



**APPENDIX AVAILABLE ON
THE HEALTH EFFECTS INSTITUTE-ENERGY WEBSITE**

Communication 1

**HUMAN EXPOSURE TO UNCONVENTIONAL OIL AND
GAS DEVELOPMENT:
A LITERATURE SURVEY FOR RESEARCH PLANNING**

HEI-Energy Research Committee

Appendix A. References for Executive Summary and Section 4 Figures

Correspondence may be addressed to Dr. Donna Vorhees, Health Effects Institute – Energy, 75 Federal Street, Suite 1400, Boston, MA 02110; e-mail: dvorhees@healtheffects.org.

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APPENDIX A

REFERENCES FOR EXECUTIVE SUMMARY AND SECTION 4 FIGURES

APPENDIX A

This Appendix contains the list of references for studies included in each figure presented in Executive Summary and Section 4.

Table A1. References for Figure ES-2 - Number of studies reporting measured or predicted levels of UOGD-related chemical and non-chemical agents by year of publication

Abualfaraj et al. 2018; Agency for Toxic Substances and Disease Registry 2010, 2016; Ahmadi and John 2015; Ahmadov et al. 2015; Akob et al. 2016; Alawattagama et al. 2015; ATSDR Division of Community Health Investigations 2016; Austin et al. 2017; Bahreini et al. 2018; Banan and Gernand 2018; Bari and Kindzierski 2018; Barth-Naftilan et al. 2018; Bean et al. 2018; Benedict et al. 2018; Bien and Helmig 2018; Blair et al. 2018; Boyer et al. 2012; Boyle et al. 2017; Bunch et al. 2014; Burton et al. 2016; Casey et al. 2015; Chambers et al. 2018; Chang et al. 2016; Cheadle et al. 2017; Colborn et al. 2012; Collett et al. 2016; Collett and Ham 2016; Colorado Department of Public Health and Environment 2012, 2016, 2017c, 2017b, 2017a, 2018c, 2018b, 2018a, 2018e, 2018d; Crowe et al. 2016; Darrah et al. 2014; DiGiulio and Jackson 2016; Drollette et al. 2015; Durant et al. 2016; Eapi et al. 2014; Eastern Research Group and Sage Environmental Consulting 2011; Edwards et al. 2014; Eisele et al. 2016; Eisenlord et al. 2018; Elliott et al. 2018; Esswein et al. 2013, 2014; Ethridge et al. 2015; Evansoski-Cole et al. 2017; Evans and Helmig 2017; Fann et al. 2018; Ferrar et al. 2013; Field et al. 2015; Fontenot et al. 2013; Franco et al. 2016; Frazier 2009; Gebhart et al. 2018; Ghosh 2018; Gilman et al. 2013; Goetz et al. 2017, 2015; Goodman et al. 2016; Gradient Corporation 2013; Grieve et al. 2018; Gross et al. 2013; Gvakharia et al. 2017; Halliday et al. 2016; Harkness et al. 2017; Hayes 2009; Helmig et al. 2014, 2015; Hildenbrand et al. 2015, 2016c, 2016b, 2016a; Hill and Ma 2017; Hladik et al. 2014; Islam et al. 2016; Jackson et al. 2013; Kassotis et al. 2016; Koss et al. 2017; Lan et al. 2015; Landis et al. 2016; Larson et al. 2018; LeDoux et al. 2016; Lewis et al. 2016; Li and Carlson 2014; Ling and Heglie 2016; Llewellyn et al. 2015; Lorig 2016; Low et al. 2016; Macey et al. 2014; Majid et al. 2017; Marrero et al. 2016; Maskrey et al. 2016; McCawley 2013; McClellan and Snipes 2010; McDuffie et al. 2016; McKenzie et al. 2012, 2018; McMahon et al. 2017; McMullin et al. 2018; Meng 2018; Mitchell et al. 2016; Molofsky et al. 2016; Nelson et al. 2015; Nicot et al. 2017; Niu et al. 2018; Olaguer 2012; Olawoyin 2015; Olmstead et al. 2013; Oltmans et al. 2014; Orem et al. 2017; Osborn et al. 2011; Pacsi et al. 2013; Paulik et al. 2016, 2018; Peischl et al. 2018; Pekney et al. 2018, 2014; Pelak and Sharma 2014; Penningroth et al. 2013; Pennsylvania Department of Environmental Protection 2010, 2018; Pennsylvania Department of Health 2018; Pétron et al. 2012; Pfister et al. 2017; Post van der Burg and Tangen 2015; Prenni et al. 2016; Preston et al. 2014; Preston and Chesley-Preston 2015; Radtke et al. 2017; Regli et al. 2015; Reilly et al. 2015; Rich and Crosby 2013; Rich et al. 2014; Rich and Orimoloye 2016; Richburg and Slagley 2018; Rish and Pfau 2018; Roohani et al. 2017; Rossabi and Helmig 2018; Rowan and Kraemer 2012; Rutter et al. 2015; Santos et al. 2018; Schade and Roest 2016, 2018; Shanafield et al. 2018; Sherwood et al. 2016; Shores et al. 2017; Skalak et al. 2013; States et al. 2013; Steinzor et al. 2013; Swarhout et al. 2013, 2015; Texas Department of State Health Services 2010; Thompson et al. 2014; Tormey 2012; Torres et al. 2017, 2018; U. S. Environmental Protection Agency 2015; U.S. Environmental Protection Agency 2011; Van Sice et al. 2018; Vigil 2015; Vinciguerra et al. 2015; Walter et al. 2012; Walther 2011; Warneke et al. 2014; Warner et al. 2013a, 2013b; Weaver et al. 2015; Wen et al. 2018; Williams et al. 2018; Wilson et al. 2014; Wilson and VanBriesen 2012; Woda et al. 2018; Wright et al. 2012; Yan et al. 2017; Zavala-Araiza et al. 2014; Zhang et al. 2015; Zhu et al. 2017; Zielinska et al. 2014; Ziemkiewicz et al. 2013a, 2013b.

Table A2. References for Figure ES-3 – Study locations relative to shale basins and plays, by media investigated

Shale or Basin	Air Monitoring	Air Modeling	Air Monitoring and Modeling	Water Monitoring	Water Modeling	Water Monitoring and Modeling	Biomonitoring	Sensory	Sediment
Anadarko			Ghosh 2018						
Arkoma			Ghosh 2018						
Bakken	Esswein et al. 2013; Koss et al. 2017; Majid et al. 2017; Prenni et al. 2016	Olawoyin 2015	Evanoski-Cole et al. 2017; Gebhart et al. 2018; Gvakharia et al. 2017; Peischl et al. 2018		Torres et al. 2017	Torres et al. 2018			
Barnett	Bunch et al. 2014; Eapi et al. 2014; Eisele et al. 2016; Ethridge et al. 2015; Koss et al. 2017; Lim et al. 2019; Majid et al. 2017; Nathan and Lary 2019; Rich et al. 2014; Rich and Orimoloye 2016; Rossabi and Helmig 2018	Khalaj and Sattler 2019; Olaguer 2012; Pacsi et al. 2013	Ahmadi and John 2015; Eastern Research Group and Sage Environmental Consulting 2011; Lan et al. 2015; Marrero et al. 2016; Peischl et al. 2018; Rutter et al. 2015; Zavala-Araiza et al. 2014; Zielinska et al. 2014	Darrah et al. 2014; Fontenot et al. 2013; Hildenbrand et al. 2015; Rich and Crosby 2013	Burton et al. 2016	Larson et al. 2018	Texas Department of State Health Services 2010		
Cherokee Platform			Ghosh 2018						

Table A2. References for Figure ES-3 – Study locations relative to shale basins and plays, by media investigated

Shale or Basin	Air Monitoring	Air Modeling	Air Monitoring and Modeling	Water Monitoring	Water Modeling	Water Monitoring and Modeling	Biomonitoring	Sensory	Sediment
Denver-Julesberg	Allshouse et al. 2019; Benedict et al. 2018; Bien and Helmig 2018; Cheadle et al. 2017; Colorado Department of Public Health and Environment 2012, 2016, 2017c, 2017b, 2017a, 2018b, 2018c, 2018a, 2018e, 2018d; Eisele et al. 2016; Esswein et al. 2013, 2014; Evans and Helmig 2017; Gilman et al. 2013; Halliday et al. 2016; Helmig et al. 2015; Koss et al. 2017; Macey et al. 2014; McKenzie et al. 2012, 2018; McMullin et al. 2018; Vigil 2015	Lindaas et al. 2019; Nsanzineza et al. 2019; Olawoyin 2015; Pfister et al. 2017	Bahreini et al. 2018; McDuffie et al. 2016; Oltmans et al. 2019; Peischl et al. 2018; Pétron et al. 2012; Swarthout et al. 2013	Gross et al. 2013; Li and Carlson 2014; Sherwood et al. 2016	Shores et al. 2017			Allshouse et al. 2019; Blair et al. 2018	
Duvernay			Bari and Kindzierski 2018						

Table A2. References for Figure ES-3 – Study locations relative to shale basins and plays, by media investigated

Shale or Basin	Air Monitoring	Air Modeling	Air Monitoring and Modeling	Water Monitoring	Water Modeling	Water Monitoring and Modeling	Biomonitoring	Sensory	Sediment
Eagle Ford	Esswein et al. 2013; Hildenbrand et al. 2016c; Koss et al. 2017; Majid et al. 2017; Schade and Roest 2016, 2018	Olawoyin 2015; Pacsi et al. 2013	Cardoso Saldana et al. 2019; Peischl et al. 2018	Hildenbrand et al. 2016b; Nicot et al. 2017; Santos et al. 2018		McMahon et al. 2017			
Fayetteville	Esswein et al. 2013; Macey et al. 2014	Olawoyin 2015		Austin et al. 2017; Warner et al. 2013b		McMahon et al. 2017			
Green River	Meng 2018; Walther 2011								
Haynesville	Koss et al. 2017; Majid et al. 2017; Rossabi and Helmig 2018	Pacsi et al. 2013	Peischl et al. 2018			McMahon et al. 2017			
Horn River	Islam et al. 2016								
Inglewood or California Site	Rossabi and Helmig 2018			Tormey 2012*					

Marcellus	Casey et al. 2015; Esswein et al. 2013; Goetz et al. 2017; Gradient Corporation 2019; Haynes et al. 2019; Lewis et al. 2016; Macey et al. 2014; Majid et al. 2017; Maskrey et al. 2016; McCawley 2013; Paulik et al. 2018; Pekney et al. 2014; Pennsylvania Department of Environmental Protection 2010, 2018; Pennsylvania Department of Health 2018; Rossabi and Helmig 2018; Rowan and Kraemer 2012; Steinzor et al. 2013; Swarthout et al. 2015; Vinciguerra et al. 2015; Williams et al. 2018	Banan and Gernand 2018; Olawoyin 2015; Roohani et al. 2017; Xu et al. 2019	Chang et al. 2016; Goetz et al. 2015; Mitchell et al. 2016	Agency for Toxic Substances and Disease Registry 2010; Akob et al. 2016; Alawattegama et al. 2015; Barth-Naftilan et al. 2018; Boyer et al. 2012; Darrah et al. 2014; Ferrar et al. 2013; Harkness et al. 2017; Hayes 2009; Haynes et al. 2019; Hladik et al. 2014; Jackson et al. 2013; Kassotis et al. 2016; LeDoux et al. 2016; Llewellyn et al. 2015; Low et al. 2016; McMahan et al. 2019; Molofsky et al. 2016; Niu et al. 2018; Orem et al. 2017; Osborn et al. 2011; Pelak and Sharma 2014; Penningroth et al. 2013; Reilly et al. 2015; States et al. 2013; Warner et al. 2013a; Wen et al. 2018, 2019; Wilson et al. 2014; Woda et al. 2018; Yan et al. 2017; Ziemkiewicz et al. 2013a, 2013b	Abualfaraj et al. 2018; Durant et al. 2016; Hill and Ma 2017; Landis et al. 2016; Olmstead et al. 2013; Rish and Pfau 2018; Weaver et al. 2015	Drollette et al. 2015; Grieve et al. 2018; U. S. Environmental Protection Agency 2015; Zhang et al. 2015		Boyle et al. 2017; Lorig 2016; McCawley 2013; Richburg and Slagley 2018	Skalak et al. 2013; Van Sice et al. 2018
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Table A2. References for Figure ES-3 – Study locations relative to shale basins and plays, by media investigated

Shale or Basin	Air Monitoring	Air Modeling	Air Monitoring and Modeling	Water Monitoring	Water Modeling	Water Monitoring and Modeling	Biomonitoring	Sensory	Sediment
Niobrara-Codell	Majid et al. 2017; Rossabi and Helmig 2018								
Permian	Eisenlord et al. 2018; Frazier 2009; Koss et al. 2017; Majid et al. 2017; Rossabi and Helmig 2018			Eisenlord et al. 2018; Hildenbrand et al. 2016a		Bean et al. 2018			
Piceance	Agency for Toxic Substances and Disease Registry 2010; Colborn et al. 2012; Esswein et al. 2014; McMullin et al. 2018	Nsanzineza et al. 2019	Collett et al. 2016a, 2016b						
Powder River Basin		Nsanzineza et al. 2019							
Rogersville				Zhu et al. 2017					
San Juan	Koss et al. 2017	Nsanzineza et al. 2019		Nelson et al. 2015					
Upper Green River Basin	Esswein et al. 2014; Field et al. 2015; Koss et al. 2017; Oltmans et al. 2014			Walters et al. 2019					
Uinta	Helmig et al. 2014; Koss et al. 2017; Oltmans et al. 2014; Warneke et al. 2014	Ahmadov et al. 2015; Edwards et al. 2014; Nsanzineza et al. 2019							

Table A2. References for Figure ES-3 – Study locations relative to shale basins and plays, by media investigated

Shale or Basin	Air Monitoring	Air Modeling	Air Monitoring and Modeling	Water Monitoring	Water Modeling	Water Monitoring and Modeling	Biomonitoring	Sensory	Sediment
Utica	Haynes et al. 2019; Macey et al. 2014; Majid et al. 2017; Paulik et al. 2016, 2018; Rossabi and Helmig 2018	Roohani et al. 2017; Xu et al. 2019		Elliott et al. 2018; Haynes et al. 2019; Osborn et al. 2011; Penningroth et al. 2013					
Wattenberg	Thompson et al. 2014								
Williston					Preston and Chesley-Preston 2015	Post van der Burg and Tangen 2015; Preston et al. 2014			
Wind River	Macey et al. 2014; McClellan and Snipes 2010	Nsanzineza et al. 2019		DiGiulio and Jackson 2016; Ling and Heglie 2016; U.S. Environmental Protection Agency 2011; Wright et al. 2012					
Not Applicable		Fann et al. 2018; Goodman et al. 2016	Franco et al. 2016		Gradient Corporation 2013; Regli et al. 2015; Shanafield et al. 2018		Chambers et al. 2018		
Not Reported	Agency for Toxic Substances and Disease Registry 2010	Walter et al. 2012					Crowe et al. 2016	Radtke et al. 2017	

Note: 1) Tormey et al. 2012 represents samples collected near a horizontal, multistage fracturing site in the shale within Inglewood Oil Field, which is considered a “conventional” resource. The study was conducted to inform air concentrations at both conventional and unconventional oil and gas development. 2) Some multi-national regional air quality studies were mapped to specific shales or basins for visual purposes, but used data collected using regional air quality networks monitors that were not located directly in those shales or basins (e.g., Rossabi and Helmig 2018)

Table A3. References for Figure 4-2 – Number of studies published each year by study media

Abualfaraj et al. 2018; Agency for Toxic Substances and Disease Registry 2010, 2016; Ahmadi and John 2015; Ahmadov et al. 2015; Akob et al. 2016; Alawattagama et al. 2015; ATSDR Division of Community Health Investigations 2016; Austin et al. 2017; Bahreini et al. 2018; Banan and Gernand 2018; Bari and Kindzierski 2018; Barth-Naftilan et al. 2018; Bean et al. 2018; Benedict et al. 2018; Bien and Helmig 2018; Blair et al. 2018; Boyer et al. 2012; Boyle et al. 2017; Bunch et al. 2014; Burton et al. 2016; Casey et al. 2015; Chambers et al. 2018; Chang et al. 2016; Cheadle et al. 2017; Colborn et al. 2012; Collett et al. 2016; Collett and Ham 2016; Colorado Department of Public Health and Environment 2012, 2016, 2017c, 2017b, 2017a, 2018c, 2018b, 2018a, 2018e, 2018d; Crowe et al. 2016; Darrah et al. 2014; DiGiulio and Jackson 2016; Drollette et al. 2015; Durant et al. 2016; Eapi et al. 2014; Eastern Research Group and Sage Environmental Consulting 2011; Edwards et al. 2014; Eisele et al. 2016; Eisenlord et al. 2018; Elliott et al. 2018; Esswein et al. 2013, 2014; Ethridge et al. 2015; Evanoski-Cole et al. 2017; Evans and Helmig 2017; Fann et al. 2018; Ferrar et al. 2013; Field et al. 2015; Fontenot et al. 2013; Franco et al. 2016; Frazier 2009; Gebhart et al. 2018; Ghosh 2018; Gilman et al. 2013; Goetz et al. 2017, 2015; Goodman et al. 2016; Gradient Corporation 2013; Grieve et al. 2018; Gross et al. 2013; Gvakharia et al. 2017; Halliday et al. 2016; Harkness et al. 2017; Hayes 2009; Helmig et al. 2014, 2015; Hildenbrand et al. 2015, 2016c, 2016b, 2016a; Hill and Ma 2017; Hladik et al. 2014; Islam et al. 2016; Jackson et al. 2013; Kassotis et al. 2016; Koss et al. 2017; Lan et al. 2015; Landis et al. 2016; Larson et al. 2018; LeDoux et al. 2016; Lewis et al. 2016; Li and Carlson 2014; Ling and Heglie 2016; Llewellyn et al. 2015; Lorig 2016; Low et al. 2016; Macey et al. 2014; Majid et al. 2017; Marrero et al. 2016; Maskrey et al. 2016; McCawley 2013; McClellan and Snipes 2010; McDuffie et al. 2016; McKenzie et al. 2012, 2018; McMahon et al. 2017; McMullin et al. 2018; Meng 2018; Mitchell et al. 2016; Molofsky et al. 2016; Nelson et al. 2015; Nicot et al. 2017; Niu et al. 2018; Olaguer 2012; Olawoyin 2015; Olmstead et al. 2013; Oltmans et al. 2014; Orem et al. 2017; Osborn et al. 2011; Pacsi et al. 2013; Paulik et al. 2016, 2018; Peischl et al. 2018; Pekney et al. 2018, 2014; Pelak and Sharma 2014; Penningroth et al. 2013; Pennsylvania Department of Environmental Protection 2010, 2018; Pennsylvania Department of Health 2018; Pétron et al. 2012; Pfister et al. 2017; Post van der Burg and Tangen 2015; Prenni et al. 2016; Preston et al. 2014; Preston and Chesley-Preston 2015; Radtke et al. 2017; Regli et al. 2015; Reilly et al. 2015; Rich and Crosby 2013; Rich et al. 2014; Rich and Orimoloye 2016; Richburg and Slagley 2018; Rish and Pfau 2018; Roohani et al. 2017; Rossabi and Helmig 2018; Rowan and Kraemer 2012; Rutter et al. 2015; Santos et al. 2018; Schade and Roest 2016, 2018; Shanafield et al. 2018; Sherwood et al. 2016; Shores et al. 2017; Skalak et al. 2013; States et al. 2013; Steinzor et al. 2013; Swarthout et al. 2013, 2015; Texas Department of State Health Services 2010; Thompson et al. 2014; Tormey 2012; Torres et al. 2017, 2018; U. S. Environmental Protection Agency 2015; U.S. Environmental Protection Agency 2011; Van Sice et al. 2018; Vigil 2015; Vinciguerra et al. 2015; Walter et al. 2012; Walther 2011; Warneke et al. 2014; Warner et al. 2013a, 2013b; Weaver et al. 2015; Wen et al. 2018; Williams et al. 2018; Wilson et al. 2014; Wilson and VanBriesen 2012; Woda et al. 2018; Wright et al. 2012; Yan et al. 2017; Zavala-Araiza et al. 2014; Zhang et al. 2015; Zhu et al. 2017; Zielinska et al. 2014; Ziemkiewicz et al. 2013a, 2013b.

Table A4. References for Figure 4-3 – Number of studies by chemical agent

Chemical agent category	References
Black carbon	Allshouse et al. 2019; Gvakharia et al. 2017; Prenni et al. 2016; Rutter et al. 2015
Brine	Akob et al. 2016; Austin et al. 2017; Barth-Naftilan et al. 2018; Burton et al. 2016; Darrah et al. 2014; DiGiulio and Jackson 2016; Ferrar et al. 2013; Fontenot et al. 2013; Grieve et al. 2018; Harkness et al. 2017; Hayes 2009; Hildenbrand et al. 2015, 2016a, 2016b; Hladik et al. 2014; Kassotis et al. 2016; Landis et al. 2016; LeDoux et al. 2016; Li and Carlson 2014; Ling and Heglie 2016; Llewellyn et al. 2015; Low et al. 2016; McMahon et al. 2017, 2019; Molofsky et al. 2016; Nicot et al. 2017; Niu et al. 2018; Olmstead et al. 2013; Osborn et al. 2011; Pelak and Sharma 2014; Post van der Burg and Tangen 2015; Preston et al. 2014; Preston and Chesley-Preston 2015; Regli et al. 2015; Reilly et al. 2015; Santos et al. 2018; Sherwood et al. 2016; U. S. Environmental Protection Agency 2015; U.S. Environmental Protection Agency 2011; Walters et al. 2019; Warner et al. 2013a, 2013b; Weaver et al. 2015; Wen et al. 2018, 2019; Wilson et al. 2014; Wilson and VanBriesen 2012; Woda et al. 2018; Wright et al. 2012; Yan et al. 2017; Zhang et al. 2015; Zhu et al. 2017; Ziemkiewicz et al. 2013a, 2013b.
Hydrogen sulfide	Colorado Department of Public Health and Environment 2017a; Eapi et al. 2014; Pennsylvania Department of Environmental Protection 2010, 2018; Vigil 2015
Metals	Abualfaraj et al. 2018; Agency for Toxic Substances and Disease Registry 2016; ATSDR Division of Community Health Investigations 2016; Austin et al. 2017; Caron-Beaudoin et al. 2019; Durant et al. 2016; Eisenlord et al. 2018; Evanoski-Cole et al. 2017; Hayes 2009; Hildenbrand et al. 2015, 2016a, 2016b; Lan et al. 2015; Li and Carlson 2014; Ling and Heglie 2016; Low et al. 2016; Nelson et al. 2015; Pelak and Sharma 2014; Penningroth et al. 2013; Post van der Burg and Tangen 2015; Reilly et al. 2015; Rich and Crosby 2013; Rish and Pfau 2018; Santos et al. 2018; Sherwood et al. 2016; Tormey 2012; U.S. Environmental Protection Agency 2011; Walters et al. 2019; Warner et al. 2013b; Wen et al. 2018; Wright et al. 2012; Zhu et al. 2017; Ziemkiewicz et al. 2013a, 2013b
Nitrogen oxides	Bahreini et al. 2018; Bean et al. 2018; Benedict et al. 2018; Chang et al. 2016; Edwards et al. 2014; Eisenlord et al. 2018; Ethridge et al. 2015; Gebhart et al. 2018; Goetz et al. 2017, 2015; Goodman et al. 2016; Halliday et al. 2016; Helmig et al. 2015; Islam et al. 2016; Khalaj and Sattler 2019; Koss et al. 2017; Lan et al. 2015; Larson et al. 2018; Majid et al. 2017; McCawley 2013; McDuffie et al. 2016; Oltmans et al. 2014; Pacsi et al. 2013; Pekney et al. 2018, 2014; Pennsylvania Department of Environmental Protection 2010, 2018; Pennsylvania Department of Health 2018; Pfister et al. 2017; Prenni et al. 2016; Roohani et al. 2017; Rutter et al. 2015; Schade and Roest 2016, 2018; Swarthout et al. 2013; Vinciguerra et al. 2015; Walther 2011; Warneke et al. 2014; Zielinska et al. 2014
Ozone	Ahmadi and John 2015; Ahmadov et al. 2015; Bien and Helmig 2018; Chang et al. 2016; Cheadle et al. 2017; Edwards et al. 2014; Evans and Helmig 2017; Fann et al. 2018; Field et al. 2015; Helmig et al. 2014, 2015; Lindaas et al. 2019; McCawley 2013; McClellan and Snipes 2010; McDuffie et al. 2016; Nsanzineza et al. 2019; Olaguer 2012; Oltmans et al. 2019, 2014; Pacsi et al. 2013; Pekney et al. 2014; Pennsylvania Department of Environmental Protection 2018; Pennsylvania Department of Health 2018; Pfister et al. 2017; Prenni et al. 2016; Roohani et al. 2017; Rutter et al. 2015; Vinciguerra et al. 2015; Walther 2011
Particulate Matter	Allshouse et al. 2019; ATSDR Division of Community Health Investigations 2016; Banan and Gernand 2018; Bean et al. 2018; Eisenlord et al. 2018; Fann et al. 2018; Frazier 2009; Goodman et al. 2016; Gradient Corporation 2019; Khalaj and Sattler 2019; McCawley 2013; Pacsi et al. 2013; Pekney et al. 2018, 2014; Pennsylvania Department of Health 2018; Prenni et al. 2016; Roohani et al. 2017
Radon	Casey et al. 2015; Gradient Corporation 2013; Grieve et al. 2018; Mitchell et al. 2016; Nelson et al. 2015; Penningroth et al. 2013; Rowan and Kraemer 2012; Torres et al. 2018; Walter et al. 2012; Warner et al. 2013a; Wright et al. 2012; Xu et al. 2019; Zhang et al. 2015

Table A4. References for Figure 4-3 – Number of studies by chemical agent

Chemical agent category	References
Volatile organic compounds	<p>Abualfaraj et al. 2018; Agency for Toxic Substances and Disease Registry 2010, 2016; Alawattagama et al. 2015; ATSDR Division of Community Health Investigations 2016; Bahreini et al. 2018; Bari and Kindzierski 2018; Barth-Naftilan et al. 2018; Boyer et al. 2012; Bunch et al. 2014; Burton et al. 2016; Chambers et al. 2018; Chang et al. 2016; Cheadle et al. 2017; Colborn et al. 2012; Collett et al. 2016; Collett and Ham 2016; Colorado Department of Public Health and Environment 2012, 2016, 2017c, 2017b, 2017a, 2018b, 2018c, 2018a, 2018e, 2018d; Crowe et al. 2016; Darrah et al. 2014; DiGiulio and Jackson 2016; Drollette et al. 2015; Durant et al. 2016; Eastern Research Group and Sage Environmental Consulting 2011; Eisele et al. 2016; Eisenlord et al. 2018; Elliott et al. 2018; Esswein et al. 2014; Ethridge et al. 2015; Fann et al. 2018; Ferrar et al. 2013; Field et al. 2015; Fontenot et al. 2013; Franco et al. 2016; Frazier 2009; Gebhart et al. 2018; Ghosh 2018; Gilman et al. 2013; Goetz et al. 2017, 2015; Gradient Corporation 2013, 2019; Grieve et al. 2018; Gross et al. 2013; Halliday et al. 2016; Harkness et al. 2017; Hayes 2009; Haynes et al. 2019; Helmig et al. 2014, 2015; Hildenbrand et al. 2015, 2016a, 2016b, 2016c; Jackson et al. 2013; Koss et al. 2017; Lan et al. 2015; Larson et al. 2018; Lewis et al. 2016; Li and Carlson 2014; Lim et al. 2019; Lindaas et al. 2019; Ling and Heglie 2016; Llewellyn et al. 2015; Macey et al. 2014; Marrero et al. 2016; Maskrey et al. 2016; McCawley 2013; McClellan and Snipes 2010; McDuffie et al. 2016; McKenzie et al. 2012, 2018; McMahon et al. 2017, 2019; McMullin et al. 2018; Meng 2018; Nathan and Lary 2019; Nicot et al. 2017; Oltmans et al. 2014; Orem et al. 2017; Pacsi et al. 2013; Peischl et al. 2018; Pekney et al. 2018, 2014; Pennsylvania Department of Environmental Protection 2010, 2018; Pétron et al. 2012; Pfister et al. 2017; Prenni et al. 2016; Rich and Orimoloye 2016; Rish and Pfau 2018; Roohani et al. 2017; Rossabi and Helmig 2018; Rutter et al. 2015; Santos et al. 2018; Schade and Roest 2018; Sherwood et al. 2016; Shores et al. 2017; States et al. 2013; Steinzor et al. 2013; Swarthout et al. 2013, 2015; Texas Department of State Health Services 2010; Thompson et al. 2014; Tormey 2012; U.S. Environmental Protection Agency 2011; Vinciguerra et al. 2015; Walther 2011; Warneke et al. 2014; Wen et al. 2018; Woda et al. 2018; Wright et al. 2012; Zavala-Araiza et al. 2014; Zhu et al. 2017; Zielinska et al. 2014; Ziemkiewicz et al. 2013a, 2013b</p>
Carbonyls	<p>Colorado Department of Public Health and Environment 2017a; Eastern Research Group and Sage Environmental Consulting 2011; Eisenlord et al. 2018; McClellan and Snipes 2010; McMahon et al. 2019; Pennsylvania Department of Environmental Protection 2010; Pennsylvania Department of Health 2018</p>

Table A5. References for Figure 4-5 – Air monitoring or modeling study locations

Shale or Basin	Monitoring	Modeling	Monitoring and Modeling
Anadarko			Ghosh 2018
Ark			Ghosh 2018
Bakken	Esswein et al. 2013; Koss et al. 2017; Majid et al. 2017; Prenni et al. 2016	Olawoyin 2015	Evanoski-Cole et al. 2017; Gebhart et al. 2018; Gvakharia et al. 2017; Peischl et al. 2018
Barnett	Bunch et al. 2014; Eapi et al. 2014; Eisele et al. 2016; Ethridge et al. 2015; Koss et al. 2017; Lim et al. 2019; Majid et al. 2017; Nathan and Lary 2019; Rich et al. 2014; Rich and Orimoloye 2016; Rossabi and Helmig 2018	Khalaj and Sattler 2019; Olaguer 2012; Pacsi et al. 2013	Ahmadi and John 2015; Eastern Research Group and Sage Environmental Consulting 2011; Lan et al. 2015; Marrero et al. 2016; Peischl et al. 2018; Rutter et al. 2015; Zavala-Araiza et al. 2014; Zielinska et al. 2014
Cherokee Platform			Ghosh 2018
Denver-Julesberg	Allshouse et al. 2019; Benedict et al. 2018; Bien and Helmig 2018; Cheadle et al. 2017; Colorado Department of Public Health and Environment 2012, 2016, 2017c, 2017b, 2017a, 2018b, 2018c, 2018a, 2018e, 2018d; Eisele et al. 2016; Esswein et al. 2013, 2014; Evans and Helmig 2017; Gilman et al. 2013; Halliday et al. 2016; Helmig et al. 2015; Koss et al. 2017; Macey et al. 2014; McKenzie et al. 2012, 2018; McMullin et al. 2018; Vigil 2015	Lindaas et al. 2019; Nsanzineza et al. 2019; Olawoyin 2015; Pfister et al. 2017	Bahreini et al. 2018; McDuffie et al. 2016; Oltmans et al. 2019; Peischl et al. 2018; Pétron et al. 2012; Swarthout et al. 2013
Duvernay			Bari and Kindzierski 2018
Eagle Ford	Esswein et al. 2013; Hildenbrand et al. 2016c; Koss et al. 2017; Majid et al. 2017; Schade and Roest 2016, 2018	Olawoyin 2015; Pacsi et al. 2013	Cardoso Saldana et al. 2019; Peischl et al. 2018
Fayetteville	Esswein et al. 2013; Macey et al. 2014	Olawoyin 2015	
Green River	Meng 2018; Walther 2011		
Haynesville	Koss et al. 2017; Majid et al. 2017; Rossabi and Helmig 2018	Pacsi et al. 2013	Peischl et al. 2018
Horn River	Islam et al. 2016		
California	Rossabi and Helmig 2018;		
Marcellus	Casey et al. 2015; Esswein et al. 2013; Goetz et al. 2017; Gradient Corporation 2019; Haynes et al. 2019; Lewis et al. 2016; Macey et al. 2014; Majid et al. 2017; Maskrey et al. 2016; McCawley 2013; Paulik et al. 2018; Pekney et al. 2014; Pennsylvania Department of Environmental Protection 2010, 2018; Pennsylvania Department of Health 2018; Rossabi and Helmig 2018; Rowan and Kraemer 2012; Steinzor et al. 2013; Swarthout et al. 2015; Vinciguerra et al. 2015; Williams et al. 2018	Banan and Gernand 2018; Olawoyin 2015; Roohani et al. 2017; Xu et al. 2019	Chang et al. 2016; Goetz et al. 2015; Mitchell et al. 2016
Niobrara-Codell	Majid et al. 2017; Rossabi and Helmig 2018		

Table A5. References for Figure 4-5 – Air monitoring or modeling study locations

Shale or Basin	Monitoring	Modeling	Monitoring and Modeling
Permian	Eisenlord et al. 2018; Frazier 2009; Koss et al. 2017; Majid et al. 2017; Rossabi and Helmig 2018		
Piceance	Agency for Toxic Substances and Disease Registry 2010; Colborn et al. 2012; Esswein et al. 2014; McMullin et al. 2018	Nsanzineza et al. 2019	Collett et al. 2016a, 2016b
Powder River Basin		Nsanzineza et al. 2019	
San Juan	Koss et al. 2017	Nsanzineza et al. 2019	
Upper Green River Basin	Esswein et al. 2014; Field et al. 2015; Koss et al. 2017; Oltmans et al. 2014		
Uinta	Helmig et al. 2014; Koss et al. 2017; Oltmans et al. 2014; Warneke et al. 2014	Ahmadov et al. 2015; Edwards et al. 2014; Nsanzineza et al. 2019	
Utica	Haynes et al. 2019; Macey et al. 2014; Majid et al. 2017; Paulik et al. 2016, 2018; Rossabi and Helmig 2018	Roohani et al. 2017; Xu et al. 2019	
Wattenberg	Thompson et al. 2014		
Wind River	Macey et al. 2014; McClellan and Snipes 2010	Nsanzineza et al. 2019	
Not Applicable		Fann et al. 2018; Goodman et al. 2016	Franco et al. 2016
Not Reported	Agency for Toxic Substances and Disease Registry 2010	Walter et al. 2012	
Note: Some multi-national regional air quality studies were mapped to specific shales or basins for visual purposes, but used data collected using regional air quality networks monitors that were not located directly in those shales or basins (e.g., Rossabi and Helmig 2018)			

Table A6. References for Figure 4-6 – Sampler placement in air monitoring studies.

Chemical agent category	References
Area	Agency for Toxic Substances and Disease Registry 2010; Ahmadi and John 2015; Allshouse et al. 2019; Bari and Kindzierski 2018; Benedict et al. 2018; Bien and Helmig 2018; Cardoso Saldana et al. 2019; Chang et al. 2016; Cheadle et al. 2017; Colborn et al. 2012; Collett and Ham 2016; Colorado Department of Public Health and Environment 2017c, 2017a; Eastern Research Group and Sage Environmental Consulting 2011; Evanoski-Cole et al. 2017; Franco et al. 2016; Gebhart et al. 2018; Ghosh 2018; Gilman et al. 2013; Goetz et al. 2015; Gradient Corporation 2019; Halliday et al. 2016; Helmig et al. 2014, 2015; Hildenbrand et al. 2016c; Islam et al. 2016; Koss et al. 2017; Lan et al. 2015; Lim et al. 2019; Macey et al. 2014; Majid et al. 2017; Marrero et al. 2016; Maskrey et al. 2016; McClellan and Snipes 2010; McDuffie et al. 2016; McKenzie et al. 2018, 2018; McMullin et al. 2018; Meng 2018; Nathan and Lary 2019; Oltmans et al. 2019, 2014; Peischl et al. 2018; Pekney et al. 2014; Pennsylvania Department of Environmental Protection 2010; Pétron et al. 2012; Prenni et al. 2016; Rossabi and Helmig 2018; Rutter et al. 2015; Schade and Roest 2016, 2018; Swarthout et al. 2013, 2015; Vinciguerra et al. 2015; Walther 2011; Warneke et al. 2014; Williams et al. 2018; Zavala-Araiza et al. 2014; Zielinska et al. 2014
Community	ATSDR Division of Community Health Investigations 2016; Bien and Helmig 2018; Bunch et al. 2014; Cheadle et al. 2017; Colorado Department of Public Health and Environment 2012, 2016, 2017b, 2018d; Eisele et al. 2016; Eisenlord et al. 2018; Ethridge et al. 2015; Goetz et al. 2017; Haynes et al. 2019; Helmig et al. 2015; Lan et al. 2015; Lim et al. 2019; Macey et al. 2014; McCawley 2013; McKenzie et al. 2012, 2018; McMullin et al. 2018; Pennsylvania Department of Environmental Protection 2010; Pennsylvania Department of Health 2018; Rich and Orimoloye 2016; Thompson et al. 2014; Walther 2011; Williams et al. 2018
Fenceline	Eapi et al. 2014; Eastern Research Group and Sage Environmental Consulting 2011; Eisele et al. 2016; McKenzie et al. 2012; Warneke et al. 2014; Zielinska et al. 2014
Onsite	Collett et al. 2016; Collett and Ham 2016; Eisenlord et al. 2018; Esswein et al. 2013, 2014; Evans and Helmig 2017; Franco et al. 2016; Frazier 2009; Hildenbrand et al. 2016c; Marrero et al. 2016; Paulik et al. 2018; Pekney et al. 2018; Pennsylvania Department of Environmental Protection 2010; Rowan and Kraemer 2012; Vigil 2015
Residence indoor	Casey et al. 2015; Colorado Department of Public Health and Environment 2018c; Lewis et al. 2016; McCawley 2013
Residence outdoor	Colorado Department of Public Health and Environment 2016, 2017c, 2017a, 2018b, 2018a, 2018e; Haynes et al. 2019; Islam et al. 2016; Lewis et al. 2016; Maskrey et al. 2016; Paulik et al. 2016; Pennsylvania Department of Environmental Protection 2010; Steinzor et al. 2013; Thompson et al. 2014; Zielinska et al. 2014
Various distances	Agency for Toxic Substances and Disease Registry 2010; ATSDR Division of Community Health Investigations 2016; Bunch et al. 2014; Cheadle et al. 2017; Colborn et al. 2012; Colorado Department of Public Health and Environment 2017b; Eisele et al. 2016; Ethridge et al. 2015; Evans and Helmig 2017; Frazier 2009; Goetz et al. 2015; Lewis et al. 2016; McCawley 2013; McClellan and Snipes 2010; Paulik et al. 2016, 2018; Pennsylvania Department of Environmental Protection 2010; Rich et al. 2014; Rich and Orimoloye 2016

Table A7. References for Figure 4-7 – Air sample averaging times.

Chemical agent category	References
Grab sample	Casey et al. 2015; Colorado Department of Public Health and Environment 2016, 2017c, 2017a, 2018b, 2018c, 2018a, 2018e; Macey et al. 2014; Marrero et al. 2016; Rowan and Kraemer 2012; Swarthout et al. 2015; Vigil 2015
< 5 minutes	Allshouse et al. 2019; ATSDR Division of Community Health Investigations 2016; Ghosh 2018; Goetz et al. 2017; Halliday et al. 2016; Koss et al. 2017; Lan et al. 2015; McCawley 2013; McDuffie et al. 2016; McKenzie et al. 2018, 2018; Pekney et al. 2018; Pennsylvania Department of Environmental Protection 2010; Prenni et al. 2016; Warneke et al. 2014; Williams et al. 2018
10-15 minutes	Oltmans et al. 2019; Swarthout et al. 2013
1 hour	Bien and Helmig 2018; Bunch et al. 2014; Cardoso Saldana et al. 2019; Cheadle et al. 2017; Collett et al. 2016; Collett and Ham 2016; Colorado Department of Public Health and Environment 2017b, 2018d; Ethridge et al. 2015; Evanoski-Cole et al. 2017; Evans and Helmig 2017; Field et al. 2015; Frazier 2009; Gradient Corporation 2019; Helmig et al. 2014; Lim et al. 2019; McClellan and Snipes 2010; McMullin et al. 2018; Nathan and Lary 2019; Oltmans et al. 2014; Pekney et al. 2014; Rich and Orimoloye 2016; Rutter et al. 2015; Schade and Roest 2016, 2018; Vinciguerra et al. 2015; Walther 2011; Zavala-Araiza et al. 2014; Zielinska et al. 2014
3-12 hours	Ahmadi and John 2015; Chang et al. 2016; Colborn et al. 2012; Colorado Department of Public Health and Environment 2012; Eisenlord et al. 2018; Esswein et al. 2013, 2014; Helmig et al. 2015
24 hours	Agency for Toxic Substances and Disease Registry 2010; Bahreini et al. 2018; Bari and Kindzierski 2018; Benedict et al. 2018; Eastern Research Group and Sage Environmental Consulting 2011; Franco et al. 2016; Gilman et al. 2013; Haynes et al. 2019; Lewis et al. 2016; Maskrey et al. 2016; McKenzie et al. 2012; Pennsylvania Department of Health 2018; Pétron et al. 2012; Steinzor et al. 2013
2 weeks – 1 month	Eisele et al. 2016; Islam et al. 2016; Majid et al. 2017; Rossabi and Helmig 2018
Annually	Gebhart et al. 2018; Thompson et al. 2014

Table A8. References for Figure 4-8 – Number of outdoor air quality studies in four Texas shale basins, by sampling location, time of year, and sample averaging time.

Location	References
Barnett	Bunch et al. 2014; Eastern Research Group and Sage Environmental Consulting 2011; Eisele et al. 2016; Ethridge et al. 2015; Koss et al. 2017; Lan et al. 2015; Lim et al. 2019; Marrero et al. 2016; Rich et al. 2014; Rich and Orimoloye 2016; Rossabi and Helmig 2018; Rutter et al. 2015; Zavala-Araiza et al. 2014; Zielinska et al. 2014
Eagle Ford	Hildenbrand et al. 2016c; Koss et al. 2017; Schade and Roest 2016, 2018
Permian	Koss et al. 2017
Haynesville	Koss et al. 2017

Table A9. References for Figure 4-9 –Water monitoring or modeling study locations

Shale or Basin	Monitoring	Modeling	Monitoring and Modeling
Bakken		Torres et al. 2017	Torres et al. 2018
Barnett	Darrah et al. 2014; Fontenot et al. 2013; Hildenbrand et al. 2015; Rich and Crosby 2013	Burton et al. 2016	Larson et al. 2018
Denver-Julesberg	Gross et al. 2013; Li and Carlson 2014; Sherwood et al. 2016	Shores et al. 2017	
Eagle Ford	Hildenbrand et al. 2016b; Nicot et al. 2017; Santos et al. 2018		McMahon et al. 2017
Fayetteville	Austin et al. 2017; Warner et al. 2013b		McMahon et al. 2017
Haynesville			McMahon et al. 2017
Inglewood	Tormey 2012 ¹		
Marcellus	Agency for Toxic Substances and Disease Registry 2010; Akob et al. 2016; Alawattegama et al. 2015; Barth-Naftilan et al. 2018; Boyer et al. 2012; Darrah et al. 2014; Ferrar et al. 2013; Harkness et al. 2017; Hayes 2009; Haynes et al. 2019; Hladik et al. 2014; Jackson et al. 2013; Kassotis et al. 2016; LeDoux et al. 2016; Llewellyn et al. 2015; Low et al. 2016; McMahon et al. 2019; Molofsky et al. 2016; Niu et al. 2018; Orem et al. 2017; Osborn et al. 2011; Pelak and Sharma 2014; Penningroth et al. 2013; Reilly et al. 2015; States et al. 2013; Warner et al. 2013a; Wen et al. 2018, 2019; Wilson et al. 2014; Woda et al. 2018; Yan et al. 2017; Ziemkiewicz et al. 2013a, 2013b	Abualfaraj et al. 2018; Durant et al. 2016; Hill and Ma 2017; Landis et al. 2016; Olmstead et al. 2013; Rish and Pfau 2018; Weaver et al. 2015	Drollette et al. 2015; Grieve et al. 2018; U. S. Environmental Protection Agency 2015; Zhang et al. 2015
Permian	Eisenlord et al. 2018; Hildenbrand et al. 2016a		Bean et al. 2018
Rogersville	Zhu et al. 2017		
San Juan	Nelson et al. 2015		
Upper Green River Basin	Walters et al. 2019		
Utica	Elliott et al. 2018; Haynes et al. 2019; Osborn et al. 2011; Penningroth et al. 2013		
Williston		Preston and Chesley-Preston 2015	Post van der Burg and Tangen 2015; Preston et al. 2014
Wind River	DiGiulio and Jackson 2016; Ling and Heglie 2016; U.S. Environmental Protection Agency 2011; Wright et al. 2012		
Not Applicable		Gradient Corporation 2013; Regli et al. 2015; Shanafield et al. 2018	
¹ Tormey et al. 2012 Inglewood Oil Field represents samples collected near a horizontal, multistage fracturing site in the shale within Inglewood Oil Field, which is considered a “conventional” resource. The study was conducted to inform air concentrations at both conventional and unconventional oil and gas development.			

Table A10. References for Figure 4-10 – Number of studies by type of water sample.

Chemical agent category	References
Effluent	Akob et al. 2016; Ferrar et al. 2013; Hayes 2009; Hladik et al. 2014; Kassotis et al. 2016; Landis et al. 2016; Olmstead et al. 2013; States et al. 2013; U. S. Environmental Protection Agency 2015; Warner et al. 2013a; Weaver et al. 2015
Groundwater	Agency for Toxic Substances and Disease Registry 2016; Alawattagama et al. 2015; Barth-Naftilan et al. 2018; Boyer et al. 2012; Burton et al. 2016; Darrah et al. 2014; DiGiulio and Jackson 2016; Drollette et al. 2015; Eisenlord et al. 2018; Elliott et al. 2018; Fontenot et al. 2013; Grieve et al. 2018; Gross et al. 2013; Harkness et al. 2017; Hildenbrand et al. 2015, 2016a, 2016b; Hill and Ma 2017; Jackson et al. 2013; Larson et al. 2018; LeDoux et al. 2016; Li and Carlson 2014; Ling and Heglie 2016; Llewellyn et al. 2015; McMahon et al. 2017, 2019; Molofsky et al. 2016; Nelson et al. 2015; Nicot et al. 2017; Osborn et al. 2011; Penningroth et al. 2013; Preston et al. 2014; Preston and Chesley-Preston 2015; Reilly et al. 2015; Santos et al. 2018; Shanafield et al. 2018; Sherwood et al. 2016; Shores et al. 2017; Tormey 2012; U.S. Environmental Protection Agency 2011; Warner et al. 2013b; Wen et al. 2018, 2019; Woda et al. 2018; Wright et al. 2012; Yan et al. 2017; Zhu et al. 2017; Ziemkiewicz et al. 2013a, 2013b
Municipal water	Hildenbrand et al. 2015, 2016b; Larson et al. 2018; Low et al. 2016; McMahon et al. 2017; Nelson et al. 2015; Orem et al. 2017; Regli et al. 2015; Rish and Pfau 2018; U.S. Environmental Protection Agency 2011
Produced water	Bean et al. 2018; DiGiulio and Jackson 2016; Durant et al. 2016; Hayes 2009; Llewellyn et al. 2015; McMahon et al. 2017; Reilly et al. 2015; Rich and Crosby 2013; Shores et al. 2017; Torres et al. 2017; Warner et al. 2013b; Zhang et al. 2015; Ziemkiewicz et al. 2013a, 2013b.
Spill	Abualfaraj et al. 2018; Gross et al. 2013; Harkness et al. 2017; Rish and Pfau 2018; Shores et al. 2017
Surface water	Akob et al. 2016; Austin et al. 2017; Darrah et al. 2014; Elliott et al. 2018; Ferrar et al. 2013; Grieve et al. 2018; Harkness et al. 2017; Hayes 2009; Haynes et al. 2019; Hladik et al. 2014; Kassotis et al. 2016; Landis et al. 2016; Llewellyn et al. 2015; Low et al. 2016; Nelson et al. 2015; Niu et al. 2018; Olmstead et al. 2013; Orem et al. 2017; Pelak and Sharma 2014; Penningroth et al. 2013; Post van der Burg and Tangen 2015; Preston et al. 2014; Preston and Chesley-Preston 2015; Regli et al. 2015; Shanafield et al. 2018; States et al. 2013; Torres et al. 2017; U. S. Environmental Protection Agency 2015; U.S. Environmental Protection Agency 2011; Walters et al. 2019; Warner et al. 2013a; Weaver et al. 2015; Wen et al. 2018; Wilson et al. 2014; Woda et al. 2018; Ziemkiewicz et al. 2013a, 2013b
Tap water	Elliott et al. 2018; Fontenot et al. 2013; Grieve et al. 2018; Haynes et al. 2019; LeDoux et al. 2016; Zhu et al. 2017

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