

## APPENDIX A

### Odor Wheels

Figure A.1 Wastewater odor wheel (Burlingame et al., 2004)

Figure A.2 Compost odor wheel (Suffet et al., 2009; Rosenfeld and Suffet, 2003)

Figure A.3 Urban odor wheel (Curren, 2012)

Figure A.4 Industrial odor wheel (Curren, 2012)

Figure A.5 Refinery odor wheel (Curren, 2012)

Figure A.6 Foundry odor wheel (Curren, 2012)

Figure A.7 Landfill odor wheel (Decottignies et al., 2009)

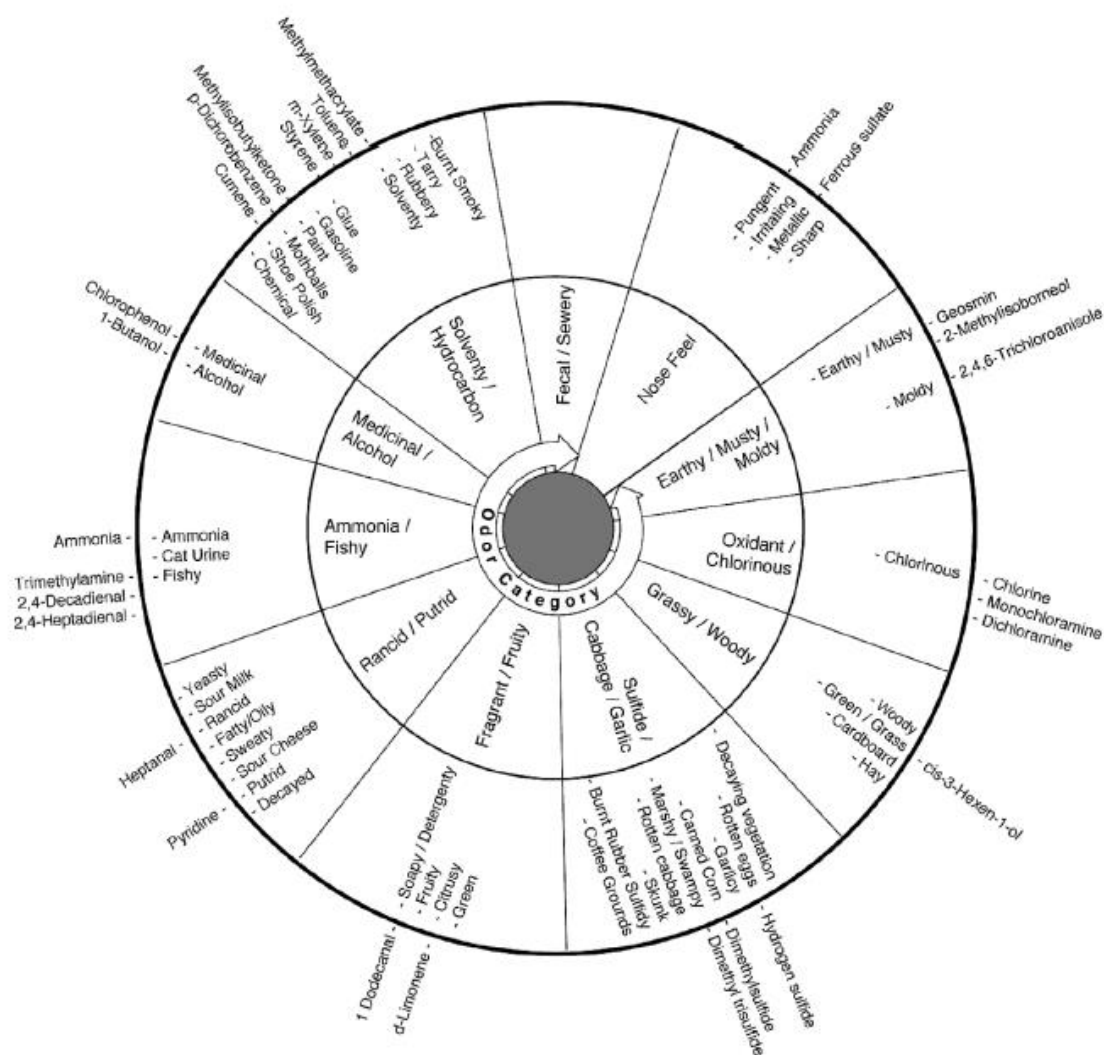
Figure A.8 Biosolids processing odor wheel (Fisher et al., 2018)

Figure A.9 Odor wheel (ATSDR, 2016)

Figure A.10 Odor wheel (Metro Vancouver, 2019)

*Reference is included with each figure.*

Table A.1 Common odor notes and their associated odorants and sources (*i.e., the odor wheels displayed as a table*)



**Figure A.1 Wastewater odor wheel (Burlingame et al., 2004)**

Burlingame, G.A., Suffet, I.H., Khiari, D. and Bruchet, A.L., 2004. Development of an odor wheel classification scheme for wastewater. *Water Science and Technology*, 49(9), pp.201-209.

Nicholas HURTREZ - 8/24/06

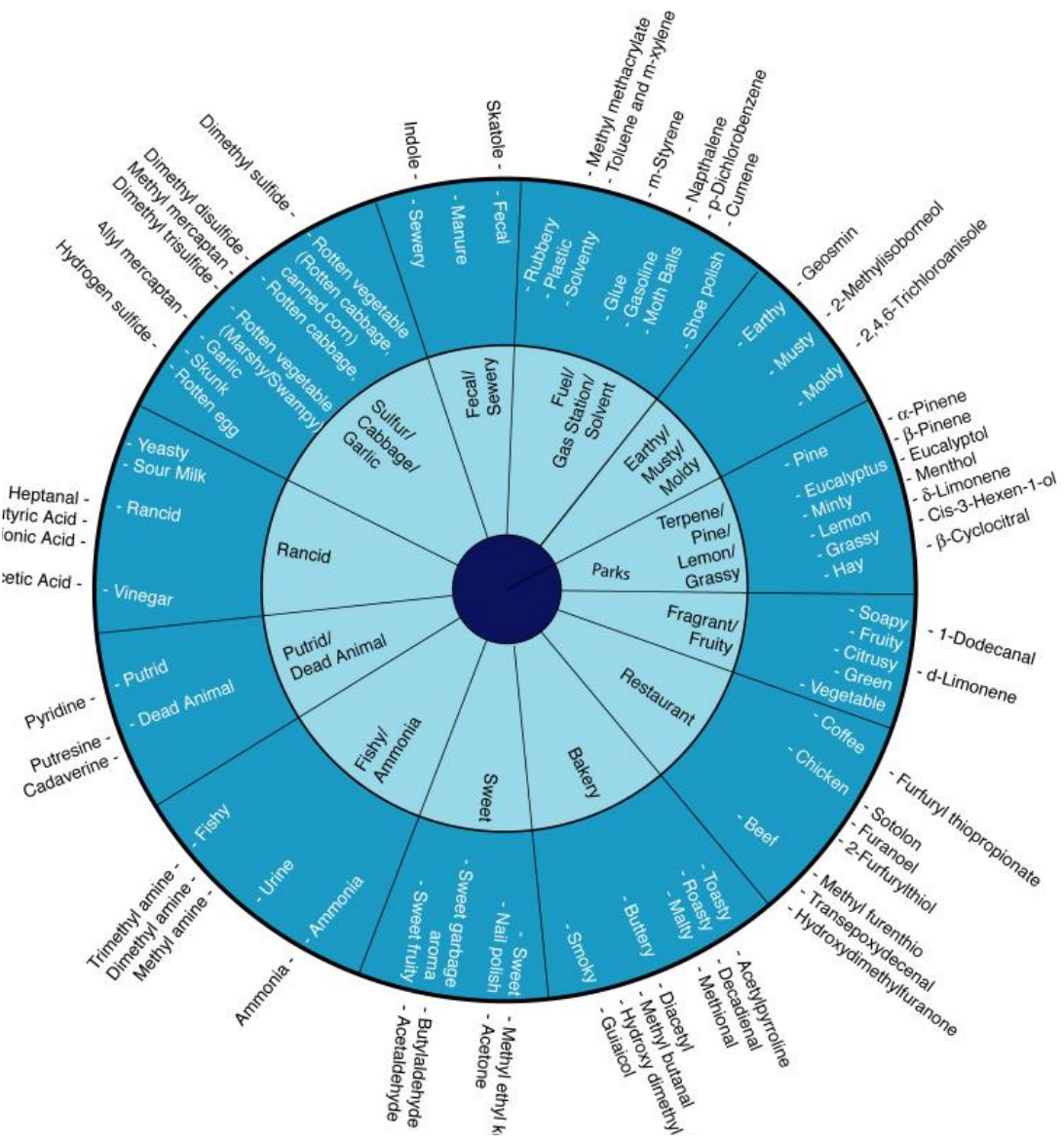


Figure A.2 Compost odor wheel (Suffet et al., 2009; Rosenfeld and Suffet, 2003)

Suffet, I.H., Decottignies, V., Senante, E. and Bruchet, A., 2009. Sensory assessment and characterization of odor nuisance emissions during the composting of wastewater biosolids. *Water Environment Research*, 81(7), pp.670-679.

Rosenfeld, P., Suffet, I.H., 2003. The first step to odor management is identifying the compounds that cause odors: development of an odor wheel that characterizes the smells and associated compounds. *Proceedings of the BioCycle West Coast Conference* –

*Composting, organics recycling and bioenergy: new realities, new opportunities.* Los Angeles, California, March 4. JG Press, Emmaus, Pennsylvania.

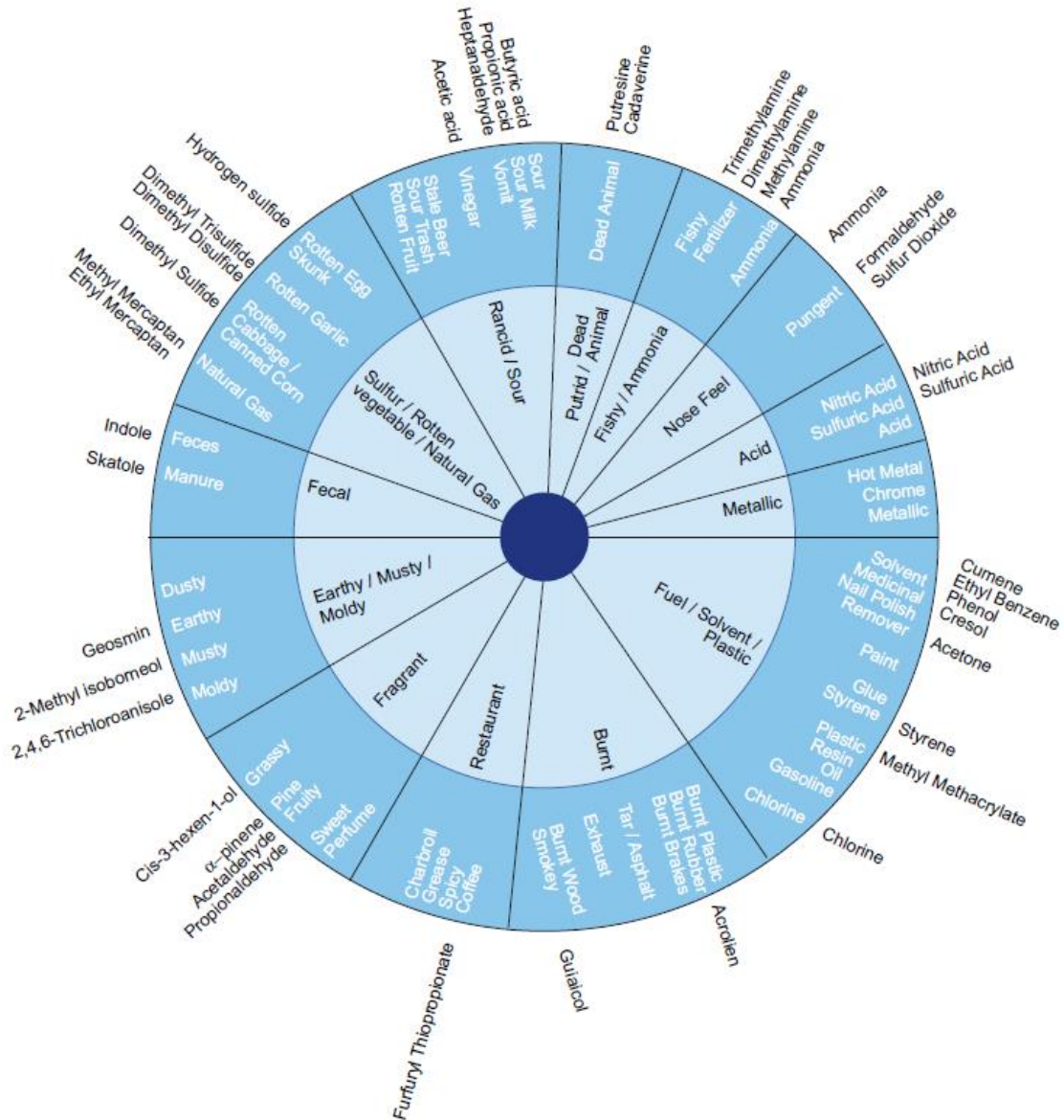


Figure A.3 Urban odor wheel (Curren, 2012)

Curren, J., 2012. *Characterization of odor nuisance*. Doctoral thesis, University of California, Los Angeles.

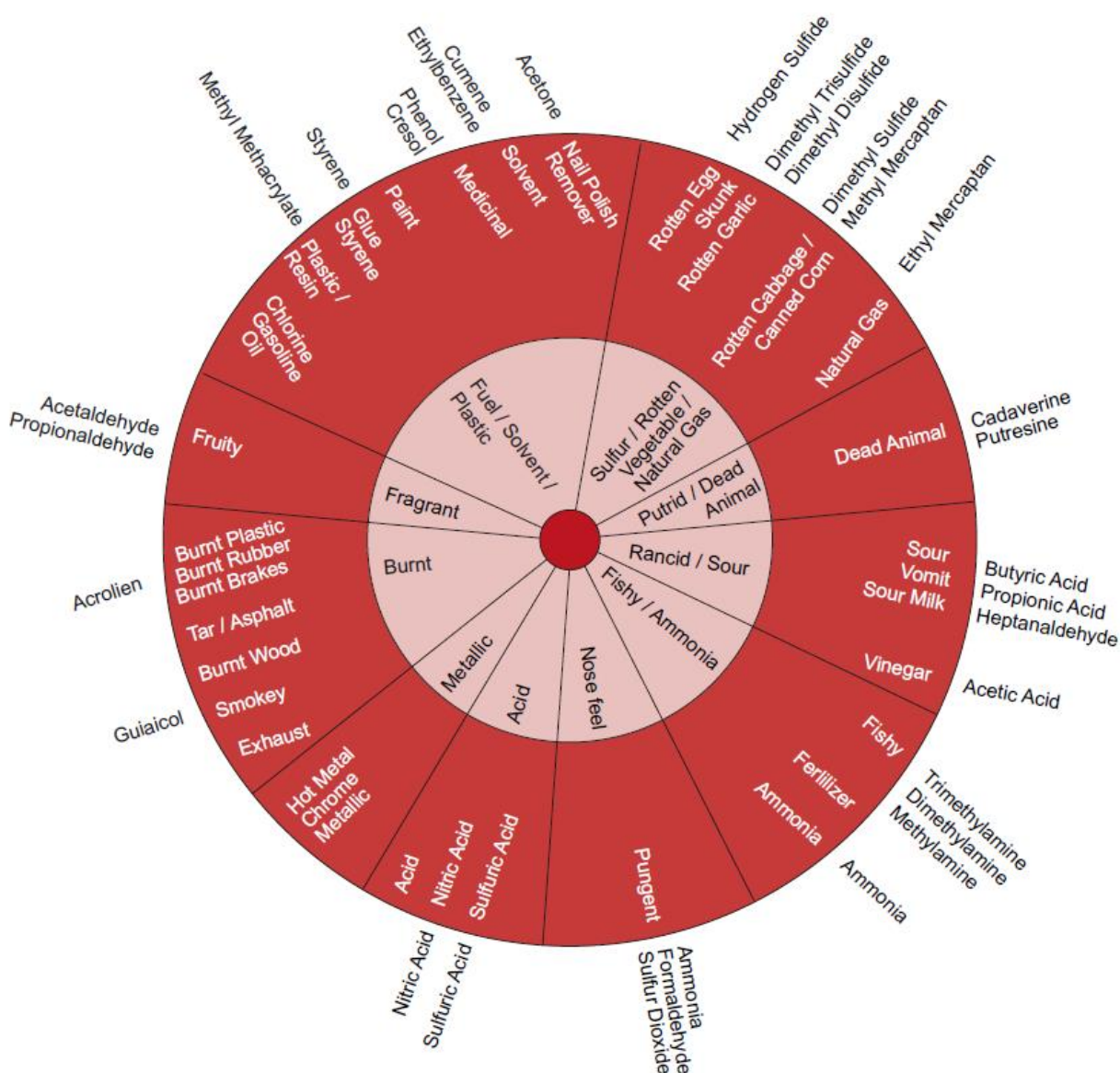
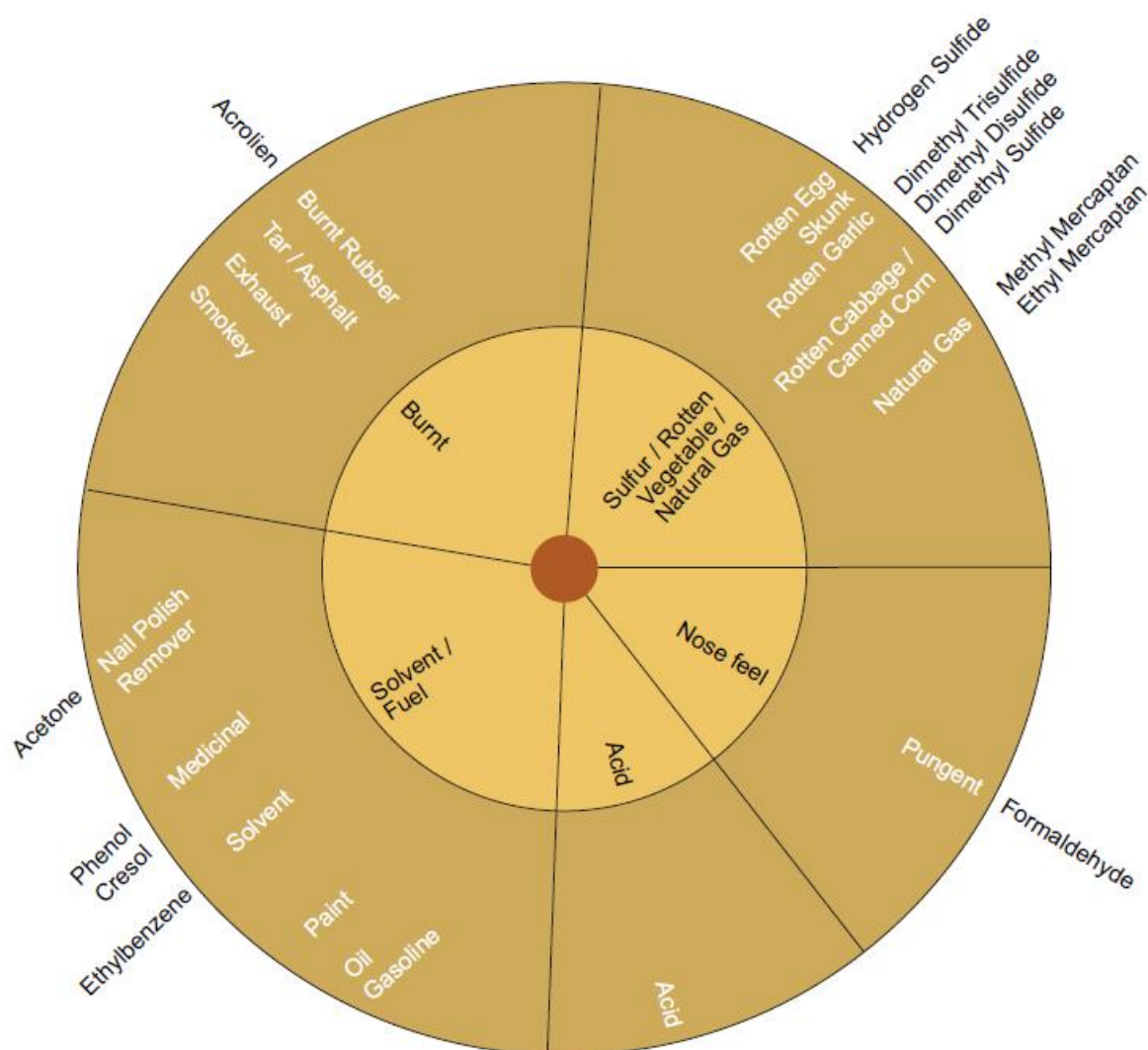


Figure A.4 Industrial odor wheel (Curren, 2012)

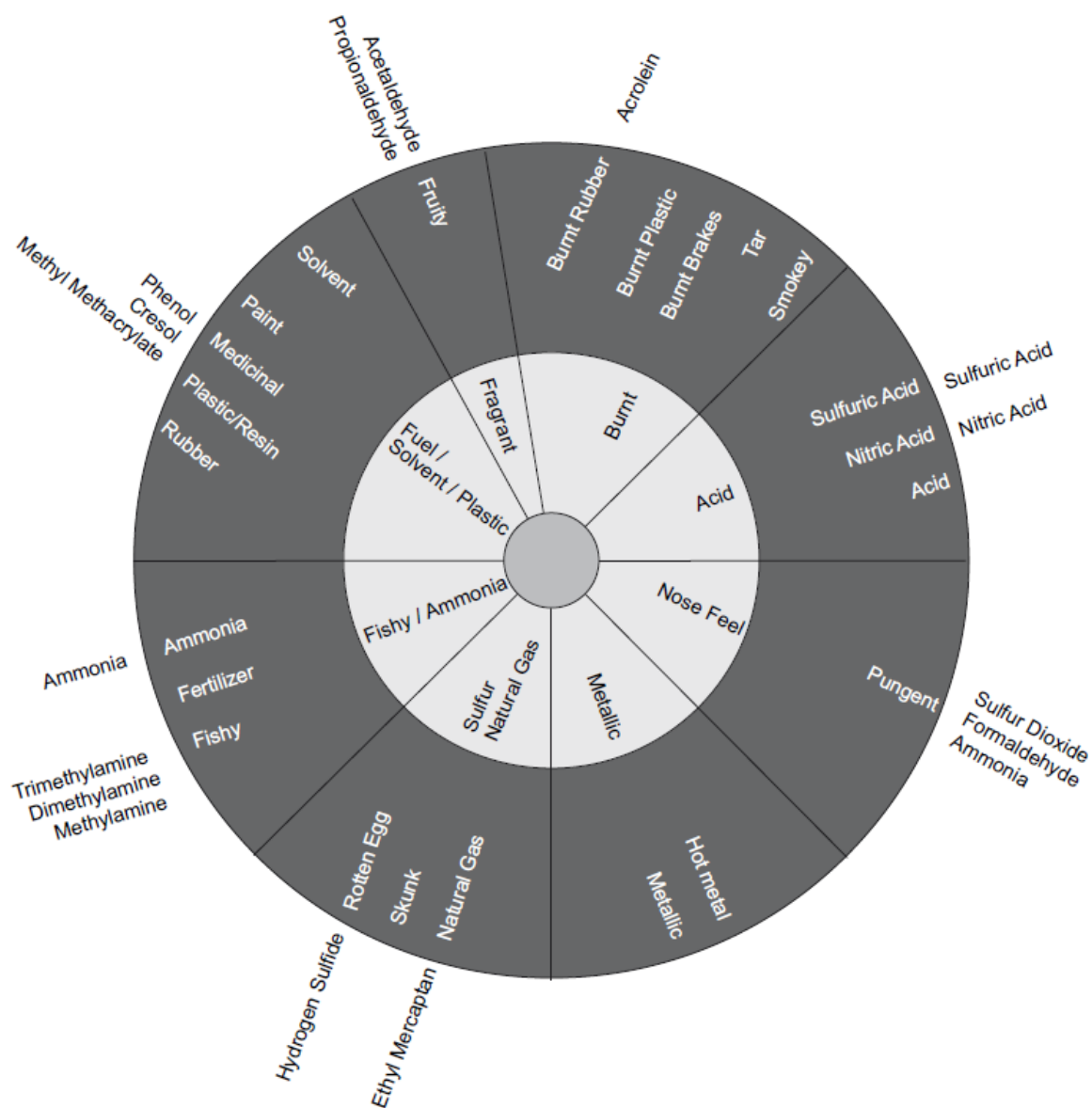
Curren, J., 2012. *Characterization of odor nuisance*. Doctoral thesis, University of California, Los Angeles.





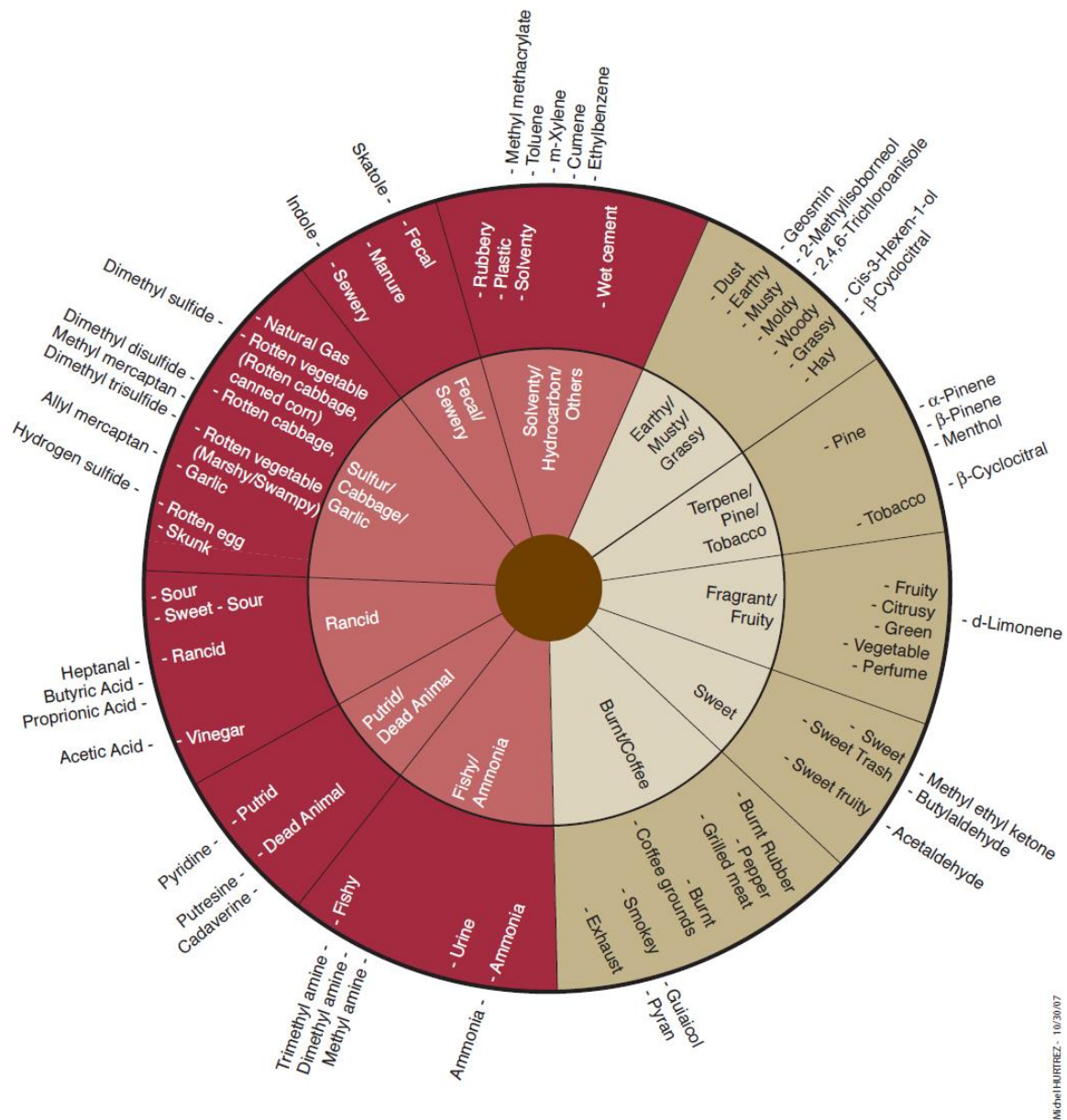
**Figure A.5 Refinery odor wheel (Curren, 2012)**

Curren, J., 2012. *Characterization of odor nuisance*. Doctoral thesis, University of California, Los Angeles.



**Figure A.6 Foundry odor wheel (Curren, 2012)**

Curren, J., 2012. *Characterization of odor nuisance*. Doctoral thesis, University of California, Los Angeles.



**Figure A.7 Landfill odor wheel (Decottignies et al., 2009)**

Decottignies, V., Bruchet, A. and Suffet, I.H., 2009, October. Landfill odour wheel: a new approach to characterize odour emissions at landfill sites. In *12th International Waste Management and Landfill Symposium (International Waste Working Group, IWWG)*.



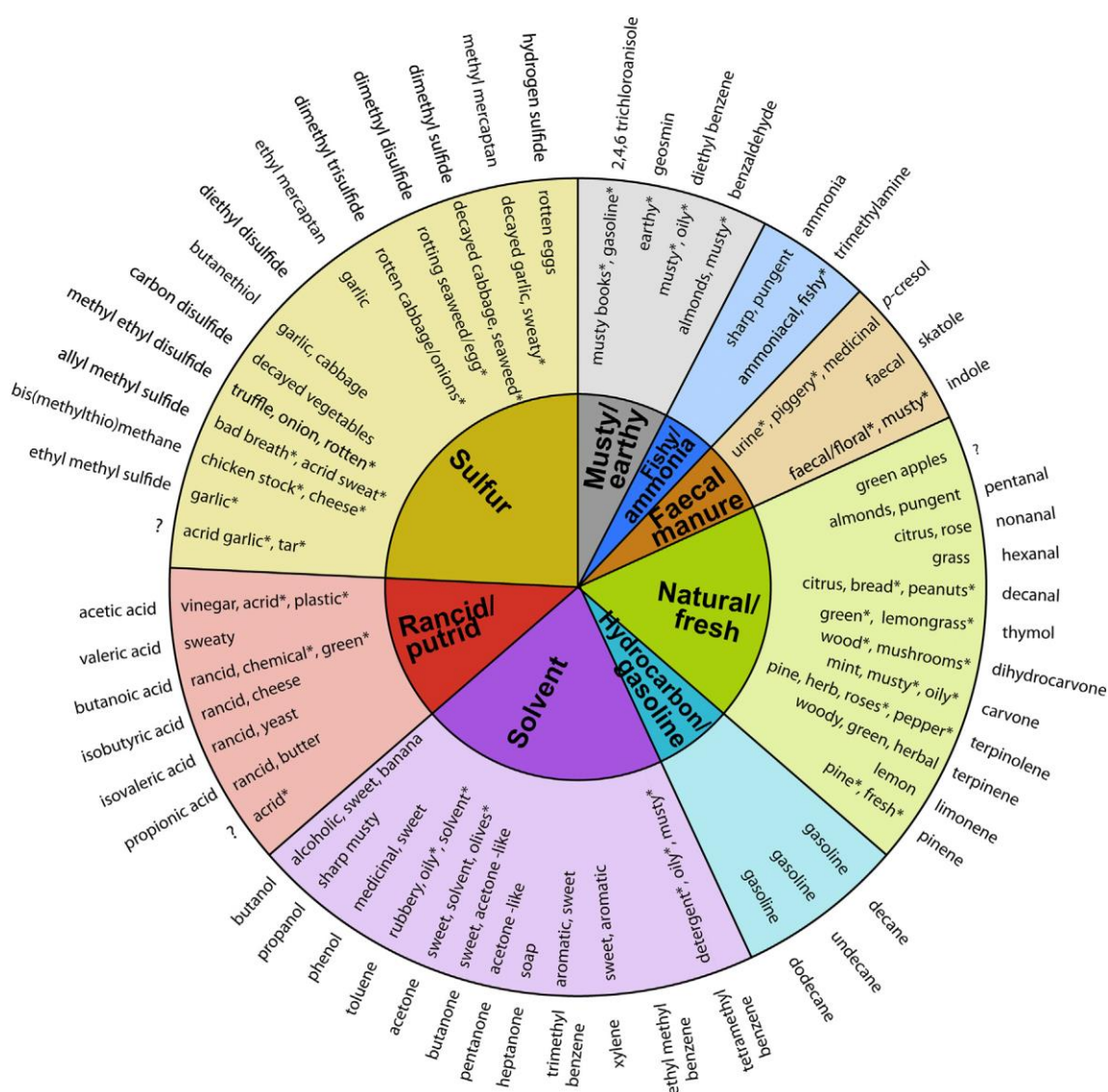


Figure A.8 Biosolids processing odor wheel (Fisher et al., 2018)

Fisher, R.M., Barczak, R.J., Hayes, J.E. and Stuetz, R.M., 2018. Framework for the use of odour wheels to manage odours throughout wastewater biosolids processing. *Science of the Total Environment*, 634, pp.214-223.



Figure A.9 Odor wheel (ATSDR, 2016)

ATSDR, 2016. *Community member assessment of environmental odors*. Atlanta, Georgia.



Figure A.10 Odor wheel (Metro Vancouver, 2019)

Metro Vancouver, 2019. *Tips on making an odour complaint*. Available at <http://www.metrovancouver.org/services/Permits-regulations-enforcement/air-quality/air-quality-complaints/complaint-tips/Pages/default.aspx> (accessed April 28, 2019)

**Table A.1 Common odor notes and their associated odorants and sources**

Odor Note (Broad)	Odor Note (Specific)	Odorant	Odor Source						
			Waste Water	Landfill	Compost	Urban	Industry	Refinery	Foundry
Nose feel	Pungent	ammonia	X			X	X		X
		formaldehyde				X	X	X	X
		sulfur dioxide				X	X		X
	Irritating	—	X						
Acid	Metallic, hot metal, chrome	ferrous sulfate	X			X	X		X
	Sharp	—	X						
	Nitric acid	nitric acid				X	X		X
	Sulfuric acid	sulfuric acid				X	X		X
Earthy, musty, moldy	Acid	—				X	X	X	X
	Earthy	geosmin	X	X	X	X			
	Musty	2-methylisoborneol	X	X	X	X			
	Moldy	2,4,6-trichloroanisole	X	X	X	X			
Oxidant, chlorinous	Dusty	—		X		X			
	Chlorinous	chlorine	X			X	X		
		monochloramine	X						
		dichloramine	X						
Grassy, woody, smoky	Woody	—	X	X	X				
	Green, grass	cis-3-hexen-1-ol	X	X	X	X			
	Cardboard	—	X						
	Hay	β-cyclocitral	X	X	X				
Sulfur, cabbage, garlic	Decaying vegetation	—	X						
	Rotten egg	hydrogen sulfide	X	X	X	X	X	X	X
	Natural gas	ethyl mercaptan		X		X	X	X	X
	Garlicy	allyl mercaptan	X	X	X				
Fragrant, fruity	Canned corn, rotten vegetable	dimethylsulfide	X	X	X	X	X	X	
	Rotten cabbage	dimethyldisulfide	X	X	X	X	X	X	
		methyl mercaptan			X	X	X	X	
	Marshy, swampy, rotten garlic	dimethyltrisulfide	X		X	X	X	X	
Fragrant, fruity	Skunk	—	X	X	X	X	X	X	X
	Burnt rubber sulfidy	—	X						
	Coffee grounds	—	X						
	Soapy, detergenty	1-dodecanal	X		X				
	Fruity	—	X	X	X	X			
	Citrusy	D-limonene	X	X	X				
	Green	—	X	X					
	Vegetable	—		X	X				
	Perfume	—		X		X			
	Yeasty	—	X		X				

Odor Note (Broad)	Odor Note (Specific)	Odorant	Odor Source						
			Waste Water	Landfill	Compost	Urban	Industry	Refinery	Foundry
Rancid, sour, putrid, dead animal	Vinegar	acetic acid		X	X	X	X		
	Sour milk	heptanaldehyde	X	X	X		X		
		heptanal	X	X	X				
	Rancid	butyric acid		X	X	X	X		
		propionic acid		X	X	X			
		heptanaldehyde				X			
	Vomit	propionic acid					X		
	Fatty, oily	—	X						
	Sweaty	—	X						
	Sour cheese	—	X						
	Putrid	pyridine	X	X	X				
	Decayed	—	X						
	Dead animal	putresine		X	X	X	X		
		cadaverine		X	X	X	X		
	Stale beer	—				X			
	Sour trash	—				X			
	Rotten fruit	—				X			
	Ammonia	ammonia (repeat)	X	X	X	X	X		X
	Cat urine	—	X						
	Urine	—		X	X				
Ammonia, fishy		trimethylamine	X	X	X	X	X		X
		dimethylamine			X	X	X		X
	Fishy	trimethylamine			X				X
		2,4-decadienal	X	X					
		2,4-heptadienal	X	X					
Medicinal, alcohol	Fertilizer	methylamine					X		X
	Medicinal	Chlorophenol	X						
	Alcohol	1-butanol	X						
	Burnt, smoky	—	X						
	Tarry	—	X						
	Rubbery	—	X	X	X				X
		methylmethacrylate	X	X	X	X	X		X
		tolunene	X	X	X				
	Solventy, plastic	m-xylene	X	X	X				
		ethylbenzene		X		X	X	X	
Solventy, hydrocarbon, fuel, plastic		phenol				X	X	X	X
	Glue	styrene	X		X	X	X		
	Gasoline	—	X		X	X	X	X	
	Oil	—				X	X	X	
	Paint	methylisobutylketone	X			X	X	X	X
		naphthalene			X				
	Mothballs	p-dichlorobenzene	X		X				
	Shoe polish	cumene	X	X	X	X	X		
	Chemical	—	X						



Odor Note (Broad)	Odor Note (Specific)	Odorant	Odor Source						
			Waste Water	Landfill	Compost	Urban	Industry	Refinery	Foundry
Fecal, sewery	Wet cement	–		X					
	Medicinal	cresol				X	X	X	X
	Fecal	indole	X	X	X	X			
	Manure	skatole	X	X	X	X			
	Sewery	valeric acid	X	X	X				
Terpenes, pine, lemon, tobacco		$\alpha$ -pinene		X	X	X			
	Pine	$\beta$ -pinene		X	X				
		menthol		X					
	Tobacco	$\beta$ -cyclocitral (repeat)		X	X				
	Eucalyptus	eucalyptol			X				
Sweet	Minty	menthol (repeat)							
	Lemon	$\delta$ -limonene			X				
	Sweet	methyl ethyl ketone		X	X	X			
	Sweet trash	butylaldehyde		X	X				
	Sweet fruity	acetaldehyde		X	X	X	X		X
Burnt, coffee		propionaldehyde				X	X		X
	Nail polish	acetone			X	X	X	X	
	Burnt rubber	acrolein		X		X	X		X
	Pepper	–		X					
	Grilled meat	–		X					
Restaurant	Burnt	–		X	X				
	Coffee grounds	–		X					
		guiaicol		X	X	X	X	X	X
	Smokey	pyran		X	X				
		furan			X				
Restaurant	Exhaust	–		X		X	X	X	
	Burnt plastic	acrolein				X	X	X	X
	Burnt brakes	–				X	X		X
	Tar, asphalt	–				X	X	X	X
	Burnt wood	–				X	X		
Restaurant	Chartoli					X			
	Grease	–				X			
	Spicy	–				X			
	Coffee	furfuryl thiopropionate				X			

## **APPENDIX B**

### **Bibliography of Guidance Documents and Standard Methods for Environmental Odor Exposure Assessment**

1. United States
2. Canada
3. European Union
4. Australia
5. New Zealand
6. Japan
7. International Organizations

## 1. United States

### ***National Research Council (NRC)***

NRC, 1979. *Odors from stationary and mobile sources*. National Academies of Sciences.

NRC, 2016a. *Acute Exposure Guideline Levels for Selected Airborne Chemicals: Volume 20*. Washington, DC: The National Academies Press.

NRC, 2016b. *Refinements to the Methods for Developing Spacecraft Exposure Guidelines*. Washington, DC: The National Academies Press.

### ***U.S. Environmental Protection Agency (USEPA, and predecessors; in chronological order)***

U.S. Department of Health, Education, and Welfare, 1967. *Selection and training of judges for sensory evaluation of the intensity and character of diesel exhaust odors*. Prepared by A. Turk, The City College of the City University of New York.

Sullivan, R.J., 1969. *Air pollution aspects of odorous compounds*. Littleton Systems, Bethesda, Maryland. Prepared for the National Air Pollution Control Administration, Consumer Protection & Environmental Health Service, Department of Health, Education and Welfare, Washington, DC.

National Air Pollution Control Administration, 1970. *National survey of the odor problem: Phase I of a study of the social and economic impact of odors*. Prepared by Copley International Corporation, La Jolla, California.

USEPA, 1971a. *A study of the social and economic impact of odors: Phase II*. Prepared by Copley International Corporation, La Jolla, California.

USEPA, 1971b. *Working papers for the conference on the dose-response relationships affecting human reactions to odorous compounds*. Prepared by Arthur D. Little, Cambridge, Massachusetts.

USEPA, 1972a. *Evaluation of community odor exposure*. Prepared by Arthur D. Little, Cambridge, Massachusetts.

USEPA, 1972b. *Odors and air pollution: a bibliography with abstracts*. Office of Air Programs Publication No. AP-11.

USEPA, 1973a. *Health and annoyance impact of odor pollution*. Prepared by J.R. Goldsmith, California Department of Health, Berkeley, California.

USEPA, 1973b. *A study of the social and economic impact of odors: Phase III Development and evaluation of a model odor control ordinance*. Prepared by Copley International Corporation, La Jolla, California.

USEPA, 1978. *Air pollution regulation in state implementation plans: California, Mendocino County*. Prepared by Abcor, Wilmington, Massachusetts.

USEPA, 1980. *Regulatory options for the control of odors*. Office of Air Quality, Research Triangle Park, North Carolina. Prepared by G.H. Wahl, Jr.

USEPA, 1992. *Reference guide to odor thresholds for hazardous air pollutants listed in the Clean Air Act Amendments of 1990*. Office of Research and Development, Washington, DC.

### ***Agency for Toxic Substances and Disease Registry***

ATSDR, 2011. *Exposure history form*. Atlanta, Georgia.

ATSDR, 2016. *Community member assessment of environmental odors*. Atlanta, Georgia.

ATSDR, 2017. *Are environmental odors toxic?* Atlanta, Georgia.

### ***California***

California Air Resources Board (CARB) and California State Department of Health, 1971. *Evaluation of techniques for ambient odor measurement and character (Eureka, California study area)*. Sacramento and Berkeley, California.

CARB, 2002. *ARB/CAPCOA Complaint Resolution Protocol*. Sacramento, California. October.

California Integrated Waste Management Board (CIWMB), 2007. *Comprehensive compost odor response project*. Produced under contract by San Diego State University, San Diego, California.

South Coast Air Quality Management District (SCAQMD), 2000. *Electronic nose technologies: a survey of emerging technologies and a discussion of potential applications*. Diamond Bar, California.

## **Texas**

Texas Commission on Environmental Quality (TCEQ), 2007. *Odor complaint investigation procedures*. Austin, Texas. September 18.

TCEQ, 2015. *Approaches to derive odor-based values*. Position paper, Toxicology Division, Austin, Texas.

## **2. Canada**

Clean Air Strategic Alliance (CASA), 2014. *Alberta odour complaints overview*. Edmonton, Alberta, Canada.

CASA, 2015a. *Odour complaints in your area: A guide for developing an odour complaint process*. Edmonton, Alberta, Canada.

CASA, 2015b. *Review of odour assessment tools and practices for Alberta*. Edmonton, Alberta, Canada.

CASA, 2015c. *Review of odour prevention and mitigation tools for Alberta*. Edmonton, Alberta, Canada.

CASA, 2015d. *Report to the CASA odour management team: Enforcement and the role of regulation task group*. Edmonton, Alberta, Canada.

CASA, 2015e. *Odour and health backgrounder*. Edmonton, Alberta, Canada.

CASA, 2015f. *Symptom and odour tracking tool*. Edmonton, Alberta, Canada.

CASA, 2015g. *Good practices guide for odour management in Alberta: From prevention and mitigation to assessment and complaints*. Edmonton, Alberta, Canada.

Government of Alberta, 2017. *Odours and human health*. Environmental Public Health Science Unit, Health Protection Branch, Public Health and Compliance Division, Alberta Health. Edmonton, Alberta, Canada.

## **3. European Union**

European Committee for Standardization (CEN), 2003. *EN 13725: Air Quality: Determination of Odour Concentration by Dynamic Olfactometry*. Brussels, Belgium.



CEN, 2016a. *EN 16841-1:2016 Ambient air - Determination of odour in ambient air by using field inspection - Part 1: Grid method*. Brussels, Belgium.

CEN, 2016b. *EN 16841-2:2016 Ambient air - Determination of odour in ambient air by using field inspection - Part 2: Plume method*. Brussels, Belgium.

### **United Kingdom**

Scottish Environment Protection Agency, 2010. *Odor guidance 2010*. Available at <https://www.sepa.org.uk/regulations/air/odour/> (accessed April 17, 2019).

UK Environment Agency, 2002. *IPPC Guidance Note H4: DRAFT Horizontal Guidance for Odour Part 1 - Regulation and Permitting*. Bristol, UK.

UK Environment Agency, 2011. *H4 odor management: How to comply with your environmental permit*. Bristol, UK.

UK Health Protection Agency, 2011a. *Odor frequently asked questions*.

UK Health Protection Agency, 2011b. *Odor complaints checklist*.

### **Germany**

German Guideline on Odour in Ambient Air, 2008. *Determination and assessment of odor in ambient air, including grounds and advice on interpretation*. Second version, February 29.

VDI (German Engineering Association), 2015. *VDI standards catalog*. Beuth Verlag GmbH, Berlin, Germany.

- 3880: Olfactometry - Static Sampling. 2011.
- 3882 Part 1 Olfactometry: Determination of odour intensity. 1992.
- 3882 Part 2 Olfactometry: Determination of hedonic odour tone. 1994.
- 3883 Part 1: Effects and Assessment of Odours - Assessment of Odour Annoyance - Questionnaires. 2015.
- 3884 Part 1: Olfactometry – Determination of Odour Concentration by Dynamic Olfactometry – Supplementary Instructions for Application of DIN EN 13725. 2015.
- 3940 Part 1: Measurement of Odour Impact by Field Inspection; Measurement of the Impact Frequency of Recognizable Odours, Grid Measurement.
- 3940 Part 3: Measurement of Odour Impact by Field Inspection - Determination of Odour Intensity and Hedonic Odour Tone. 2010.
- 3940 Part 4: Determination of the Hedonic Odour Tone - Polarity Profiles. 2010.

## **Netherlands**

RIVM (National Institute for Public Health and the Environment), 2009. *Assessment of odour annoyance in chemical emergency management*. Bilthoven, Netherlands.

## **4. Australia**

Department of Environment and Conservation NSW, 2006. *Technical notes: Assessment and management of odour from stationary sources in NSW*. Sydney, NSW.

Government of Western Australia, 2018. *Draft: Odour guideline for prescribed premises*. Department of Water and Environmental Regulation, Perth, Western Australia.

New South Wales Environment Protection Agency (NSWEPA), 2001. *Draft policy: Assessment and management of odour from stationary sources in NSW*. Technical notes. January.

## **5. New Zealand**

New Zealand Ministry of the Environment, 2002. *Technical report: Review of odour management in New Zealand*. Wellington, New Zealand.

New Zealand Ministry of the Environment, 2003. *Good practice guide for assessing and managing odour in New Zealand*. Wellington, New Zealand.

## **6. Japan**

Japan Ministry of the Environment, 2006. *Odor index regulation and triangular odor bag method*.

## **7. International Organizations**

### **ASTM International**

ASTM International, 2019. *Products & services catalog 2019*. West Conshohocken, Pennsylvania.

- E544-10 *Standard practices for referencing suprathreshold odor intensity*. 2010.
- E679-04 *Standard practice for determination of odor and taste thresholds by a forced-choice ascending concentration series method of limits*. 2011.

- E1432-04 *Standard practice for defining and calculating individual and group sensory thresholds from forced-choice data sets of intermediate size*. 2011.

### ***International Organization for Standardization***

Available at <https://www.iso.org/standards-catalogue/browse-by-ics.html> (accessed May 17, 2019):

- ISO 4120:2004 Sensory analysis - - Methodology - - Triangle Test
- ISO 5495:2005 Sensory analysis - - Methodology - - Paired Comparison Test
- ISO 5496:2006 Sensory analysis - - Methodology - - Initiation and training of assessors in detection and recognition of odours
- ISO 8586:2012 Sensory analysis - - General guidelines for the selection, training and monitoring of selected assessors and expert sensory assessors
- ISO 11035:1994 Sensory analysis - - Identification and selection of descriptors for establishing a sensory profile by a multidimensional approach
- ISO 11056:1999 Sensory analysis - - Methodology - - Magnitude Estimation Method
- ISO 13301:2002 Sensory analysis - - Methodology - - General guidance for measuring odour, flavour and taste detection thresholds by a three-alternative forced-choice (3-AFC) procedure

### ***World Health Organization (WHO)***

WHO, 2000. *Air quality guidelines for Europe*, 2nd Ed. Copenhagen, Denmark.