Part I

Overview

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Global Unconventional Oil and Gas Reserves and Their Development

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1.1 Introduction

The United States Energy Information Administration (EIA) comprehensively assessed global shale reserves in 2011 and followed up in 2013 (U.S. Energy Information Administration 2015). The 2011 assessment focused on 14 regions outside the United States, and the 2013 assessment expanded to 137 formations in 95 basins from 41 countries (Table 1.1). The EIA estimates the global shale gas reserves at 7,577 Tcf and the global shale oil reserves at 419 billion bbl. The 10 largest reserves for shale gas are China (1,115 Tcf), Argentina (802 Tcf), Algeria (707 Tcf), United States (623 Tcf), Canada (573 Tcf), Mexico (545 Tcf), Australia (437 Tcf), South Africa (370 Tcf), Russia (285 Tcf), and Brazil (245 Tcf). The European Union combined has significant reserves (435 Tcf), with Poland (146 Tcf) and France (137 Tcf) having the largest reserves. The 10 largest reserves for shale oil are United States (78 Bbbl), Russia (75 Bbbl), China (32 Bbbl), Argentina (27 Bbbl), Libya (26 Bbbl), United Arab Emirates (23 Bbbl), Chad (16 Bbbl), Australia (17.5 Bbbl), Venezuela (13 Bbbl), and Mexico (13 Bbbl). To date, only the United States and Canada have reached commercial level production for shale gas and oil, followed to a lesser extent by China and Argentina. While the estimated ultimate recovery (EUR) of these resources may be significant, the current status of their development relies on several factors. These factors include whether the reserves are technically and economically recoverable (i.e., readily accessible geographically and geologically), the status of existing infrastructure, such as refining capacity and pipelines, and a favorability of regulatory frameworks and political climate. The Society of Petroleum Engineers (SPE) defines proved reserves as those that are commercially recoverable "under current economic conditions, operating methods, and government regulations" (SPE 1997). The EIA did not consider other low permeability tight formations, such as sandstones and carbonates, and only assessed those with sufficiently studied geology (EIA 2013). It also considered the current technology available for the development of these formations, including the advances in drilling and hydraulic fracturing technology (Stolz and Griffin, see Chapter 2). The EIA calculated three values: OIP/GIP concentration, Risked OIP/GIP, and Risked Recoverable (EIA 2013). Oil-in-place (OIP) and gas-in-place (GIP) estimates were based primarily on the thickness of the organic-rich shale, porosity, pressure, and temperature. Risked OIP/GIP estimates were based on two additional factors: the play

Table 1.1. *Global distribution of tight oil and gas reserves and the current status of development (US EIA 2015a)*

Area	Country	Basin	Formation	Status of Development
North America	Canada	Horn River	Muskwa/Otter Park Evie/Klua	Provence dependent mix of active development or ban. 1,2,3
		Cordova	Muskwa/Otter Park	
		Liard	Lower Besa River	
		Deep Basin	Doig Phosphate	
		Alberta Basin	Banff/Exshaw	
		East and West Shale Basin	Duvernay	
		Deep Basin	North Nordegg	
		NW Alberta Area	Muskwa	
		Southern Alberta Basin	Colorado Group	
		Williston Basin	Bakken	
		Appalachian Fold Belt	Utica	
		Windsor Basin	Horton Bluff	
	Mexico	Burgos	Eagle Ford Shale Tithonian Shales	Active development. 1,4,5
		Sabinas	Eagle Ford Shale Tithonian La Casita	
		Tampico	Pimienta	
		Tuxpan	Tamaulipas Pimienta	
		Veracruz	Maltrata	
South America	Colombia	Middle Magdalena Valley	La Luna/Tablazo	Moratorium. 1
		Llanos	Gacheta	
	Colombia/ Venezuela	Maracaibo Basin	La Luna/Capacho	
	Argentina	Neuquen	Los Molles Vaca Muerta	Active development.1,4
		San Jorge Basin	Aguada Bandera Pozo D-129	
		Austral-Magallanes Basin	L. Inoceramus-Magnas Verdes	
		Parana Basin	Ponta Grossa	
	Brazil	Parana Basin	Ponta Grossa	State dependent with active development or ban. 1,6
		Solimoes Basin	Jandiatuba	
		Amazonas Basin	Barreirinha	
	Paraguay Uruguay	Parana Basin	Ponta Grossa Cordobes	Banned. 1,2,3
	Paraguay/ Bolivia	Chaco Basin	Los Monos	
	Chile	Austral-Magallanes Basin	Estratos con Favrella	

Table 1.1. (*cont.*)

Area	Country	Basin	Formation	Status of Development
Eastern Europe	Poland	Baltic Basin/ Warsaw Trough	Llandovery	Allowed but currently inactive. 2,3,4,7
		Lublin	Llandovery	
		Podlasie	Llandovery	
		Fore Sudetic	Carboniferous	
	Lithuania/ Kaliningrad	Baltic Basin	Llandovery	Allowed but currently inactive. 7,8
	Russia	West Siberian Central	Bazhenov Central	Allowed but currently inactive.9,10,11
		West Siberian North	Bazhenov North	
	Ukraine/ Romania	Carpathian Foreland Basin	L. Silurian	Allowed but currently inactive.2,9
	Ukraine	Dniepr-Donets	L. Carboniferous	Allowed but currently inactive. 11
	Ukraine/ Romania	Moesian Platform	L. Silurian	Allowed but currently inactive. 2,3,9
	Romania/ Bulgaria		Etropole	Banned in Bulgaria. 1,2,3,12
Western Europe	UK	N. UK Carboniferous Shale Region	Carboniferous Shale	Moratorium. 1,13,14
		S. UK Jurassic Shale Region	Lias Shale	
	Spain	Cantabrian	Jurassic	Allowed but currently inactive. 1,2,3
	France	Paris Basin	Lias Shale	Banned. 1,2,3
			Permian-Carboniferous	
		Southeast Basin	Lias Shale	
	Germany	Lower Saxony	Posidonia	Banned. 2,3,15
			Wealden	
	Netherlands	West Netherlands Basin	Epen	Moratorium1,2,3,4
			Geverik Member	
			Posidonia	
	Sweden	Scandinavia Region	Alum Shale - Sweden	Allowed but currently inactive. 2,3,4
	Denmark		Alum Shale - Denmark	Moratorium. 1,2,3,4
Africa	Morocco	Tindouf	L. Silurian	
		Tadla	L. Silurian	
	Algeria	Ghadames/ Berkine	Frasnian	Allowed but currently inactive. 16,17
			Tannezuft	
		Illizi	Tannezuft	
		Mouydir	Tannezuft	
		Ahnet	Frasnian	
			Tannezuft	

Table 1.1. (*cont.*)

Area	Country	Basin	Formation	Status of Development
		Timimoun	Frasnian Tannezuft	
		Reggane	Frasnian Tannezuft	
		Tindouf	Tannezuft	
	Tunisia	Ghadames	Tannezuft Frasnian	
	Libya	Ghadames	Tannezuft Frasnian	
		Sirte	Sirte/Rachmat Fms Etel Fm	
		Murzuq	Tannezuft	
	Egypt	Shoushan/Matruh Abu Gharadig Alamein Natrun	Khatatba Khatatba Khatatba Khatatba	Allowed but currently inactive. 18,19
	Chad	Termit	L. Cretaceous U. Cretaceous	
		Bongor	L. Cretaceous	
		Doba	L. Cretaceous	
		Doseo	L. Cretaceous	
	South Africa	Karoo Basin	Prince Albert Whitehill Collingham	Allowed but currently inactive.1,4
Asia	China	Sichuan Basin	Qiongzhusi Longmaxi Permian	Active development. 4,20
		Yangtze Platform	L. Cambrian L. Silurian	
		Jianghan Basin	Niutitang/Shuijintuo Longmaxi Qixia/Maokou	
		Greater Subei	Mufushan Wufeng/Gaobiajian U. Permian	
		Tarim Basin	L. Cambrian L. Ordovician M.-U. Ordovician Ketuer	
		Junggar Basin	Pingdiquan/Lucaogou Triassic	
		Songliao Basin	Qingshankou	
	Mongolia	East Gobi Tamtsag	Tsagaantsav Tsagaantsav	

Table 1.1. (*cont.*)

Area	Country	Basin	Formation	Status of Development
	Thailand	Khorat Basin	Nam Duk Fm	
	Indonesia	C. Sumatra	Brown Shale	Active development. 21
		S. Sumatra	Talang Akar	
		Tarakan	Naintupo	
			Meliat	
			Tabul	
		Kutei	Balikpapan	
		Bintuni	Aifam Group	
	India	Cambay Basin	Cambay Shale	Active development. 4,22
		Krishna-Godavari	Permian-Triassic	
		Cauvery Basin	Sattapadi-Andimadam	
		Damodar Valley	Barren Measure	
	Pakistan	Lower Indus	Sembar	
			Ranikot	
	Turkey	SE Anatolian	Dadas	
		Thrace	Hamitabat	
	Kazakhstan	North Caspian (North Margin)	Tournaisian, Radaevskiy-Kosvinskiy L. Serpukhovian, Vereiskiy, Gzelian-Kasimovian	
		North Caspian (SE Margin)	Visean	
		Mangyshlak	Karadzhatyk	
		South Turgay	Karagansay	
			Abaleen	
Middle East	Jordan	Hamad	Batra	
		Wadi Sirhan	Batra	
	Oman	S. Oman Salt	Thuleilat Shale	
			Athel	
			U Shale	
		N. Oman Foreland	Natih	
		Rub' Al-Khali	Sahmah Shale	
	United Arab Emirates	Rub' Al-Khali	Qusaiba	
			Diyab	
			Shilaif	
Australia	Australia	Cooper	Roseneath-Epsilon-Murteree (Nappamerri)	Provence dependent mix of active development, partial ban, or moratorium. 1,2,3
			Roseneath-Epsilon-Murteree (Patchawarra)	
			Roseneath-Epsilon-Murteree (Tenappera)	
		Maryborough	Goodwood/Cherwell Mudstone	

Table 1.1. (*cont.*)

Area	Country	Basin	Formation	Status of Development
		Perth	Carynginia	
			Kockatea	
		Canning	Goldwyer	
		Georgina	L. Arthur Shale (Dulcie Trough)	
			L. Arthur Shale (Toko Trough)	
		Beetaloo	M. Velkerri Shale	
			L. Kyalla Shale	

1) Herrera (2020), 2) Mead and Maloney (2018a), 3) Mead and Maloney (2018b), 4)Vinson and Elkins (2020), 5) Bertram (2019), 6) Dias (2019), 7) Kuznestsov (2013), 8) Reed (2015), 9) Stefan (2015), 10) Rapoza (2019), 11) Thomas (2014), 12) BBC News (2012), 13) Ambrose (2019), 14) Cairney et al. (2018), 15) Gesley (2017), 16) Aczel (2020), 17) Chikhi et al. (2019), 18) Reuters (2014), 19) Gasser (2017), 20) Myers (2019), 21) Campbell (2013), 22) Yadav (2020).

success probability (how likely is the play to produce) and the prospective area success factor (which includes additional risk factors that may affect production). Risk Recoverable, or the estimated technically recoverable oil and gas, was calculated by multiplying the OIP or GIP value by a recovery efficiency factor (EIA 2013). The latter factor was based on the mineralogy of the shale and how efficiently the formation could be hydraulically fractured. Only the data for Risked Recoverable estimates are included here, as they provide a baseline for assessing how successful a play might be (EIA 2013). This chapter provides a brief review of the major shale gas and oil plays and the status of their development as of 2020, focusing on China, Argentina, Algeria, the United States, Canada, Mexico, Australia, South Africa, Russia, and Brazil. Additional discussions can be found in the chapters covering the United States (Stolz and Griffin, see Chapter 2; Graham and Rupp, see Chapter 4), Australia (McCarron and Doughal, see Chapter 3), and France and the United Kingdom (Graham and Rupp, see Chapter 4).

1.2 China

China has seven areas that have been assessed for technically recoverable oil and gas, namely the Sichuan, Tarim, Junggar, Songliao, Jianghan, and Subei basins, and the Yangtze Platform (US EIA 2015e). The Sichuan (626 Tcf), Tarim (216 Tcf), Junggar (36 Tcf), and Songliao (16 Tcf) basins have the greatest potential for shale gas. The major shale oil reserves are found in the Junggar, Tarim, and Songliao basins with an estimated 8 Bbbl, 12 Bbbl, and 11.5 Bbbl, respectively. South China has marine black shales, with major development in the Sichuan Basin and Yangtze Platform. Commercial exploration

and production has been underway, reportedly reaching nearly 600 wells and 9 bcm of production in 2017 (Vinson and Elkins 2020). The expansion has been driven by the 13th Five-Year-Plan for Energy Development announced by the National Development and Reform Commission and National Energy Administration in early 2017 with the goal of increasing proven reserves to 1 tcm by 2020 (Vinson and Elkins 2020). The geological complexity of the basins, with their faults and seismic activity, has proven to be a challenge. Development in Sichuan has been hampered by earthquakes (Myers 2019). Other challenges include the extreme depth of the deposits (3,200 m on average), limited accessibility, the lack of water resources, limited geologic data, clay-rich deposits that are more difficult to hydraulically fracture, lack of pipelines in some areas, and the high cost of development (US EIA 2015e). China has made investments in other global shale plays such as the United States in an effort to gain greater expertise. Sinopec is the major oil and gas company involved in the development, as many of the foreign companies such as Shell, Chevron, and BP have dropped out. China has also created its own oilfield services industry, manufacturing the equipment required for shale gas and oil extraction (Vinson and Elkins 2020).

1.3 Argentina

Argentina, traditionally known for its oil production, has four basins, the Neuquén, Golfo San Jorge, Austral, and Paraná (US EIA 2015c). Together, they are estimated to contain 802 Tcf and 27 Bbbl of risked recoverable gas and oil. The Neuquén is a marine shale, Jurassic to Cretaceous in age. The Golfo San Jorge is a lacustrine shale, Jurassic to Cretaceous in age. The Austral basin is a marine black shale, Cretaceous in age, while the Paraná is a black shale of Devonian age (US EIA 2015c). The Neuquén is the most promising for development with commercial production by the Argentine national company YPF SA, as well as foreign companies Apache, EOG Resources, ExxonMobil, and TOTAL. Development for shale oil began in the Vaca Muerta formation in 2010 (US EIA 2015c). The industry, as a whole, has expanded since then with the passage of key legislation. The Hydrocarbon Sovereignty Law, passed in 2012 and enacted by an Executive Branch decree, reclaimed the country's hydrocarbon deposits by public domain (Beller and Schiariti 2012). The law also declared a 51% share of YPF SA and Respol YPF Gas SA, essentially repatriating the companies after several years of private ownership. Further stimulation was provided by the recently decreed "Argentine Natural Gas Production and Demand Scheme Promotion Plan," also known as the 2020–2024 Gas Plan. The plan set production goals for the Austral (20 MMm^3/d) and Neuquén (47.2 MMm^3/d) basins. It has reinvigorated the operations of the regional private companies Tecpetrol SA and Pluspetrol SA. The main challenge limiting development has been financing, as the country continues to suffer from high inflation and interest rates (Newberry 2019). The high cost of drilling and completion also contributes as it continues to be greater than the price break point (Newbery 2019). An emerging issue has been social unrest in response to the rapid inflation and the country's response to COVID-19, with

oilfield workers striking and healthcare providers (i.e., nurses, doctors, orderlies) blockading roads in protesting for better pay and health benefits (Otaola 2021).

1.4 Algeria

The geologic history of Algeria has created a patchwork of seven different basins scattered across the country. From west to east, they are the Tindouf, Reggane, Timimoun, Ahnet, Mouydir, Illizi, and Ghadames/Berkine basins. Together, they are estimated to contain 707 Tcf and 5.7 Bbbl of risked recoverable gas and oil, respectively. There are two major shale gas and oil formations in Algeria, the Tannezuft shale (Silurian) and the Frasnian shale (Upper Devonian) within these basins (US EIA 2015b). Exploratory drilling occurred in the Ahnet basin near In Salah in late 2014 (Belakhdar 2020). Despite Algeria's reliance on petroleum exports for their economy, the development of Algerian shales has been met with public protests (Chikhi et al. 2019; Belakhdar 2020) and political unrest (Aczel et al. 2018; Aczel 2020). The National Assembly passed legislation in 2013 to promote shale gas and later actively sought international partners for their development. This resulted, however, in large protests held in the cities of Adrar and Ouargla in 2014 and 2015. There was again political unrest after the 2019 Hydrocarbon Law was passed to encourage development and international support. Further development is on hold (Aczel 2020).

1.5 United States

The United States has several large shale deposits, with more than 24 basins and 38 formations (US EAI 2020; Stolz and Griffin 2021, see Table 2.1). Alabama, Alaska, Arkansas, California, Colorado, Indiana, Kansas, Louisiana, Michigan, Mississippi, Montana, Nebraska, Nevada, New Mexico, North Dakota, Ohio, Oklahoma, Pennsylvania, Tennessee, Texas, Utah, Virginia, West Virginia, and Wyoming all have deposits that are being or could be developed (see map in Chapter 2, Figure 2.1). Most of the shale oil is being produced from seven shale basins, namely, the Permian Basin (Texas), Eagle Ford (Upper Cretaceous) in Texas, Bakken (Upper Devonian) in North Dakota and Montana, Niobrara (Upper Cretaceous) in Colorado and Wyoming, Haynesville (Jurassic) in Louisiana and Texas, and the Utica (Ordovician) and Marcellus (Devonian) both in Pennsylvania, Ohio, and West Virginia (US EIA 2020). While fracking is permitted and there are sizable shale deposits in Alaska (Gryc 1985), the focus has been exclusively on conventional reserves. Greater discussion of unconventional oil and gas extraction in the United States can be found in Chapter 2.

Three states currently ban hydraulic fracturing, Maryland, New York, and Vermont. Other bans or moratoria exist at the city or county level. Attempts to ban fracking in Denton and Dallas, Texas, were overturned by the state legislature (Chapter 4). In Pennsylvania, Pittsburgh City Council passed an ordinance prohibiting the commercial extraction of natural gas in 2010 (Baca 2010). Subsequently, Bucks and Monroe County councils passed similar ordinances. None have been challenged to date. Most recently, the Delaware River

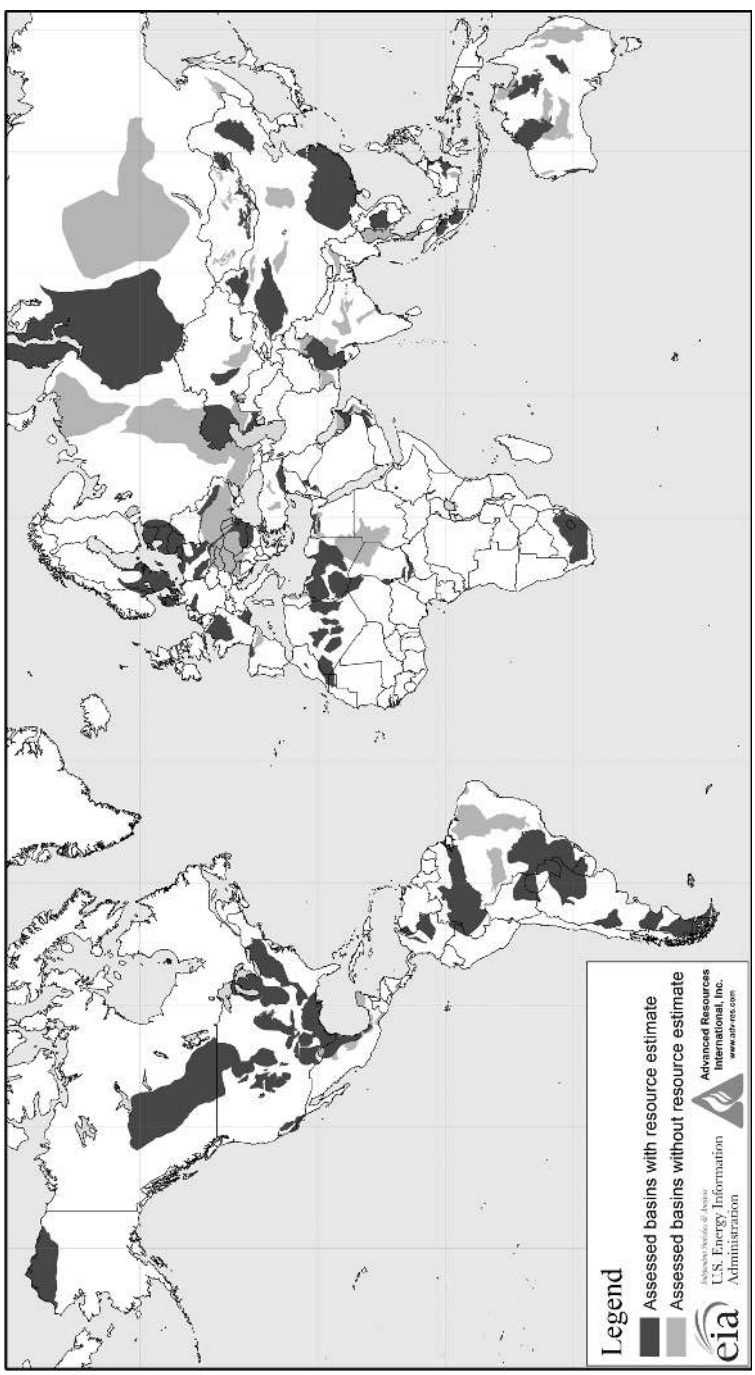

Figure 1.1 Global distribution of tight oil and gas reserves (US EIA 2014) (A black and white version of this figure will appear in some formats. For the colour version, refer to the plate section.)