3$	
Di-n-butyl phthalate	$C_6H_4(COOC_4H_9)_2$	
Di-n-octyl phthalate	$C_6H_4(CO_2)(n\text{-}C_8H_{17})_2$	g213,g214,g215,287
Di-(2-ethylhexy) phthalate (DEHP)	$C_6H_4[COOCH_2CH(C_2H_5)C_4H_9]_2$	
Endosulfan	$C_9H_6Cl_60_3S$	
Endrin aldehyde/ endrin	$(C_{12}H_8OCl_6)$	
Epichlorohydrin	CH_2OCHCH_2Cl	
Ethyl acrylate	CH_2:$CHCOOC_2H_5$	
Ethyl chloroformate	$ClCOOC_2H_5$	
Ethylbenzene	$C_6H_5C_2H_5$	134,149,151,g154,g155, g213,g214,g215,240, g325,767,768,
Ethylene	H_2C:CH_2	g17,g206,g548,g680
Ethylene glycol	CH_2OHCH_2OH	361
Ethylene oxide	CH_2CH_2O	
Ethylene thiourea	$NHCH_2CH_2NHCS$	
Ethyleneimine (Aziridine)	CH_2NHCH_2	
Fluometuron [Urea, N,N-dimethyl-N'-[3-(trifluoromethyl)phenyl]-]	$C_{10}H_{11}F_3N_2O$	
Fluoranthene	$C_{16}H_{10}$	
Fluorene	$C_6H_4CH_2C_6H_4$	
Fluorotrichloromethane	CCl_3F	
Formaldehyde	HCHO	g18,419,g537,g547,g698, g699,850
Heptachlor/heptachlor epoxide	$C_{10}H_7Cl_7$	
Heptane	$CH_3(CH_2)_5CH_3$	
Hexachlorobenzene	C_6Cl_6	
Hexachlorobutadiene	Cl_2C:$CClCCl$:CCl_2	
Hexachlorocyclopentadiene	C_5Cl_6	
Hexachloroethane	Cl_3CCCl_3	
Hexachloronaphthalene	$C_{10}H_2Cl_6$	
Hexamethylphosphoramide	$[(N(CH_3)_2]_3PO$	
Hexamethylene-1,6-diisocyanate	$OCN(CH_2)_6NCO$	
Hexane	$CH_3(CH_2)_4CH_3$	g154,g155
Hydroquinone	$C_6H_4(OH)_2$	250,278
Indeno(1,2,3-cd)pyrene	$C_{22}H_{12}$	
Isophorone	$C(O)CHC(CH_3)CH_2C(CH_3)_2CH_2$	
Isopropyl alcohol	$(CH_3)_2CHOH$	g102,g103,130,190,191, 192,253,311,337,341,397,

Table 1. Organic Compounds in EPA Lists of Priority Pollutants, Air Toxics, or Toxic Release Inventory

Substance	Formula	Reference
		403,525,g552,562,703
Lindane(gamma-Benzenehexachloride)	$C_6H_6Cl_6$	248,767,768
Malachite Green	$C_{23}H_{25}ClN_2$	848
Malathion	$(CH_3O)_2P(S)SCH(CO_2C2H_5)$-$CH_2CO_2C_2H_5$	
Maleic anhydride	HC:CHC(O)OC(O)	
Maneb (Carbamodithioic acid, 1,2-ethanediylbis-,manganese complex)	$(SSCNCH_2CH_2NHCSS)Mn$	
Mechlorethamine	$CH_3N(CH_2CH_2Cl)_2$	
Melamine	$H_2NCNC(NH_2)NC(NH_2)N$	
Methanol	CH_3OH	20,g154,g155,190,191, 192,458,486,496,g638
Methoxychlor	$Cl_3CCH(C_6H_4OCH_3)_2$	
Methyl acrylate	CH_2:$CHCOOCH_3$	g154,g155
Methyl butyl ketone	$CH_3COC_4H_9$	
Methyl ethyl ketone	$CH_3COCH_2CH_3$	g154,g155
Methyl iodide	CH_3I	
Methyl isobutyl ketone	$(CH_3)_2CHCOCH_3$	
Methyl isocyanate	CH_3NCO	
Methyl methacrylate	CH_2:$C(CH_3)COOCH_3$	
Methyl tert-butyl ether	$(CH_3)_3COCH$	g154,g155
Methylene bromide	CH_2Br_2	
Methylene chloride	CH_2Cl_2	g5,116,139,g154,g155, 227, g488,571,574,750, g837
Methylenebis(phenylisocyanate) (MBI)	$CH_2(C_6H_4NCO)_2$	
Methylhydrazine	CH_3NHNH_2	
Michler's ketone	$CO[C_6H_4N(CH_3)_2]_2$	
Mirex	$C_{10}Cl_{12}$	
Mustard gas	$S(CH_3CH_2Cl)_2$	
m-Nitroaniline	$NO_2C_6H_4NH_2$	
N,N-Dimethylaniline	$C_6H_5N(CH_3)_2$	275
Naphthalene	$C_{10}H_8$	g590,599,741
Naphthylamine (alpha-, beta-)	$C_{10}H_7NH_2$	
Nitrilotriacetic acid	$N(CH_2COOH)_3$	769
Nitrobenzene	$C_6H_5NO_2$	190,191,192,588,589
Nitrofen [Benzene, 2,4-dichloro-1-(4-nitrophenoxy)-]	$C_{12}H_7Cl_2NO_3$	
Nitrogen mustard (2-Chloro-N-(2-chloroethyl)-N-methylethanamine)	$(ClCH_2CH_2)_2NCH_3$	
Nitroglycerin	$CH_2NO_3CHNO_3CH_2NO_3$	g511,g512,g719
Nitrophenol	$NO_2C_6H_4OH$	
n-Butyl alcohol	$CH_3(CH_2)_2CH_2OH$	
n-Dioctyl phthalate	$(C_8H_{17}OOC)_2C_6H_4$	
N-Nitrosodiethylamine	$C_4H_{10}N_2O$	
N-Nitrosodimethylamine	$(CH_3)_2N_2O$	

Table 1. Organic Compounds in EPA Lists of Priority Pollutants, Air Toxics, or Toxic Release Inventory

Substance	Formula	Reference
N-Nitrosodiphenylamine	$(C_6H_5)_2NNO$	
N-Nitrosodi-n-butylamine	$ONN(n\text{-}C_4H_9)_2$	
N-Nitrosodi-n-propylamine	$ONN(n\text{-}C_3H_7)_2$	
N-Nitrosomethylvinylamine	$ONN(CH_3)(C_2H_3)$	
N-Nitrosomorpholine	$ONNC_4H_8O$	
N-Nitrosonornicotine		
N-Nitrosopiperidine	$C_5H_{10}NHNO$	
N-Nitroso-N-ethylurea	$C(O)(NH_2)N(NO)C_2H_5$	
N-Nitroso-N-methylurea	$C(O)(NH_2)N(NO)(CH_3)$	
n-Pentane	$CH_3(CH_2)_3CH_3$	
Octachloronaphthalene	$C_{10}Cl_8$	
Octane	$CH_3(CH_2)_6CH_3$	185,186,g244
Oxirane	H_2COCH_2	
o-Anisidine	$CH_3OC_6H_4NH_2$	
o-Anisidine hydrochloride	$CH_3OC_6H_4NH_2.HCl$	
o-Nitroaniline	$NO_2C_6H_4NH_2$	
o-Toluidine	$CH_3C_6H_4NH_2$	
o-Toluidine hydrochloride	$CH_3C_6H_4NH_2.HCl$	
Parathion (DNTP)	$(C_2H_5O)_2P(S)OC_6H_4NO_2$	137,138
PCBs (Aroclor 1260,1254,1248, 1242)	$C_{12}Cl_xH_{10\text{-}x}$	119, 120,159,385
Pentachlorobenzene	C_6Cl_5H	
Pentachlorophenol	C_6Cl_5OH	231,273,333,452,465,579
Peracetic acid	CH_3COOOH	
Phenanthrene	C_4H_{10}	
Phenol	C_6H_5OH	6,7,14,85,98,100,107,117, 170,197,225,228,229,243, 278,297,408,462,468,501, 601,602,603,625,626,666, 678,687,688,714,731,752, 753,789,798,808,809
Phenol,2-methyl	$CH_3C_6H_4OH$	
Phosgene	$COCl_2$	
Phthalic anhydride	$C_6H_4(CO)_2O$	321
Picric acid	$C_6H_2(NO_2)_3OH$	
Polybrominatedbiphenyls	$C_{12}BrxH_{10\text{-}x}$	
Propane sultone	$C_3H_6SO_2$	
Propionaldehyde	C_2H_5CHO	g726
Propiolactone, beta-	OCH_2CH_2CO	
Propoxur [Phenol, 2-(1-methylethoxy)-methylcarbamate]	$C_{11}H_{15}NO_3$	
Propylene oxide	CH_2OCHCH_3	
Propylene (Propene)	$CH_3CH{:}CH_2$	
Propyleneimine	$CH_3HCNHCH_2$	
Pyrene	$C_{16}H_{10}$	
p-Anisidine	$CH_3OC_6H_4NH_2$	

Table 1. Organic Compounds in EPA Lists of Priority Pollutants, Air Toxics, or Toxic Release Inventory

Substance	Formula	Reference
p-Chloro-m-cresol	$C_6H_3CH_3OHCl$	
p-Cresidine	$CH_3C_6H_3(NH_2)OCH_3$	
p-Nitrosodiphenylamine	$(C_6H_5)_2NNO$	
p-Phenylenediamine	$C_6H_4(NH_2)_2$	
Quinoline	C_9H_7N	122
Quinone	$C_6H_4O_2$	278
Quintozene (Pentachloronitrobenzene)	$C_6Cl_5NO_2$	
Safrole	$C_3H_5C_6H_3O_2CH_2$	
sec-Butyl alcohol	$CH_3CH_2CHOHCH_3$	
Sevin (carbaryl)	$C_{10}H_7OOCNHCH_3$	
Sodium Alizarinsulfonate	$SO_3C_6H_3(CO)_2C_6H_2(OH)_2Na$	
Styrene	$C_6H_5CH:CH_2$	
Styrene oxide	$C_6H_5CHOCH_2$	
Terephthalic acid	$C_6H_4(COOH)_2$	
tert-Butyl alcohol	$(CH_3)_3COH$	
tert-Butylformate	$(CH_3)_3COC(O)H$	
Tetrachloroethylene	$Cl_2C:CCl_2$	g5,g18,227,g304,g305, 330,g330,349,535,571, 574,g822
Tetrachlorvinphos	$C_{10}H0Cl_4O_4P$	
Tetrahydrofuran	$CH_2CH_2CH_2CH_2O$	
Thioacetamide	CH_3CSNH_2	
Thiourea	$(NH_2)_2CS$	182
Toluene	$C_6H_5CH_3$	g46,130,149,151,g154, g155,176,g213,g214, g215,240,g325,g329, g394,g410,g439,g484, 494,g547, g639,g648, g717,756
Toluene diisocyanate	$CH_3C_6H_3(NCO)_2$	
Toxaphene	$C_{10}H_{10}Cl_8$	
Triaziquone	$C_{12}H_{13}N_3O_2$	
Trichlorfon	$(CH_3O)_2P(O)CH(OH)CCl_3$	
Trichloroethylene	$CHCl:CCl_2$	g5,8,9,10,g21,97,111,130, 139,143,150,g154,g155, g173,g174,g302,g303, g305,g309,330,g330,349, g359,g360,g377,g410, g427,g428,g429,g439, 447,448,449,g491,510, g510, 535,571,574,g608, g755, 757,g763,g778, g780,g781, g822,g829
Triethylamine	$N(C_2H_5)_3$	130
Trifluralin	$F_3C(NO_2)_2C_6H_2N(C_3H_7)_2$	

Table 1. Organic Compounds in EPA Lists of Priority Pollutants, Air Toxics, or Toxic Release Inventory

Substance	Formula	Reference
Trinitrophenylmethylnitramine	$(NO_2)_3C_6H_2N(NO_2)CH_3$	
Tris(2,3-dibromopropyl) phosphate	$(CH_2BrCHBrCH_2O)_3PO$	
Urethane (ethyl carbamate)	$CO(NH_2)OC_2H_5$	
Vinyl acetate	$CH_3COOCH:CH_2$	g154,g155
Vinyl bromide	CH_2CHBr	
Vinyl chloride	$CH_2:CHCl$	
Vinylidene chloride	$CH_2:CCl_2$	
Xylene (mixed isomers)	$C_6H_4(CH_3)_2$	151,g154,g155,240,g325, g394,g590,756
Zineb	$Zn(CS_2NHCH_2)_2$	

Table 2. Other Organic Compounds Treated by a Photocatalytic Process

Substance	Formula	Reference
1,1,1,2-Tetrachloroethane	Cl_3CCH_2Cl	
1,1,1,2-Tetrafluoroethane	F_3CCH_2F	467
1,3,5,7-Tetramethylcyclotetrasiloxane		
1,1,1-Trifluoro-2,2,2-trichloroethane	F_3CCCl_3	g325
1,1,1-Trifluorobromochloroethane	C_2HF_3ClBr	
1,1,3-Trichloropropene	Cl_2CCHCH_2Cl	
1,1-Difluoro-1,2,2-trichloroethane	ClF_2CCHCl_2	
1,1-Difluoro-1,2-dichloroethane	$FClCCClH_2$	
1,1-Difluoroethylene	CH_2CF_2	
1,1-Dimethyl-3-phenylurea	$C_6H_5NHC(O)N(CH_3)_2$	
1,1-Diphenylethylene	$(C_6H_5)CCH_2$	
1,2-Dimethoxybenzene	$(CH_3O)_2C_6H_4$	614
1,2-Bis(2-chloroethoxy)ethane	$(ClC_2H_4)_2C_2H_4$	
1,2-, 1,3-, or 1,4-Dinitrobenzene	$(NO_2)_2C_6H_4$	93,94
1,2,4-Benzenetricarboxylic acid	$C_6H_3(CO_2H)_3$	42
1,2,4-Trinitrobenzene	$C_6H_3(NO_2)_2$	162,166
1,3,5-Trinitrobenzene	$C_6H_3(NO_2)_2$	516
1,2,4,5-Benzenetetracarboxylic acid	$C_6H_2(CO_2H)_4$	42
1,2,4,5-Tetramethylbenzene	$(CH_3)_4C_6H_2$	
1,3-Dimethoxybenzene	$(CH_3O)_2C_6H_4$	
1,3-Diphenylisobenzofuran	$(C_6H_5)_2C_6H_2OC_6H_4$	
1,3,5-Benzenetricarboxylic acid	$C_6H_3(CO_2H)_3$	42
1,3,5-Trimethylbenzene	$(CH_3)_3C_6H_3$	g325
1,4-Dimethoxybenzene	$(CH_3O)_2C_6H_4$	614
1,4-Dinitrobenzene	$(NO_2)C_6H_4$	190,191
1,4-Napthoquinone	$C_{10}H_6O_2$	
1,4-Pentanediole	$CH_3CH(OH)(CH_2)_3OH$	
1-Benzylnicotinamide	$(C_6H_5)CH_2(C_5H_3N)C(O)NH_2$	
1-Bromodecane	$BrC_{10}H_{21}$	
1-Bromododecane	$BrC_{12}H_{25}$	
1-Butanol	$CH_3(CH_2)_3OH$	g154,g155
1-Decene	$CH_2CHC_8H_{17}$	g558
1-Dodecanol	$CH_3(CH_2)_{11}OH$	
1-Hexene	C_6H_{12}	g558
1-(Methoxyphenyl)-2-propanol	$(CH_3OC_6H_4)(CH_3)CHOH$	
1-Phenylethanol	$CH_3CH(C_6H_5)OH$	
1-Propanol	$n\text{-}C_3H_7OH$	
1-Nitronaphthalene	$C_{10}H_7NO_2$	
2,2-Dichloropropionic acid	$CH_3CCl_2CO_2H$	
2,3-Dichloropyridine	$Cl_2C_5H_3N$	390
2,3- , 2,4- or 3,4-Difluorophenol	$F_2C_6H_3OH$	
Tris-(2,4-dichlorophenoxy)ethyl-phosphite	$C_2H_5P[OC_6H_3Cl_2]_3$	
2,6-Dichlorophenol	$C_6H_3Cl_2OH$	

Table 2. Other Organic Compounds Treated by a Photocatalytic Process

Substance	Formula	Reference
2,7-Dichlorodibenzo-p-dioxin	$Cl_2C_{12}H_6O_2$	
2-, 3-, or 4-Chlorobenzoic acid	$ClC_6H_4CO_2H$	723
2-, 3-, or 4-Fluorophenol	FC_6H_4OH	
2-,3-, or 4-Nitrotoluene	$N0_2C_6H_4CH_3$	385
2,3-Benzofuran	C_8H_6O	
2,3- and 2,5-Dichlorophenol	$Cl_2C_6H_3OH$	
2,3-Dihydrobenzofuran	C_8H_8O	
2,3,5-Trichlorophenol	$Cl_3C_6H_2OH$	333,753
2,4-Dihydroxybenzoic acid	$(HO)_2C_6H_4(OH)CO_2H$	72
2,4-Dimethoxybenzene	$(CH_3O)_2C_6H_4$	
2,4-xylindine	$H_2NC_6H_3(CH_3)_2$	600
2,5-Dinitrophenol	$(NO_2)_2C_6H_3OH$	
2,6-Dichloroindophenol	$C_8H_2N(OH)Cl_2$	
2,5-Furandimethanol	$C_4H_2O(CH_2OH)_2$	
2,4,6-Trichlorophenyl oxalate	$(Cl_3C_6H_2)C_2O_4$	807
2,4,6-Trinitrobenzoic acid	$(NO_2)_3C_6H_2CO_2H$	
2-Amino-5-diethylaminotoluene	$(NH_2)[(C_2H_5)_2N]C_6H_3CH_3$	432
2-Chloroaniline	$ClC_6H_4NH_2$	275
2-Chlorobenzaldehyde	$ClC_6H_4C(O)H$	67
2-Chlorobiphenyl	$ClC_6H_4C_6H_5$	281
2-Chlorodibenzo-p-dioxin	$ClC_{12}H_7O_2$	
2-Chloroethylethylsulfide	$(ClC_2H_4)C_2H_5S$	636
2-Chloroethylmethylsulfide	$(ClC_2H_4)CH_3S$	
2-Coumaranone	$C_8H_6O_2$	
2-Furoic Acid	$(CH_2)_3CHOCO_2H$	
2-Hexene	C_6H_{12}	g557
2 or 3 or 4-Hydroxyacetophenone	$HOC_6H_4C(O)CH_3$	812
2-Hydroxypyridine	HOC_5H_4N	
2-Hydroxytetrahydropyran	HOC_5H_9O	
2-Methylbenzamidazole	$C_6H_4N_2HCCH_3$	777
2-Methylisoborneol	$C_{11}H_{20}OH$	364
2-Methylpropionic acid	$(CH_3)_2CH_2CO_2H$	717
2-Methyl-1,4-hydroquinone	$CH_3C_6H_3(OH)_2$	195
2-Methyl-2-nitropropane	$(CH_3)_2CHNO_2$	190,191,192
2-Naphthol	$C_{10}H_7OH$	
2-Nitroaniline	$O_2NC_6H_4NH_2$	
2-Tolualdehyde	$CH_3C_6H_4CHO$	
2,2'-Dihydroxybiphenyl	$C_{12}H_8(OH)_2$	
3,3,3-Trifluoropropene	CH_2CHCF_3	
3,3'-Dichlorobiphenyl	$(ClC_6H_4)_2$	
3,4,5-Trichlorophenol	$Cl_3C_6H_2OH$	
3,4-Dichloroaniline	$Cl_2C_6H_3NH_2$	705
3,4-Dichlorophenol	$3,4\text{-}Cl_2C_6H_3OH$	
3,5-Dichlorophenol	$3,5\text{-}Cl_2C_6H_3OH$	333
3-Aminoanisole	$CH_3OC_6H_4NH_3$	

Table 2. Other Organic Compounds Treated by a Photocatalytic Process

Substance	Formula	Reference
3-Chloroaniline	$CH_3OC_6H_4Cl$	
3-Chloroanisole	$ClC_6H_4NH_2$	275
3-Chlorobenzaldehyde	$ClC_6H_4C(O)H$	67
3-Chlorophenol	m-ClC_6H_4OH	
3-Chlorosalicylic acid	$C_7H_5ClO_3$	
3-Chlorotoluene	$CH_3C_6H_4Cl$	
3-Fluoroanisole	$CH_3OC_6H_4F$	
3-Fluorotoluene	$CH_3C_6H_4F$	
3-hydroxyanisole	$CH_3OC_6H_4OH$	
3-Methyl-2-oxobutanoic acid	$(CH_3)CHC(O)CO_2H$	
3-Nitroanisole	$CH_3OC_6H_4NO_2$	
3-Nitrophenol	$O_2NC_6H_4OH$	476
3-Nitrotoluene	$CH_3C_6H_4NO_2$	
3-Octanol	$CH_3CH_2CH(OH)(CH_2)_4CH_3$	715
3-Octanone	$CH_3CH_2C(O)(CH_2)_4CH_3$	715
4-Acetobenzaldehyde	$CH_3C(O)C_6H_4CHO$	
4-Aminoanisole	$CH_3OC_6H_4NH_2$	
4-Bromophenol	BrC_6H_4OH	
4-t-Butyltoluene	p-(t-C_4H_9)$C_6H_4CH_3$	
4-Chloroanisole	$CH_3OC_6H_4Cl$	
4-Chlorobenzaldehyde	$ClC_6H_4C(O)H$	67,615
4-Chlorocatachol	$ClC_6H_3(OH)_2$	351,352,353,354,695
4-Chloro-3-nitro-benzotrifluoride	$C_6HCl(NO_2)F_3$	
4-Chlorophenol	ClC_6H_4OH	43,201,202,204,247,278, 362,408,422,423,465,501, 577,578,579,625,687,694, 695,696,742,743,753,761
4-Chlorophenoxyacetic acid	$ClC_6H_4CH_2CO_2H$	614
4-Chlorophenylisocyanate	ClC_6H_4NCO	
4-Chlorotoluene	$CH_3C_6H_4Cl$	
4-Fluoroanisole	$CH_3OC_6H_4F$	
4-Fluorophenol	FC_6H_4OH	
4-Fluorotoluene	$CH_3C_6H_4F$	
4-Hydroxyanisole	$CH_3OC_6H_4OH$	
4-Hydroxyacetophenone	$HOC_6H_4C(O)CH_3$	
4-Hydroxybenzyl Alcohol	p-$HO(C_6H_4)CH_2OH$	
4-Hydroxybiphenyl	$C_{12}H_9OH$	
4-Iodophenol	IC_6H_4OH	
4-Methoxybenzylalcohol	$CH_3OC_6H_4CH_2OH$	49
4-Methoxybenzyl(methyl) ether	$CH_3OC_6H_4CH_2OCH_3$	49
4-Methoxybenzyl(3-phenylpropyl)-ether	$CH_3OC_6H_4CH_2O(CH_2)_3C_6H_5$	
4-Methoxybenzyl(t-buytyl) ether	$CH_3OC_6H_4CH_2OC(CH_3)_3$	49
4-Methoxybenzyl(phenyl)sulfide	$CH_3OC_6H_4CH_2SC_6H_5$	50
4-Methoxyphenol	$CH_3C_6H_4OH$	147
4-Nitroaniline	$NO_2C_6H_4NH_2$	

Table 2. Other Organic Compounds Treated by a Photocatalytic Process

Substance	Formula	Reference
4-Nitroanisole	$CH_3OC_6H_4NO_2$	190,191,192
4-Nitrobenzaldehyde	$NO_2C_6H_4CHO$	190,191,192
4-Nitrobenzamide	$NO_2C_6H_4CONH_2$	190,191,192
4-Nitrobenzenesulfanamide	$NO_2C_6H_4SO_2NH_2$	190,191,192
4-Nitrobenzoic acid	$O_2NC_6H_4CO_2H$	614
4-Nitrocatechol	$(NO_2)C_6H_3(OH)_2$	190,191,192
4-Nitromethylbenzenesulfonate	$NO_2C_6H_4SO_3CH_3$	190,191,192
4-Nitromethylbenzoate	$NO_2C_6H_4CO_2CH_3$	190,191,192
4-Nitrophenylethylphosphinate	$(NO_2)C_6H_4(C_2H_5)PO_2$	
4-Nitrophenylisopropylphosphinate	$(NO_2C_6H_5)(C_3H_7)HPO_3$	
4-Nitrophenyldiethylphosphate	$(NO_2C_6H_5)(C_2H_5)_2PO_4$	
4-Nitrosophenol	ONC_6H_4OH	588,589
4-Nitrotoluene	$CH_3C_6H_4NO_2$	190,191,192
4-Phenylbutylamine	$C_6H_5(CH_2)_4NH_2$	
4-Picoline	$CH_3C_5H_4N$	
4-Thiophenyl-1-butanol	$C_6H_5S(CH_2)_4OH$	
4-Trifluoromethylphenol	$CF_3C_6H_4OH$	
4,4'-Dihydroxybiphenyl	$C_{12}H_8(OH)_2$	
5-Bromouracil	$BrC_4H(NH)_2(O)_2$	11
5-Chlorouracil	$ClC_4H(NH)_2(O)_2$	11,766
5-Fluorouracil	$FC_4H(NH)_2(O)_2$	11,766
5-Hydroxypentanoic acid	$HO(CH_2)_4CO_2H$	
6-Methoxytetralin	$CH_3OC_8H_5O$	
5-Methylresorcinol	$CH_3C_6H_5O_2$	601,602
9,10-Anthraquinone		741
12-Nitrododecanoic acid	$NO_2C_{11}H_{22}CO_2H$	
12-phenyldodecanesulfonate, sodium salt	$C_6H_5(CH_2)_{12}SO_3H$	
Acenapthane	$C_{10}H_{16}(CH_2)_2$	
Acetic Acid or acetate ion	CH_3CO_2H	203,369,374,496,543,632, 658,681,731
Acetophenone	$CH_3COC_6H_5$	811,812,813
Acetylene	C_2H_2	
Acid Blue 40		507
Acid orange 7	$Na,O_3SC_6H_4N_2C_{10}H_6OH$	
Adipic acid	$C_5H_{11}CO_2H$	320
Aldicarb	$CH_3SC(CH_3)_2CHN(O)C(O)NHCH_3$	
L-Alanine	$CH_3CH(NH_2)CO_2H$	132,133,267,288
Alizarin Red S Biological Stain		617
p-Alkylphenol (various)	$R(C_6H_4)OH$	
Allyl alcohol	C_3H_5OH	
Alochlor		580
Ametryn		501
Aminophenol, 2, 3, or 4	$NH_2C_6H_4OH$	250,476
o-Anisidine	$CH_3OC_6H_4NH_2$	275
Anthraquinone-2-sulfonic acid	$HO_3SC_{14}H_7O_2$	
AOX or Haloform Precursors		

Table 2. Other Organic Compounds Treated by a Photocatalytic Process

Substance	Formula	Reference
L-Arginine	$H_2NCHNH(CH_2)_3CH(NH_2)CO_2H$	267
Aspartame	$HO_2CCH_2CH(NH_2)C(O)NHCH-(C_7H_7)(CO_2CH_3)$	267
L-Aspartic acid	$HO_2CCH_2CH(NH_2)CO_2H$	267
Asulam		712,732
Azinphos methyl	$C_{10}H_{12}N_3O_3PS_2$	169
Azobenzenes (various)	$XC_6H_4NNC_6H_4X$	
Azobisformamidoacetic acid		
Azodrin		138
Bacteria/Algae/Virus/Cancer Cells/ Macrophages/Skin Fibroblasts		38,64,65,73,76,86,106, 112,113,114, 115,149, 167,216,220,g239,g241, 282,283,284,285,300,301, g331,339,350,355,381, 382,387,398,399,413,414, 419,459,471,502,530,587, 643,644,645,647,700,704, 716,733,744,748,773,795, 796,814,826,845
Basagran		
Benthiocarb		254
Benzaldehyde	$C_6H_5C(O)H$	g394
Benzofuran	C_8H_6O	263
Benzophenone	$(C_6H_5)_2CO$	
Benzoquinone	$C_6H_4O_2$	588
Benzyldodecyldimethylamonium chloride	$(C_6H_5CH_2)(C_{12}H_{25})(CH_3)_2N,Cl$	
Benzyl ethers	$C_6H_5CH_2O-R$ $R=CH_3$, $n-C_6H_{13}$, $t-C_4H_9$, $(CH2)_3C_6H_5$, $CH_2C_6H_5$	
N-Benzylidineaniline (para substituted)	$p-R-C_6H_4CHNC_6H_5$ (R=H, OCH_3, CH_3, Cl, or Br)	690
Benzyl(phenyl)sulfide	$C_6H_5CH_2SC_6H_5$	50
Benzyltetradecyldimethylamonium chloride	$(C_6H_5CH_2)(C_{14}H_{27})(CH_3)_2N,Cl$	
Biomass		
Biphthalate	$(C_6H_4)(CO_2H)CO_2)(-1)$	
Bromobenzene	BrC_6H_5	
Bromothymol Blue		710
Butane	C_4H_{10}	
But-1-ene	$CH_2CHCH_2CH_3$	
But-2-ene	$CH_3CHCHCH_3$	g313
Butylacrylate	$C_4H_9O_2CCHCH_2$	88
Butylamine	$n-C_4H_7NH_2$	
t-Butylazine		
n-Butyltin chloride	$C_4H_9SnCl_3$	

Table 2. Other Organic Compounds Treated by a Photocatalytic Process

Substance	Formula	Reference
But-1-yne	$CHCCH_2CH_3$	
Butyric acid	$C_3H_7CO_2H$	
Carbetamide		11,198
Carbofuran		739
Carbon dioxide (reduction)	CO_2	34,35,36,340,341,674,675, 827
Carbon monoxide	CO	g18,g771,g772
Carbon tetrabromide	CBr_4	
Catalase		382
Catechol	$C_6H_4(OH)_2$	666
C12-Betaine	$(C_{12}H_{25})(CH_3)_2NCO_2$	
C12-Amidobetaine		
Cetyldimethylbenzylamonium chloride	$CH_3(CH_2)_{15}(CH_3)_2$- $(C_6H_5CH_2)N,Cl$	
Cetylpyridinium chloride or bromide	N-$[CH_3(CH_2)_{15}](C_5H_5N),Cl$ (or Br)	544,685,720
Cetyltrimethylammonium bromide	$CH_3(CH_2)_{15}(CH_3)_3N,Cl$	
Chloroacetaldehyde	$CH_2ClC(O)H$	
Chlorobenzoic acids, o-, m-, or p-	$Cl(C_6H_4)CO_2H$	
Chlorofluorocarbons, various		325
Chloral hydrate	$Cl_3CO(OH)_2$	
Chloranil, o- and p-	$C_6Cl_4O_2$	
Chloroethylammonium chloride	ClH_3N,Cl	
Chlorpyrifos		
Ciba Orange RI		
Cinnamyl alcohol	$C_6H_4C_2H_2OH$	
Citric acid	$HO_2CCH_2C(OH)(CO_2H)CH_2CO_2H$	
Coal or Carbon		
Color and/or COD (in wastewater)		
Congo Red	$C_{32}H_{22}O_6N_6S_2Na_2$	
Cresol violet	$C_{16}H_8NO(NH_2),Cl$	
Creosote phenolics		
p-Coumaric acid	$HOC_6H_4CHCHCO_2H$	51
Cyanamide	$NCNH_2$	182
Cyanuric acid	$C_3N_3(OH)_3$	475
Cyclododecanol	$C_{12}H_{23}OH$	
Cyclohexanedicarboxylic acids	$C_6H_{10}(CO_2H)_2$	
Cyclohexanol	$C_6H_{11}OH$	
Cyclohexene	C_6H_{10}	87
Cyclohexene oxide	$C_6H_{10}O$	
Cyclooctatetraene	C_8H_8	
Cyclopentane	C_5H_{10}	
Cyclophosphamide	$OPONHC_3H_6[N(C_2H_4Cl)_2]$	
D,L-Cysteine	$HSCH_2CH(NH_2)CO_2H$	267,382
DDT	$(ClC_6H_4)_2CHCCl_3$	142
DNA and RNA		171,177,269,300,773

Table 2. Other Organic Compounds Treated by a Photocatalytic Process

Substance	Formula	Reference
Decalin	$C_{10}H_{18}$	
Decamethyltetrasiloxane	$(CH_3)_{10}Si_4O_3$	g582
Decanoic acid	$C_9H_{19}CO_2H$	
Decanol	$HOC_{10}H_{21}$	
Desipramine	$(C_6H_4)_2(CH_2)_2N(CH_2)_3NHCH_3$	
Diazinon	$[(CH_3)_2CHC_4N_2H(CH_3)O]$-$PS(OC_2H_5)_2$	254
Dibenzothiophene	$C_{12}H_8S$	1
Dibenzo-p-dioxines, various	$X_nC1_2H_{(8-n)}O_2$ (X=Cl or Br)	274
Dibenzylsulfone	$[C_6H_5CH_2)_2SO_2$	152
Dibromomethane	CH_2Br_2	
Dichloroacetic acid	Cl_2CHCO_2H	52,53,59,60,89,90,91,227, 235,357,421,422,423,462, 465,579,668,684,764,823
Dichloroacetyl Chloride	$Cl_2CHCOCl$	
Diethyl ether	$(C_2H_5)_2O$	g770,g771
Diethylmethylphosphonate	$(C_2H_5)_2CH_3PO_2$	546
Dihexadecylphosphate	$(C_{16}H_{33})_2PO_4H$	386
Dimethoate	$(CH_3O)_2PSSCH_2CONHCH_3$	169
Dimethylacetamide	$CH_3C(O)N(CH_3)_2$	
Dimethylamine	(CH_3)2NH	
Dimethylmethylphosphonate	$(CH_3)_2CH_3PO_2$	546
Dimethyl-2,2,2-trichloro-1-hydroxyethyl-phosphonate	$(CH_3)_2[CCl_3CH_2(OH)]PO_2$	731
Dimethylphenols (Xylenols)	$(CH_3)_2C_6H_3OH$	
Dimethylsulfide	$(CH_3)_2S$	g582
Dimethyl-2,2-dichlorovinyl phosphate	$(CH_3)_2(Cl_2CCH)PO_4$	
Diphenylacetylene	$(C_6H_5)_2C_2$	
Diphenylamine	$(C_6H_5)_2NH$	93,94,275
Diphenylmethane	$(C_6H_5)_2CH_2$	
Diphenylsulfide	$(C_6H_5)_2S$	
Diphenyltin chloride	$(C_6H_5)_2SnCl_2$	524
Direct blue 1	$[(Na,O_3S)C_{16}H_6(NH_2)(OH)$-$(OCH_3)N_2]_2$	
Diquat		
Disinfection by-products		629
Disperse blue 79		523
Disperse red 74		
Diuron	$C_6H_3Cl_2NHC(O)N(CH_3)_2$	378,508
Dodecane	$C_{12}H_{26}$	134,494
Dodecyl sulfate, sodium salt	$(C_{12}H_{25})_2SO_4$,Na	396,606,765
Dodecylbenzenesulfonate	$(C_{12}H_{25})C_6H_4SO_3(-1)$	169
Dodecyldecaoxyethylenephosphates		
Dodecylpyridinium chloride	$(C_{12}H_{25})C_5H_5NH$,Cl	
Doxycycline		
Drimarene Yellow 3 GLI		710

Table 2. Other Organic Compounds Treated by a Photocatalytic Process

Substance	Formula	Reference
Dyes, unspecified		207,208,209,210,233,365, 401,415,542,605,735,785, 804,805,825,842,843,853,
Eosin		615,844
Ethambutol		
Ethane	C_2H_6	
Ethanol	C_2H_5OH	89,318,g347,g348,g504, g505,g506,g511,g512, g521,g734,g770,g771
Ethylacetate	$CH_3CO_2C_2H_5$	g770,g771
Ethylenediaminetetraacetic acid and metal complexes	$(HO_2CCH_2)_4N_2C_2H_4$	124,278,338,424,442,443, 709
2-, 3-, or 4-Ethylphenol	$(C_2H_5)C_6H_4OH$	
Fast Orange GC Base		710
Fenitrothion	$C_9H_{12}NO_5PS$	254
Fenobucarb		254
Fluorescein	$C_20H_{12}O_5$	
Folicur		
Formamide	$HC(O)NH_2$	
Formic acid or formate ion	HCO_2H	160,203,205,251,310,358, 424,501
Fullerenes	C_{60}, C_{70}, and C_{84}	
Fulvic acid		
beta-D-Galactosidase		301
Geosmin		364
Glucose	$C_6H_{11}O_6$	
L-Glutamic acid	$HO_2C(CH_2)_2CH(NH_2)CO_2H$	267
L-Glutamine	$H_2NC(CH_2)_2CH(NH_2)CO_2H$	267
Glycerol	$C_3H_5(OH)_3$	
Glycolic Acid	$HOCH_2CO_2H$	466
Halothane	CF_3CBrCl	58,61
HCFC or HFC		467,g652,g653
Heparin		
Heptanal	$C_6H_{13}CHO$	
Hexafluorobenzene	C_6F_6	
Hexafluoropropene	CF_2CFCF_3	
HMX	$(CH_2)_4(NNO_2)_4$	
Hexanol	$C_6H_{13}OH$	
L-Histidine	$C_3N_2H_3CH_2CH(NH_2)CO_2H$	267
Humic Acids		63,66,178,794
Hydroxybenzoic acid (various)	$HOC_6H_4(OH)CO_2H$	
Hydroxycarboxylic acids, alpha	$RCH(OH)CO_2H$	
Hydroxyethylcellulose		
Imidacloprid		3
Imidazole	$C_3H_4N_2$	541
Indole	C_8H_6NH	g582,615

Table 2. Other Organic Compounds Treated by a Photocatalytic Process

Substance	Formula	Reference
Iprobenfos		254
Isobutane	C_4H_{10}	
Isobutanol	$CH_3CH(CH_3)CH_2OH$	
Isobutene	C_4H_8	
Isobutyric Acid	$CH_3CH(CH_3)CO_2H$	
L-iso-Lucine	$C_2H_5CH(CH_3)CH(NH_2)CO_2H$	267
Isonicotinaldehyde	C_5H_4NCHO	
Isoprene	$CH_2C(CH_3)CHCH_2$	g325
Isoprothiolane		254
Isosorbide dinitrate	$C_6O_2H_8(ONO_2)_2$	
Iso-octane	$(CH_3)_2CH(CH_2)_4CH_3$	
L-Lysine	$NH_2(CH_2)_4CH(NH_2)CO_2H$	563
Lactic acid	$C_3H_6O_3$	47
Landfill leachate		
Lignin		120
Limonene	C_9H_{16}	g325
Linoleic acid	$C_{18}H_{31}CO_2H$	679
L-Leucine	$(CH_3)_2CHCH_2CH(NH_2)CO_2H$	267
Luminol-CL		807
Malachite green oxalate	$(C_6H_5)[C_6H_4N(CH_3)_2][C_6H_4N$-$(CH_3)_2]C,(C_2O_4H)_2.H_2C_2O_4$	
Maleic acid	$HO_2CCHCHCO_2H$	121
Maleic anhydride	$O_2CCHCHCO_2$	121,123
Malic acid	$HO_2CCH_2CH(OH)CO_2H$	262
Malonaldehyde	$H(O)CCH_2C(O)H$	459
Malonic acid	$CH_2(CO_2H)_2$	654
Manitol	$HOCH_2[CH(OH)]_4CH_2OH$	356
Mercaptotetrazole	HSN_4H	776
Mesitylene	$(CH_3)_3C_6H_3$	g394
Methane	CH_4	g172,g564
Methanethiol	CH_3SH	717
L-Methionine	$CH_3S(CH_2)_2CH(NH_2)CO_2H$	267
Methomyl		846
N-Methylaniline	$C_6H_5NHCH_3$	275
Methylcyclohexane	$CH_3C_6H_{11}$	
Methyl-2-naphthoate	$C_{10}H_7CO_2CH_3$	754
Methylnitrophos		138
Methyl orange	$Na,O_3SC_6H_4N_2C_6H_4N(CH_3)_2$	450,784,785,786,787,788, 851
alpha-Methylstyrene	$C_6H_5(CH_3)CCH_2$	
Methyl viologen	$(CH_3C_5H_4N)_2,Cl_2$	55,58,61,386,432
Methylene blue	$(CH_3)_2NC_6H_3NSC_6H_3N(CH_3)_2,Cl$	40,144,479,513,522,671, 691,774
Methylvinylketone	$CH_3COC_2H_3$	
Microcystin-LR or YR or YA		188,633,634,702
Mixed waste		

Table 2. Other Organic Compounds Treated by a Photocatalytic Process

Substance	Formula	Reference
Molasses		
Monocrotophos		137,379
Monuron	$ClC_6H_4NHCON(CH_3)_2$	
Morpholine	C_4H_8ONH	
Myrcene	$C_{10}H_{16}$	g325
m-Phenoxytoluene	m-C_6H_5O-$C_6H_4CH_3$	
N-Benzyldiphenylamine	$(C_6H_5CH_2)(C_6H_5)_2N$	
N-Docanoyl-beta-alanine		267
N-Dodecanoylglutamate		267
N'-Dodecyl-N,N-dimethyl ammonium-acetate, sodium salt		270
N'-Dodecylamidopropyl-N,N-dimethyl-ammonium acetate, sodium salt		270
N-Dodecanoyl-N-(2-hydroxyethyl)amide	$CH_3(CH_2)_{10}C(O)NH(CH_2)_2OH$	270
N-Dodecanoyl-N,N-bis(2-hydroxyethyl)-amide	$CH_3(CH_2)_{10}C(O)N[(CH_2)_2OH]_2$	
N-Hydroxysuccinimide	$C_2H_4(C(O))_2NOH$	
N-Phenyl-1,4-phenylenediamine	$C_6H_5NHC_6H_4NH_2$	275
N,N,N',N'-Tetraethyloxonine		
alpha-Naphthaleneacetic acid	$C_{10}H_7CH_2CO_2H$	855
Naphthol	$C_{10}H_7OH$	
Naphthol blue black	$(C_6H_5N_2)C_{12}H_2(OH)(NH_2)$-$(SO_3Na)_2$	523
Nicotinamide Coenzymes		92
Nicotine	$C_5H_4NC_4H_7NCH_3$	
Nile Blue A	$C_{16}NO(NH_2)N(C_2H_5)_2,SO_4$	
Nitrocellulose		
o-Nitrophenyl-beta-D-galactopyranoside	$C_{12}H_{15}NO_8$	301
Nitropropane	$CH_3CH_2CH_2NO_2$	190,191,192
Nitrosobenzene	ONC_6H_5	588,589
p-Nitrosodimethylanaline	$ONC_6H_4N(CH_3)_2$	424
p-Nitrotoluenesulfonic acid	$(CH_3)(NO_2)C_6H_3SO_3H$	
Nitrotoluene, various	$NO_2C_6H_4CH_3$	
Nonylphenylethoxylate	$C_9H_{17}C_6H_4OC_2H_5$	
n-Nonylphenylpolyoxyethylene ethers	$C_9H_{17}C_6H_4O(C_2H_4O)_nH$	268,850
n-Octanoic acid	$C_7H_{15}C0_2H$	665
n-Octanol	$C_8H_{17}OH$	311,820
Octanal	$C_7H_{15}CHO$	
Octaphenylcyclotetrasiloxane	$(C_6H_5)_8(SiO_2)_4$	
Oil/Petroleum		249,342,498,499
Oxalic acid or oxalate ion	$C_2O_4H_2$	108,193,278,416,590,654, 740
PCB - polyhydroxy		
Pendimethalin		
Pentachloroethane	C_2HCl_5	305
Pentaethyleneglycol n-dodecyl ether	$(HO)(CH_2CH_2O)_5(C_{12}H_{23})$	

Table 2. Other Organic Compounds Treated by a Photocatalytic Process

Substance	Formula	Reference
Pentafluorophenol	C_6F_5OH	
n-Pentyl amine	$n\text{-}C_5H_{11}NH_2$	
Permethrin		
Pesticides - unspecified		137,142
beta-Phellandrene		g325
Phenacylstyrylthioether	$C_6H_5CH_2SCH_2C(C_6H_5)CH_2$	
Phenosafranin	$C_6H_5N_2C_{12}H_4(NH_2(CH_3)_2$	
Phenoxyacetic acid	$C_6H_5OCH_2CO_2H$	689,752
Phenylacetic acid	$C_6H_5CH_2CO_2H$	689
L-Phenylalanine	$C_6H_5CH_2CH(NH_2)CO_2H$	267,288,344
Phenylsulfinylacetic acid	$C_6H_5S(O)CH_2CO_2H$	689
Phenylsulfonylacetic acid	$C_6H_5S(O)_2CH_2CO_2H$	689
Phenylthioacetic acid	$C_6H_5SCH_2CO_2H$	689
p-Phenylenediamine	$H_2NC_6H_4NH_2$	
Phenylhydroxylamine	C_6H_5NHOH	588,589
Phenylmercaptotetrazole	$C_6H_5SN_4H$	776
Phenyltetrazole	$C_6H_5N_4H$	776
Phorate	$(C_2H_5O)P(S)SCH_2SC_2H_5$	137
Phthaldialdehyde	$C_6H_4(CHO)_2$	
Phthalan		
Phthalic acid	$C_6H_4(CO_2H)_2$	741
Phthalazinylhydrazones		576
Picoline	$CH_3C_5H_4N$	
Pinene (alpha or beta)	$C_{10}H_{16}$	g196,g325,g590
Piperidene	$C_5H_{10}NH$	
Polyethoxylene alkyl ethers	$R_2(OC_2H_4)n$	551
Polyethylene	$(CH_2CH_2)n$	
Poly(methylphenylsiloxane)	$[(C_6H_5)(CH_3)SiO]n$	
Polypropylene	$[(CH_3)CHCH_2]_n$	12,391
Polyvinylalcohol	$(C_2H_3OH)n$	55,58
Polyvinylchloride (PVC)	$(CH_2CHCl)n$	287
Procion red		332
Procymidone		308
L-Proline	$C_4H_8NCO_2H$	267
Prometon		
Prometryn		501
Propane	C_3H_8	831
Propanil	$(3,4\text{-}Cl_2C_6H_3)NH(O)CC_2H_5$	705
Propazine		501
Propionamide	$CH_3CH_2C(O)NH_2$	
Propionic acid	$C_2H_5CO_2H$	
Propyzamide		254,725,828
Propylene	C_3H_6	
Propylene glycol	$CH_3CH(OH)CH_2OH$	170,361
Propylene glycol dinitrate	$CH_3CH(NO_3)CH_2(NO_3)$	

Table 2. Other Organic Compounds Treated by a Photocatalytic Process

Substance	Formula	Reference
Propyne	CH_3CCH	
Propyzamide		
Pyridine	C_5H_5N	
Pyrocatechol	o-$C_6H_4(OH)_2$	
Pyrrole	C_4H_5N	g582
Quinoline acid yellow		
Reactive Dyes		616,617,627
Reactive Red M5B		529
Red Dye 79		
Red Dye 4BS		140
Resorcinol	$C_6H_6O_2$	93,94,601,602,761
RDX, see cyclonite	$(CH_2)_3(NNO_2)_3$	
Rhodamine B	$CH_3OC(O)(C_6H_4)C_{13}H_6O(NH_2)_2$	440,441,474,499,606,849
Rhodamine 6G	$C_2H_5OC(O)C_6H_4C_{13}H_4(CH_3)_2$-[$N(C_2H_5)]_2$,Cl	39
Rhodamine 6ZH		
Rose Bengal	$Na_2,O_2CC_6Cl_4C_{13}H_2OI_4O_2$	
S-Dodecyl thioether carboxylates		
S-Ethyl-N,N-dipropyl thiocarbamate (EPTC)	$(C_2H_5)SC(O)N(C_3H_7)_2$	
S-Ethyl-N,N-diisopropylthiocarbamate (Butylate)	$(C_2H_5)SC(O)N(i\text{-}C_3H_7)_2$	
S-Ethyl-4-hexahydro-1-H-azepine-1-carbothionate (molinate)		
S-Propyl-N-cyclohexyl thiocarbamate (cycloate)	$(C_3H_7)SC(O)NH(C_6H_{11})$	
S-Propyl-N,N-dipropyl thiocarbamate (vernolate)	$(C_3H_7)SC(O)(NC_3H_7)_2$	767,768
Sabinine		g325
Salicylaldehyde	$C_7H_6O_2$	
Salicylic acid	$C_7H_6O_3$	197,245,278,392,411,451, 572,573,614,713,758
L-Serine	$HOCH_2CH(NH_2)CO_2H$	267,288
Simazine	$(C_2H_5)Cl(NHC_2H_5)C_3N_3$	254
Sodium chloroacetate	CH_3CO_2Na	
Sodium dodecylbenzene sulfonate	$C_{12}H_{25}C_6H_4SO_3Na$	
Special brilliant blue FFR		43
Stearic acid	$CH_3(CH_2)_{16}CO_2H$	659
Stilbene	$C_6H_5CHCHC_6H_5$	
Succinic acid	$HO_2CCH_2CH_2CO_2H$	319
Succinimide	$HNC(O)CH_2CH_2C(O)$	541
Sucrose	$C_{12}H_{22}O_{11}$	74
Sulfones	$RS(O)_2R'$	
Superoxide dismutase (SOD)		318
Surfactants - unspecified		129
Tartaric acid	$HO_2CCH(OH)CH(OH)CO_2H$	654

Table 2. Other Organic Compounds Treated by a Photocatalytic Process

Substance	Formula	Reference
Terbutryne		435
Terpinene	$C_{10}H_{16}$	g325
alpha-Terpineol	$C_{10}H_{18}O$	39
Tetrachloroaniline	$Cl_4C_6HNH_2$	275
Tetrachlorvinphos	$CHClCH(2,4,5\text{-}Cl_3C_6H_2)(CH_3)PO_4$	
Tetrafluoroethylene	C_2F_4	
Tetralin	$C_{10}H_{12}$	
Tetramethylenediamine	$NH_2(CH_2)_4NH_2$	
Tetrabutylammonium phosphate	$[(n\text{-}C_4H_9)_4N]_4,PO_4$	
Tetradecyldimethylbenzylammonium-chloride	$CH_3(CH_2)_{13}(CH_3)_2(C_6H_5CH_2)N,Cl$	
Tetranitromethane	$C(NO_2)_4$	58,87,495
Theophylline	$C_7H_8N_4O_2{\cdot}H_2O$	
Thianthrene	$C_{13}H_8OS$	1
Thioethers	RSR'	
Thiobencarb		
Thiolactic acid	$CH_3CH(SH)CO_2H$	132,133
Thiophenol	C_6H_5SH	278
Thioxanthene	$C_{12}H_8S_2$	1
Thioxanthone	$C_{13}H_8OS$	1
Thiram		254
Thymine	$C_5H_6N_2O_2$	
Thionine	$C_{12}NS(NH_2),O_2CCH_3$	
L-Threonine	$CH_3CH(OH)CH(NH_2)CO_2H$	267
p-Toluenesulfonic acid	$CH_3C_6H_4SO_3H$	
p-Toluidine	$CH_3C_6H_4NH_2$	600
Total Organic Carbon (TOC)		52,53,94,167,168,199, 249,322,401,434,460,461,4 62, 583,584,585
s-Triazines		68,71,475
Trichloroacetic acid	Cl_3CCO_2H	145,146,227
Trietazine		
Triethanolamine	$N(CH_2CH_2OH)_3$	
Trifluoroacetic acid	CF_3CO_2H	
Trihydrazinotriazine		
Trihydroxybenzene	$(HO)_3C_6H_3$	
Trimethylamine	$(CH_3)_3N$	g328
Trimethylammonium chloride	$(CH_3)_3NH,Cl$	212
Trinitrophenol	$(NO_2)_3C_6H_2OH$	
Triphenylacetic acid	$(C_6H_5)_3CCO_2H$	
Triphenylbismuthine	$(C_6H_5)_3Bi$	
Triphenylphosphine	$(C_6H_5)_3P$	
Triphenylstibine	$(C_6H_5)_3Sb$	
L-Tryptophan	$C_8NH_6CH_2CH(NH)CO_2H$	267
Tri-(p-Tolyl)arsine	$(CH_3C_6H_4)_3As$	
Triton X-100	$C_8H_{17}C_6H_4(OCH_2CH_2)_xOH$	

Table 2. Other Organic Compounds Treated by a Photocatalytic Process

Substance	Formula	Reference
Umbelliferone	$C_9H_6O_3$	
Uracil	HNC(O)NHC(O)CHCH	766
Urea	$C(O)(NH_2)_2$	541
L-Valine	$(CH_3)_2CHCH(NH_2)CO_2H$	267
Vat Blue		710
Vinclozolin		308

Table 3. Inorganic Substances Included in EPA Lists of Hazardous Substances and/or Treated by a Photocatalytic Process

Substance/Element	Formula/Symbol	Reference
Actinides	Th,Pa,U,Np,Pu	124,180
Aluminum (fume or dust)	Al	
Aluminum oxide	Al_2O_3	
Ammonia	NH_3	95,96,g213,g214,g215, 476,541,588,589,g747
Ammonium nitrate (soln)	NH_4NO_3	
Ammonium sulfate (soln)	$(NH_4)_2SO_4$	
Antimony	Sb	
Arsenic	As	194,419
Asbestos	Mg,Si	
Azide ion	$N_3^{(-)}$	
Barium	Ba	
Beryllium	Be	
Bismuth	Bi	
Boron	B	
Bromate ion	BrO_3(-1)	489
Cadmium	Cd	442,443,593,594,595,596, 746
Chlorine	Cl	
Chlorine dioxide	ClO_2	
Chromium	Cr	157,201,202,203,204,205, 355,357,431,450,462,526, 593,594,595,596
Cobalt	Co	
Copper	Cu	132,133,442,443,480,593, 594,595,596,609
Cyanide and Complexes	CN(-1) and $M(CN)_x$	45,120,444,492,509,596
Cyanate ion	CNO(-1)	
Gold	Au	596,774
Halide ion	X(1-), X = F, Cl, Br, or I	278,513
Hydrazine	H_2NNH_2	
Hydrogen sulfide	H_2S	717
Hydroxylamine	NH_2OH	541
Hypophosphorus acid	H_2PO_2	
Iridium	Ir	
Iron	Fe	
Lead	Pb	442,443,486,740,746,769
Manganese	Mn	
Mercury	Hg	132,133,395,593,594,595, 596,740,803
Molybdenum	Mo	
Molybdenum hexacarbonyl	$Mo(CO)_6$	g566
Nickel	Ni	193,420,442,443,480,593,

Table 3. Inorganic Substances Included in EPA Lists of Hazardous Substances and/or Treated by a Photocatalytic Process

Substance/Element	Formula/Symbol	Reference
Nickel (cont'd.)	Ni	594,595,596
Nitrates/nitrites	NO_3(-1),NO_2(-1)	96,416,457,588,589,611, 612,654,852
Nitrogen oxides	NO_X, N_2O	g26,g27, g30, g31, g32, g224,g289,g290,g291, g292,g293,g312,g313, g383,g515,g519,g528, g534,g727,g747,g783, g815,g818,819,g847
Nitrogen	N_2	
Oxygen	O_2	
Ozone	O_3	
Palladium	Pd	
Phosphorus	P	
Platinum	Pt	20,55,324,487,593,594, 595,596
Radium	Ra	
Radon	Rn	
Rhodium	Rh	
Selenium	Se	
Silicon	Si	
Silver	Ag	426,438,473,513,562,593, 594,595,596,642,724
Strontium	Sr	
Sulfate radical	SO_4(1-)	
Sulfite	SO_3(1-)	61
Sulfur	S	
Sulfur oxides	SO_x	g26,187,g224,g747
Sulfuric acid	H_2SO_4	
Thallium	Tl	
Thiocyanate	SCN(1-)	55,58,60,148
Thiosulfate	S_2O_3(2-)	
Thorium	Th	
Tin	Sn	
Tritium	H,(T)	
Tungsten	W	
Vanadium	V	
Zinc	Zn	

4.0 Conclusions

The level of activity in this field remains high. The potential to develop new technology for environmental remediation is still a driving force for the R&D activity; however, applications such as indoor air purification, disinfection and cell killing, and self-cleaning surfaces have moved more quickly to commercialization. Clearly, many companies see potential markets for indoor air quality applications. In research more attention is being paid to detecting and identifying intermediates and by-products that can be formed during the photocatalytic process, both in aqueous and gas-phase systems. This is an impor- tant tool in developing an understanding of the chemical mechanisms of the processes and is necessary to ensure that potentially harmful substances are not left in the processed stream. Key areas of work identified in the last report continue to be important. Few studies include mass balances for the reactions, and kinetic models that can be used to size treatment systems are still rare. As systems are deployed in the field, it is increasingly important that the issues of catalyst lifetime and regeneration be addressed. Related to this is the need to identify those components of an air or water stream that can inhibit or kill activity. All these are important to the design of efficient and economical treatment systems. Questions concerning the economic viability of photocatalytic processes are being raised more often, and the significance of simple mineralization of one more organic compound without regard to the amount of energy or time that it took is questioned by those who want to see the process efficiency improved. This may be taken as a sign that the field is maturing. Entrepreneurs and companies would like to capitalize on the scientific foundation that has been developed for photocatalytic chemistry.

5.0 Bibliography

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