

State of Texas Advanced Resource Recovery

STARR 



**BUREAU OF
ECONOMIC
GEOLOGY**

Progress Report

JANUARY 2019

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EXECUTIVE SUMMARY

The State of Texas Advanced Resource Recovery (STARR) program has been successful in its major objective to increase severance tax income for the State of Texas through research projects that promote the drilling of profitable oil and gas wells in the state. The Bureau of Economic Geology (BEG) receives funds from the State to conduct research that assists oil and gas operators in adding new or increasing existing production throughout Texas. STARR must be revenue neutral. Revenue associated with STARR projects must equal or exceed the amount appropriated to the program by the Legislature. This report summarizes accomplishments of the STARR program from September 1, 2016, to August 31, 2018.

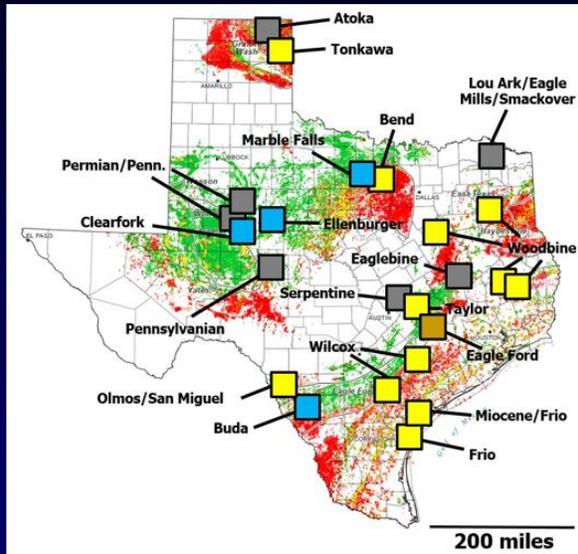
Credit to the STARR program for the 2016–2018 biennium, in accordance with methodology approved by the State of Texas Comptroller’s office, is \$160,258,918.03 (Table 1). Relative to total funding of \$9.9 million over the current biennium, STARR is revenue positive by a factor of 16.1x. To date, the STARR program has completed more than 60 field (reservoir characterization) studies Figure 1 shows the more than 20 field studies and more than 10 regional studies that were active in the 2014-2016 biennium. Figures 2 and 3 show the new field and regional studies, respectively, conducted during the 2016-2018 biennium, STARR initiated 13 field studies and 12 regional studies, of which 10 were in the Permian Basin.

Table 1. Summary of royalty and severance tax revenue from September 1, 2016, through September 30, 2018.
 Credit to the STARR program is in accordance with methodology approved by the Texas State Comptroller's office.

Regional Studies	Condensate (BBU)	Oil Well Head Value (\$)	Oil Severance Tax (4.6%)	Gas (MCF)	Gas well head value (\$)	Gas Severance Tax (7.5%)	Oil Severance (25%)	Gas Severance (25%)	Total Oil (\$)	Total Gas (\$)
Woodbine Cherokee/Anderson County	23901	1,537,962.97	69,208.33	187,799.00	552,979.22	41,473.44	17,302.08	10,368.36	17,302.08	10,368.36
Wilcox Greenhouse Deltas: South-Central Texas	354683	24,108,135.01	1,084,866.08	979,721.00	2,851,022.15	213,826.66	271,216.52	55,456.67	271,216.52	55,456.67
Wilcox Regional: Central Texas	182,354	9,052,230.74	407,350.38	4,829,197	14,672,746.94	1,100,456.02	103,837.60	275,114.01	101,837.60	275,114.01
Wilcox Group: Central to SE Texas	95,893	5,901,260.06	265,556.70	3,245,680	9,568,723.27	717,654.25	66,389.18	179,413.56	66,389.18	179,413.56
Eastern Shelf Permian Basin	144,782,110	7,877,384,900.27	354,482,320.51	290,116,954	866,305,188.17	64,972,889.11	88,620,580.13	16,743,222.28	88,620,580.13	16,743,222.28
Woodbine group Tyler & Polk Counties	669,118	33,133,018.43	1,490,985.83	5,348,647	16,071,426.89	1,205,357.02	372,746.46	301,339.25	372,746.46	301,339.25
Douglas/Tonkawa: Texas Panhandle	2,432,952	119,122,813.73	5,360,526.62	22,132,008	66,930,162.87	5,019,762.22	1,340,131.65	1,254,940.55	1,340,131.65	1,254,940.55
Cleveland/Marmaton: Texas Panhandle	47,448	2,520,407.68	113,418.35	224,701	677,011.50	50,775.86	28,354.59	12,693.97	28,354.59	12,693.97
Miocene: Refugio County area	40557204	2,554,133,623.51	114,936,013.06	100,084,295.00	294,022,495.22	22,051,687.14	28,734,003.26	5,512,921.79	28,734,003.26	5,512,921.79
Eagle ford/Buda/Austin/Chalk/Del Rio	14422032	928,376,813.35	41,776,956.60	55,640,069.00	163,710,283.06	12,278,271.23	10,444,239.15	3,069,567.81	10,444,239.15	3,069,567.81
Wolfcamp Southern Midland Basin	8885	41,098.64	1,849.44	895,794.00	456,030.92	34,202.32	462.36	8,550.58	462.36	8,550.58
Cotton Valley/East Texas Basin	51336	1,425,920.26	64,166.41	122,583.00	64,562.40	4,842.18	16,041.60	1,210.55	16,041.60	1,210.55
Glen Rose/East Texas Basin	1615122	10,596,231.64	476,830.42	8,544,474.00	4,268,628.00	320,147.10	119,207.61	80,036.78	119,207.61	80,036.78
Eagle Ford/La Salle Co. area	2790545	181,950,104.18	8,187,754.69	10,539,457.00	30,791,534.53	2,309,365.09	2,046,938.67	577,341.27	2,046,938.67	577,341.27
Wolfcamp (Core Workshop)									132,255,865.30	27,778,583.30
Regional Revenue (\$)										
160,034,448.60										
Field Studies	Condensate (BBU)	Oil Well Head Value (\$)	Oil Severance Tax (4.6%)	Gas (MCF)	Gas well head value (\$)	Gas Severance Tax (7.5%)	Oil Severance (100%)	Gas Severance (100%)	Total Oil (\$)	Total Gas (\$)
Douglas/Tonkawa: Lipscomb, Hemphill Counties	5236	248,195.88	11,168.81	39,645.00	115,326.68	8,649.50	2,792.20	2,162.38	2,792.20	2,162.38
San Miguel/Olmos, Maverick County	197,745	12,255,799.83	551,510.99	1,211,301	3,616,671.17	271,250.34	137,877.75	67,812.58	137,877.75	67,812.58
Wolfberry: Howard Glascock Irion Counties	17,726	870,216.63	39,159.75	71,563	215,176.98	16,138.27	9,789.94	4,034.57	9,789.94	4,034.57
Regional Revenue (\$)										
150,459.89										
Field Revenue (\$)										
224,469.42										
Regional Revenue (\$)										
160,034,448.60										
Total Revenue (\$)										
160,258,918.03										
Biennium Funding										
9,900,000.00										

STARR Studies: Active in 2014-2016

Field Studies



Regional Studies

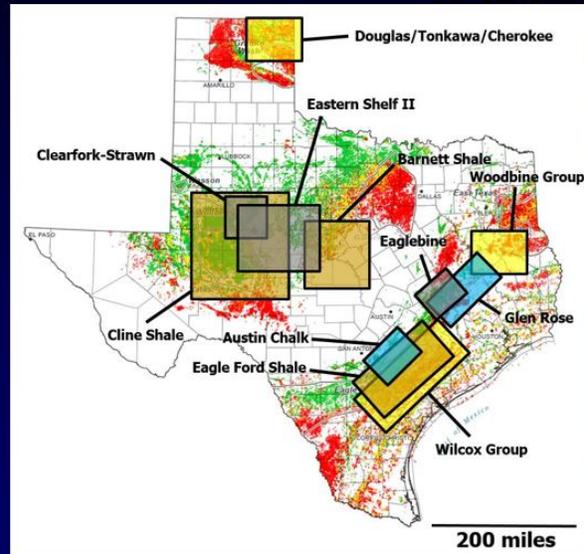


Figure 1. STARR field and regional studies in the 2014-2016 biennium. Color of box indicates dominant rock type: yellow (sandstone), blue (carbonate), brown (shale), and gray (mixed).

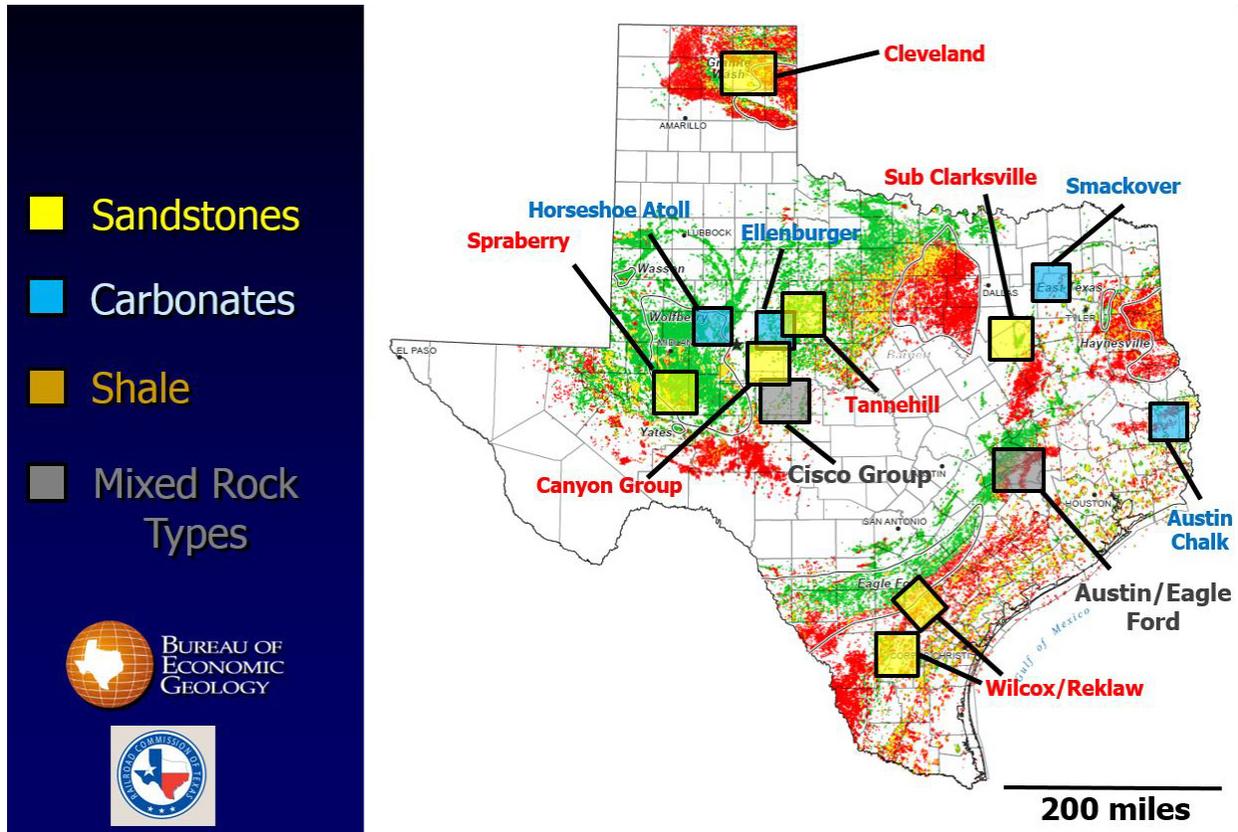


Figure 2. New STARR field studies in the 2016–2018 biennium. Color of box indicates dominant rock type: yellow (sandstone), blue (carbonate), brown (shale), and gray (mixed).

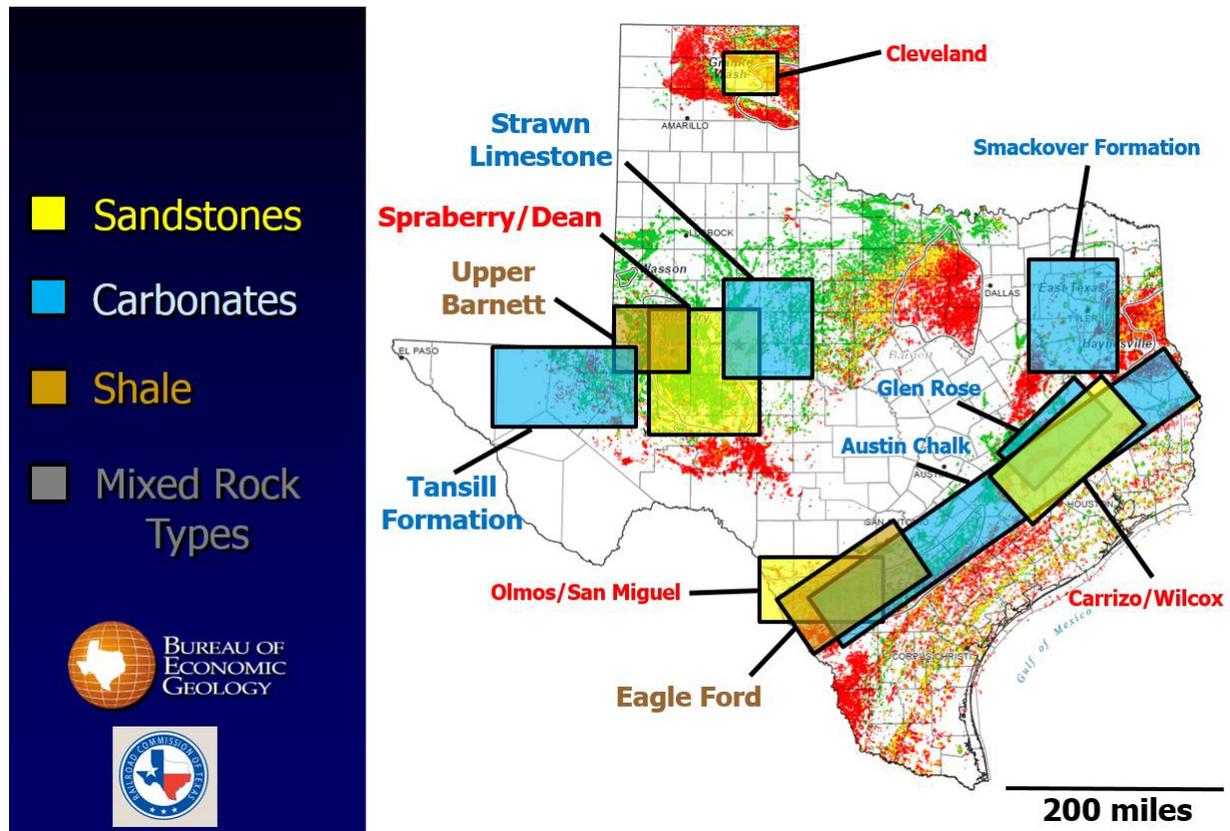


Figure 3. New STARR regional studies in the 2016–2018 biennium. Color of box indicates dominant rock type: yellow (sandstone), blue (carbonate), brown (shale), and grey (mixed).

INTRODUCTION

Texas has produced more oil and natural gas than any other state and has been the largest daily producer, with more than 3 MMbbl/d (million barrels per day) of oil and more than 9 Bcf/d (billion cubic feet per day) of gas in 2017. No other state, or other region worldwide, has been as heavily explored or drilled for oil and natural gas as Texas. In 2017, approximately 187,000 active oil wells and more than 99,000 active gas wells were producing oil and natural gas in the state (Texas Railroad Commission, 2018a and 2018b) (Fig. 4).

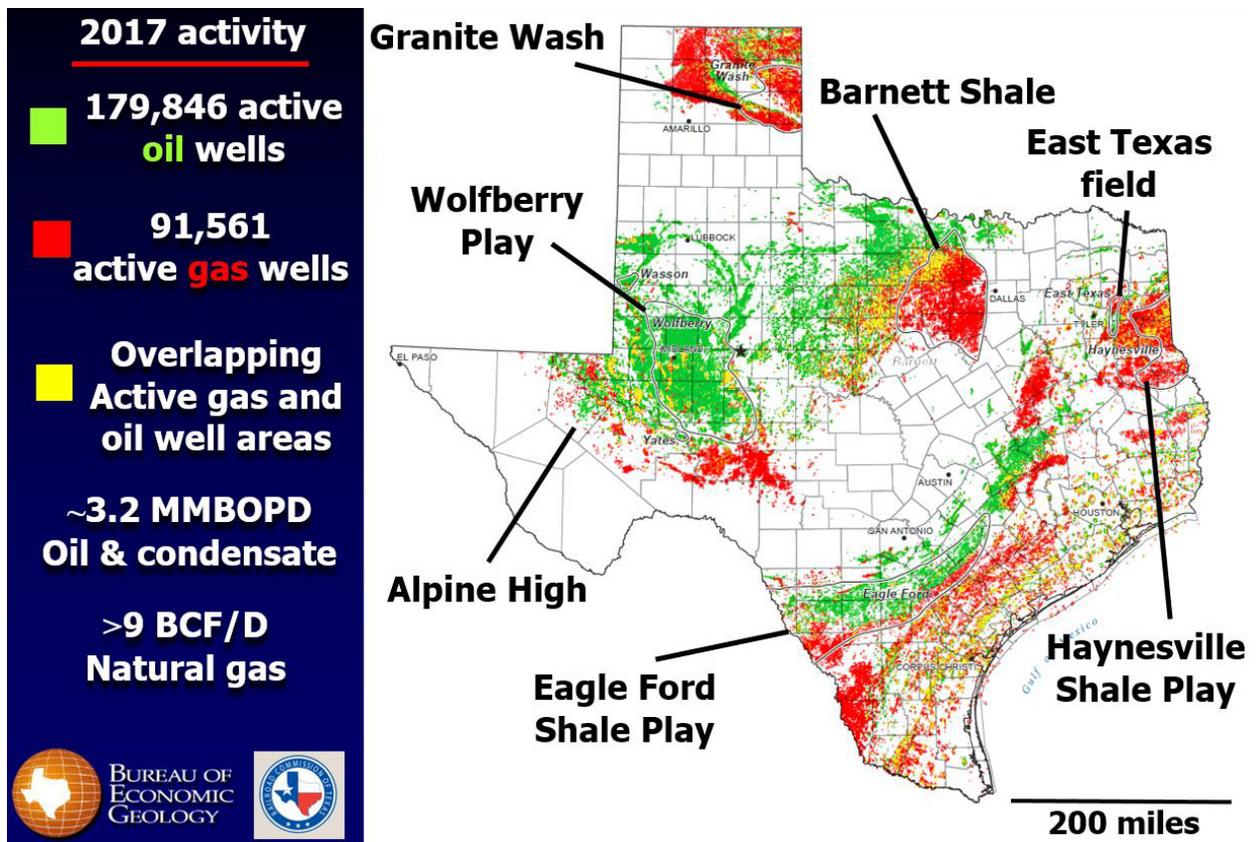


Figure 4. Oil and gas activity in Texas in 2017. Well-distribution data from the Texas Railroad Commission.

A variety of oil and gas companies request reservoir characterization and exploration assistance from STARR (see Letters of Cooperation, Appendix A). The Bureau of Economic Geology (BEG), with STARR funding from the State of Texas, provides technical support, identifying opportunities for increased production and associated reserves; these areas are then drilled by cooperating companies. STARR personnel provide assistance and advice to numerous operators on optimal development strategies, appropriate well-log suites, styles of reservoir heterogeneity and their effects on oil and gas recovery, and evaluation of exploration targets, as well as regional geology and unconventional resources.

STARR has a technology-transfer approach that includes workshops, presentations, and publications. Through technology transfer, we envision that many remaining oil and gas reserves in Texas will be explored and developed in future decades. STARR personnel have provided the public with numerous publications, workshops, and lectures. During the current 2016-2018 biennium, STARR personnel have produced a variety of publications and reports. These items are summarized in Appendix B. In addition, STARR personnel have given numerous presentations at a variety of meetings of professional geological societies in the current 2016-2018 biennium, disseminating project results to oil and gas operators. These items are listed in Appendix C.

During the 2016–2018 biennium, STARR personnel have given a variety of presentations and conducted reviews of core data for industry partners, including Gardner Energy Corporation, Haimo America, Inc., Harmonia Resources, Jones Energy, Latigo Producing, Oak Spring Energy, Prolifico Exploration, Riley Exploration, Inc., and Winchester Energy Limited, LLC. A list of other operators who have worked with STARR is in Table 2.

Table 2. STARR field studies, 1995 to present.

<u>Field</u>	<u>Operator</u>	<u>Period of Project STARR Interaction</u>
Keystone East field	Bass Enterprises, Hallwood Energy, Pioneer Natural Resources, Vista Resources	1995–1999
Geraldine Ford and Ford West fields (primary funding by U.S. Department of Energy)	Conoco, Incorporated	1995–1997
Lockridge, Waha, and Waha West fields (primary funding by U.S. Department of Energy and Gas Research Institute)	Shell Oil and Mobil Oil (now ExxonMobil)	1996–1998
Bar Mar field	Hanson Corporation	1997–1998
Ozona field	Union Pacific Resources, Cross Timbers Oil Co.	1996–1999
Duval County Ranch field	Killam Oil	1998–1999
Umbrella Point field	Panaco, Incorporated	1995–1999
Red Fish Bay field (shallow Frio)	Pi Energy	1996–1997
Corpus Christi East field (Frio)	Sabco Oil and Gas, Royal Exploration	1998–2000
Corpus Christi NW field (Frio)	Sabco Oil and Gas, Royal Exploration	1998–2000
Encinal Channel field (Frio)	Sabco Oil and Gas, Royal Exploration	1999–2000
Mustang Island 889 field (Frio)	Sabco Oil and Gas	2000–2001
Red Fish Bay field (Middle Frio)	IBC Petroleum, Cinco	2001–2008
Red Fish Bay field (Deep Frio)	Boss Exploration, Cinco	2003–2008
Mustang Island Offshore (Frio)	Cabot Oil and Gas	2003
Northeast Red Fish Bay project (Frio)	Cabot Oil and Gas	2003
Laguna Madre (Frio)	Novus	2004–2005
Yates field EOR (Permian)	Kinder Morgan	2004–2006
Galveston Bay Shelf area study (Frio)	Santos USA Corp	2004–2006
Carancahua and Matagorda Bay projects (Frio, Miocene)	Brigham Exploration Company	2004–2008
West Bay area study (Alligator Point field; Frio, Miocene)	Gulf Energy Exploration	2005–2007
LaSalle, Calhoun offshore (Frio)	Gulf Energy Exploration	2005–2007
Gold River North field (Olmos)	Huber	2006
Gold River North field (Olmos)	St. Mary's Land and Exploration	2007–2009
East Texas field (Woodbine)	Various operators	2006–2008
North Newark field (Barnett)	Various operators	2007–2009
Spur Lake and Broken Bone fields	Gunn Oil Co.	2007–2009
Mustang Island (Frio)	Sabco Operating Co.	2006–2008
Copano Bay	MPG Petroleum	2007–2009
East Texas field (Moncrief lease)	Danmark Energy	2007–2009
Sugarkane field	Texas Crude	2006–2008
Cleveland/Marmaton/Atoka field	Jones Energy, Ltd.	2008–2010
Lavaca Bay field	Neumin Production Company	2008–2010
Alabama Ferry field	Antioch Energy LLC	2009–2011
Haynesville	Petrohawk, Common Resources, BP	2009–2011
Spraberry/Wolfcamp (Midland County)	Pioneer Resources	2010–2012
Lavaca Bay field (Frio)	Neumin Production Co.	2010–2012
Eliasville/Breckinridge fields (Caddo Limestone)	BASA Resources	2011–2013
Dismukes field (Dimmit County: Austin Chalk/Eagle Ford Shale)	CML Exploration	2011–2013
Sugar Creek field (Austin Chalk/Woodbine)	BBX Operating	2011–2013
Double A Wells field (Woodbine)	Vision Resources	2011–2013
K-R-S field (Marble Falls Limestone)	Cobra Oil and Gas, Stalker Energy	2011–2013
Bend Conglomerate (Wise County)	Devon Energy	2011–2013

La Sara field (Frio)	Risco La Sara Operations	2011–2013
Ranger Limestone (Eastland County)	Stalker Energy	2011–2013
Austin Chalk (Dimmit County)	Newfield Exploration Company	2011–2013
Frio Formation (Refugio County)	T-C Oil Company	2012–2014
Cleveland/Marmaton/Granite Wash (Hemphill County)	Devon Resources, Arête Resources,	2012–2014
Woodbine Group (Leon County)	Risco La Sara Operations, Chesapeake Energy	2012–2014
Woodbine Group (Walker County)	Chesapeake Energy	2012–2014
Cisco Limestone (Tom Green County)	AEATX	2012–2014
Pearsall Formation (McMullen, Dimmit Counties)	Valence, Devon	2012–2014
San Angelo Sandstone (Irion County)	Renda Energy	2012–2014
Atoka/Cherokee Group (Ochiltree, Lipscomb, Hemphill Counties)	Arête Resources	2012–2014
Mississippian Lime (Shackelford, Stephens, Throckmorton, Young Counties)	Tracker Resources	2012–2014
Glorieta Group (Ward County)	Whiting Resources	2012–2014
Harkey, Swastika, Cline Woodbine/Eagle Ford (Polk County)	BP	2012–2014
Woodbine Group (Tyler County)	BP	2012–2014
ClearFork Formation (Iatan field)	BASA Resources	2013–2015
Buda Limestone (Dimmit County)	US Enercorp	2013–2015
Tonkawa, Douglas Formations (Hemphill County)	Chesapeake Energy	2013–2015
Woodbine Group (AA Wells, Hortense fields)	Apache Corporation	2013–2015
Pettet Limestone (Anderson County)	Arête Resources	2013–2015
Woodbine Group (East Texas field)	Zone Energy	2013–2015
Woodbine Group (Kerens, South field)	Five Star Energy	2013–2015
Wilcox Group (Bee, Goliad Counties)	Excellong	2013–2015
Wolfcamp Formation (Howard County)	Excellong	2013–2015
Eaglebine Trend (Fayette County)	Devon Resources	2014–2016
Marble Falls Formation (Jack County)	Atlas Resource Partners	2014–2016
ClearFork/Spraberry/Wolfcamp (Howard, Borden, Scurry Counties)	Harmonia Inc.	2014–2016
Wilcox Group (Bee County)	Formosa Petrochemical	2014–2016
Douglas/Tonkawa Formations (Lipscomb County)	Jones Energy	2014–2016
Wilcox Group (Lavaca County)	Imagine Resources LLC	2014–2016
Spraberry/Dean/Wolfcamp (Howard County)	Haimo America Inc.	2015–2017
Nowack/Thrall (Williamson County)	Trinity Brothers	2015–2017
Serbin (Bastrop/Lee Counties)	Riley Exploration	2015–2017
Wolfcamp Formation (Howard County)	Anadarko Petroleum	2016–2018
Thrall (Williamson County)	Patriot Operating Co.	2016–2018
Ellenburger (Nolan County)	Winchester Energy Limited	2016–2018
San Miguel/Olmos (Maverick County)	Endeavor Natural Gas LP	2016–2018
Smackover Formation (Rains County)	Dyersdale Energy	2016–2018
Reinecke Horseshoe Atoll (Borden County)	Harmonia. Inc.	2016–2018
Cleveland Formation (Hansford County)	Latigo Producing	2016–2018
Austin Chalk/Eagleford (Fayette County)	Oak Spring Energy	2016–2018
Wilcox/Carrizo (Grimes County)	Prolifico Exploration	2016–2018
Austin Chalk (Jasper County)	Fourhorses LLC	2016–2018
Tannehill Sandstone (Nolan/Taylor Counties)	TrayCon Exploration	2016–2018
Spraberry Formation (Reagan/Martin Counties)	De la Terrsa Exploration	2016–2018
Wilcox/Reklaw (Duval County)	Stalker Energy	2016–2018

STARR REVENUE-NEUTRALITY METRICS

An important goal of the STARR program is to demonstrate revenue neutrality for the Texas State Comptroller's office, with each reporting biennium to be considered for funding in the next biennium. STARR's revenue neutrality is calculated for two years. Royalties for the State and severance taxes are accounted for in revenue-neutrality calculations (Table 3). This metrics table was developed in conjunction with the Texas State Comptroller's office in 2004 and slightly modified following discussion with the Comptroller's office in 2006.

Revenue values summarized in Table 1 are derived from total production in areas defined by either field or regional studies during the present biennium. The total revenue value is the total production multiplied by the price of oil and gas for a given month and totaled in the oil and gas well head value. The State Comptroller's office provides severance tax values for the different fields and regional plays, and this number is applied to the total well head value. STARR involvement in regional plays allows the Bureau of Economic Geology to sum up 25% of the severance tax, whereas severance-tax credit for STARR field studies are at a full 100% value (Table 3). The Total revenue in Table 1 is the summation of this process for every regional and field study.

Table 3. Project STARR revenue-neutrality metrics.

Type of STARR recommendation	Expiration period following recommendation (Initial/incremental production must begin before recommendation expires)	Time period for credit following initial production	Royalty credit	Severance tax credit
1. Drilling new infill or step-out well in established field	4 years	2 years	100%	100%
2. Drilling new infill or step-out well in established field with multiple reservoir intervals	4 years	2 years following completion of each additional reservoir interval	100%	100%
3. Recompletion—missed pay well in established field	4 years	2 years	100%	100%
4. Enhanced oil recovery (EOR) field project	4 years	2 years following date selected by STARR within a 5-year period from initial operator action	100% of incremental production	100% of incremental production
5. Exploration well	4 years	2 years	100%	100%
5.a. Subsequent development wells following discovery of new field	2 years following initial production from exploration well	2 years	100%	100%
5.b. Copycat wells following discovery of new field	2 years following initial production from exploration well	2 years	25%	25%
6. Wells drilled on basis of influence of regional trend studies	4 years starting 6 months after releasing study	2 years	25%	25%

Note: Royalty credit accrues only from production on State GLO (General Land Office) Lands. Severance tax credit accrues from production anywhere in Texas.

BIENNIUM HIGHLIGHTS

- STARR is revenue positive by a net factor of 16.1. Credit to the STARR program for the 2016–2018 biennium, in accordance with methodology approved by the Texas State Comptroller’s office, is \$160,258,918.03. The high positive revenue factor is chiefly because of drilling activity in the unconventional Spraberry-Wolfcamp (Wolfberry) play in the Permian Basin and Eagle Ford unconventional oil and shale-gas play in southwest Texas, as well as other active oil and gas plays in the Gulf Coast.
- A wide variety of new reservoir characterization projects (field studies) (fig. 2) and regional studies (fig. 3) contributed to the successful completion of new wells and improved oil- and gas-recovery strategies. A partial list of examples of field studies includes the Spraberry Formation, Tannehill Sandstone, and Ellenburger and Cisco Groups in the Permian Basin; The Smackover Formation, Austin Chalk, and Eagle Ford Shale in the East Texas Basin; and the Wilcox Group and Reklaw Formations in south Texas. Results of the field study of the Wilcox Group and Reklaw Formations were published in the Bureau of Economic Geology Report of Investigations No. 284 (Ambrose et al., 2018).
- STARR’s regional studies of the Spraberry, Wolfcamp, and Dean Formations in the Permian Basin provided a detailed and comprehensive framework for continued successful drilling of tight-oil reservoirs in one of the most productive unconventional trends in Texas. Results were published in the Bureau of Economic Geology Reports of Investigations No. 281 and 282 (Hamlin and Baumgardner and Hamlin, 2016; Hentz et al. 2017, respectively).
- A regional study of the Austin Chalk trend in the Texas Gulf Coast focused on lithologic and diagenetic controls on reservoir quality in this recently renewed play where horizontal wells have led to significantly increased oil and gas production.

REFERENCES CITED

Texas Railroad Commission, 2018a, Crude oil production and well counts (since 1935): <http://www.rrc.state.tx.us/oil-gas/research-and-statistics/production-data/historical-production-data/crude-oil-production-and-well-counts-since-1935/>, last accessed May 3, 2018.

Texas Railroad Commission, 2018b, Natural gas production and well counts (since 1935): <http://www.rrc.state.tx.us/oil-gas/research-and-statistics/production-data/historical-production-data/natural-gas-production-and-well-counts-since-1935/>, last accessed May 3, 2018.

APPENDIX A

Letters of Cooperation

The following selected letters are from partner companies with whom the STARR program has recently collaborated. These letters document the strong interaction between STARR and the oil and gas industry.



William Ambrose
Project Director
STARR Project
Bureau of Economic Geology
Jackson School of Earth Sciences
The University of Texas at Austin
P. O. Box X, UT Station
Austin, Texas 78713

7/1/2018

Dear Mr. Bill Ambrose:

I would like to acknowledge the contributions made to our oil and gas exploration program for the Austin Chalk and Eagle Ford Shale (Mudstone) through core research carried out and published by the State of Texas Advanced Resource Recovery project (STARR) at the Texas Bureau of Economic Geology. The published and unpublished works by STARR has helped in a variety of areas:

- 1) Understanding the greater Houston Embayment east of the San Marcos Arch was researched by Tucker Hentz in the Report of Investigations No 274.
 - a. Having not worked this area before in my career, the research conducted by the BEG allowed me to quickly become collaborative with my fellow associates and researchers across the play who have worked this trend their entire career.

- 2) Utilizing the core repository, especially core from the City Services Ivy B #1 well (API# 42149305680000), this research allowed me to more fully understand the geology directly east of the San Marcos Arch. This updip core on the Austin Chalk Trend allowed me to differentiate the lower Austin Chalk ash beds from source beds. By investigating the mudstone stratigraphy of the Eagle Ford formation, this study allowed me to construct a work flow on its depositional environment.
 - a. Placing eyes on the core allows the geologist to more fully integrate workflows on the stratigraphy and structure of the wellbore than through advanced logs alone.

- 3) The continued professional contacts at the BEG has made it possible for the inflow and outflow of knowledge.
- 4) The work researched by the BEG allows for regional workflows to be carried out by linking stratigraphic and structural studies away from my own specific research.

In summary, the BEG's presentations, publications, research, and studies have provided an educational insight into many advancements within petroleum exploration, which have been successfully applied to our own areas of interests. This specifically demonstrates the STARR's ability to turn academic studies into economic successes. The BEG's continued interest in depositional systems within Texas, will only prove time and time again, that the research conducted at the BEG financially benefits all areas of academia, including the petroleum industry.

Respectfully submitted,

Nicolas O. Brissette, CPG #6211
Petroleum Geologist
President SWS AAPG



Lowell D. Fuller

Prolifico

Exploration.

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8017

Email:

ldfuJierl@aol.com

February 19, 2018

To: Interested Onshore Oil & Natural Gas Exploration Parties

For approximately 15 years, I have researched the field potential of "onshore frontier wildcat exploration." Giant size new field discoveries have been a priority.

I have accumulated all accessible geological books & publications, etc. through libraries and other sources.

Extensive and continuous studying has yielded quality geo comparative analysis worldwide to our onshore oil and gas exploration potential.

Through my studies, I have concluded that the Lower Cretaceous Reefs and Pre-Cambrian Fractured Granite Basement reservoirs have the greatest underexplored potential.

Over-Pressured-BPHT-H₂S reservoirs should be engineered accordingly.

When I began my study and research, Sigrid Clift was my Information Geologist at BEG. Beginning in January 2016, Bill Ambrose assisted by Sigrid Clift became my Research Scientists through the STARR Project at BEG.

Their work has been and continues to be of utmost importance in my endeavor.

Interested Exploration Parties will be expected to accept these considerations:

- a. Proprietary Data
- b. Confidentiality
- c. Intellectual Property
- d. Conflicts of Interest
- e. "Tite-Hole" Exploration

Prolifico Exploration is seeking prolific "Wild Cat" New Oilfield Discoveries!

L. D. Fuller
Principal-Senior Adviso



Mr. William Ambrose
Project Director
STARR Project
Bureau of Economic Geology
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October 24th, 2016

Dear Mr. Ambrose:

I would like to acknowledge the contributions made to our oil and gas exploration programs in the Texas Panhandle by research carried-out and published by the State of Texas Advanced Resource Recovery project (STARR) at the Bureau of Economic Geology. Through the STARR program's core workshops, as well as published and unpublished research, we at Jones Energy have broadened our geologic understanding of numerous Pennsylvanian-age hydrocarbon prospects in the western Anadarko Basin. Staff members on the STARR project a proven record of expertise in the study of depositional systems, sequence stratigraphy, diagenesis and other controls on reservoir quality --and their work reflects that.

The STARR project is a great resource for those actively exploring for, and developing oil and gas in the state of Texas and I hope that they remain able to operate in perpetuity.

Kind regards,

Logan Tussey
Geologist
Jones Energy, Inc.



BUREAU OF
ECONOMIC
GEOLOGY

William Ambrose
Project Director
STARR Project
Bureau of Economic Geology
Jackson School of Earth Sciences
The University of Texas at Austin
P. O. Box X, UT Station
Austin, Texas 78713

October 26, 2016

Dear Mr. Ambrose:

I would like to acknowledge the contributions made to our oil and gas exploration program in both the Eastern Shelf and the Permian Basin by research carried out and published by the State of Texas Advanced Resource Recovery project (STARR) at the Texas Bureau of Economic Geology. The published and unpublished work by STARR has helped in a variety of areas:

- 5) Tucker Hentz's original research carried south from Frank Brown's 1990 Report of Investigations No. 197, has allowed for greater understanding of shelf margin development along the Eastern Shelf.
- 6) Independent work and research conducted by Tucker Hentz at the BEG, has allowed independent operators, with limited exploration budgets and staff, to cross check their own research with the BEG.
- 7) The Lower Permian to Upper Pennsylvanian Sequence Stratigraphic framework research has aided in correctly naming and identifying formation tops along the Eastern Shelf.
- 8) Continued professional contacts at the BEG has made it possible for the inflow and outflow of knowledge.

- 9) The work carried out at the BEG allows for further, in the greater regional context, on how the developments of major leading stratigraphic and structural geologic settings develop away from my own research.
- 10) One of the best examples of collaboration was when I talked with Tucker Hentz at the SWS-AAPG in Abilene, Texas back in 2016. His research, conducted 100% independent of my research on the Eastern Shelf, we both found that designated shelf margin outlines, and formation tops were comparable throughout the project database. Not only did his research provide confidence in my picking and data base building, it reinforced Tucker Hentz's work that independent oil and gas geologists were on the "Same track" as his work conducted at the BEG. This not only supports and reinforces our efforts to keep building our database correctly, it allows the BEG to directly bridge independent works from academia to industry.

In summary, the BEG's presentations, publications, research, and studies have provided an education and insight to many recent advances in petroleum exploration that has been successfully applied to our areas of interests. This specifically demonstrates the STARR program's ability to turn academic studies into economic success. The BEG's continued interest in depositional systems in Texas, will only prove time and time again, that the research conducted at the BEG is financially beneficial to all areas of academia and to the petroleum industry.

Respectfully submitted,



Nicolas O. Brissette, CPG 6211
Petroleum Geologist
Delta Oil and Gas



November 10th, 2016

Dr. William Ambrose
Project Director
STARR Project
Bureau of Economic Geology
Jackson School of Earth Sciences
The University of Texas at Austin
P. O. Box X, UT Station
Austin, Texas 78713

November 10, 2016

Dear Dr. Ambrose:

I would like to acknowledge the contributions made to our Ellenburger oil project in Nolan County, Eastern Shelf Permian basin by research carried out by the State of Texas Advanced Resource Recovery project (STARR) at the Texas Bureau of Economic Geology. Work carried out to interpret the 3D seismic, review image and log data and to compare with analog research projects has assisted greatly in refining the geological model in our area and highlighting uncertainties from the data which when further evaluated will help to improve our understanding of the entire Ellenburger section in our area and it's production potential.

In addition through access to publications and insights from research team members over the course of the project the Bureau has provided an education of the latest research into karst petroleum systems which has been of great benefit to independent companies such as ourselves who do not have the benefit of access to major geologic research programs.

Best Regards,

A handwritten signature in black ink, appearing to read 'Neville Henry', is written over a light blue horizontal line.

Neville Henry
MD/CEO
Winchester Energy Limited

Cc: file

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APPENDIX B

STARR Publications

One of the major goals of Project STARR is to disseminate results and new concepts developed by the program. During the first eighteen months of the current reporting biennium (2016–2018), STARR researchers generated a wide variety of publications.

Ambrose, W. A., Dutton, S. P., and Loucks, R. G., 2016, Depositional systems, facies variability, and reservoir quality in shallow-marine reservoirs in the Eocene Upper Wilcox Group in Fandango field, Zapata County, Texas: *GCAGS Journal*, v. 5, p. 73-94.

Ambrose, W. A., Dutton, S. P., and Loucks, R. G., 2017, Depositional systems, facies variability, and their relationship to reservoir quality in the Jurassic Cotton Valley Group, Texas, Louisiana, and Mississippi onshore Texas Gulf Coast: *GCAGS Journal*, v. 6, p. 21-46.

Ambrose, W. A., and Zeng, H., 2016, Wave-dominated shoreface systems in the Lower Luling Sand, Northern Bee County, South Texas: *South Texas Geological Society Bulletin*, v. 57, no. 3, p. 32-44.

Ambrose, W. A., Zeng, H., Zhang, J., Olariu, M. I., Smith, D., and Clift, S. J., 2018, Depositional history and stratigraphic evolution of the Upper Wilcox Group and Reklaw Formation, northern Bee County, Texas: Bureau of Economic Geology, The University of Texas at Austin, Report of Investigations No. 284, 87 p., doi.org/10.23867/RIO284D.

Baumgardner, R. W., Jr., Hamlin, H. S., and Rowe, H. D., 2016, Lithofacies of the Wolfcamp and lower Leonard intervals, southern Midland Basin, Texas: Bureau of Economic Geology, Report of Investigations, no. 281, 67 p.

Brown, L. F., Jr., Ambrose, W. A., Hentz, T. F., and Carr, D. L., Guidebook to the Pennsylvanian system of north-central Texas: The University of Texas at Austin, Bureau of Economic Geology and the Austin Geological Society, Field Trip Guidebook, 49 p.

Dutton, S. P., Ambrose, W. A., and Loucks, R. G., 2016, Diagenetic controls on reservoir quality in deep upper Wilcox sandstones of the Rio Grande delta system, South Texas: *GCAGS Journal*, v. 5, p. 95-110.

Dutton, S. P., Ambrose, W. A., Horodecky, B. B., and Loucks, R. G., 2017, Regional trends in diagenesis and reservoir quality of Jurassic Cotton Valley sandstones, northern Gulf of Mexico Basin: *GCAGS Journal*, v. 6, p. 47-62.

Eluwa, A., Mohrig, D., Ogiesoba, O. C., and Ambrose, W. A., 2018, Depositional settings and history of the Lower Miocene Fleming Group, Refugio County, Texas, as defined using seismic geomorphology: *Marine and Petroleum Geology*, v. 92, p. 565-581, <http://doi.org/10.1016/j.marpetgeo.2017.11.021>.

- Fu, Q., Ambrose, W. A., and Barton, J. W., 2017, Reservoir characterization of the Pennsylvanian Caddo Limestone in Stephens County, Texas: a case study of Komia-dominated algal mounds: *Marine and Petroleum Geology*, v. 86, p. 991-1013, <http://doi.org/10.1016/j.marpetgeo.2017.06.040>.
- Hentz, T. F., Ambrose, W. A., and Hamlin, H. S., 2016, Upper Pennsylvanian and Lower Permian shelf-to-basin facies architecture and trends, Eastern Shelf of the southern Midland Basin, West Texas: *AAPG Search and Discovery*, no. 10847, 6 p.
- Hentz, T. F., Ambrose, W. A., and Hamlin, H. S., 2017, Upper Pennsylvanian and Lower Permian shelf-to-basin facies architecture and trends, Eastern Shelf of the southern Midland Basin, West Texas: *Bureau of Economic Geology, Report of Investigations*, no. 282, 68 p.
- Hentz, T. F., Ambrose, W. A., Palacios, F. C., and Baumgardner, R. W., Jr., 2017, Upper Pennsylvanian and Lower Permian shelf, slope, and basin depositional facies of the southern Eastern Shelf of the Midland Basin, *in* Hentz, T. F., ed., *Upper Pennsylvanian and Lower Permian shelf, slope, and basin depositional facies of the southern Eastern Shelf of the Midland Basin: core workshop*: Bureau of Economic Geology, The University of Texas at Austin, Workshop No. SW0023, 38 p.
- Hessler, A. M., Zhang, J., Covault, J., and Ambrose, W. A., 2017, Continental weathering coupled to Paleogene climate changes in North America: *Geology*, v. 45, no. 10, p. 911-914, <http://doi.org/10.1130/G39245.1>.
- Loucks, R. G., and Fu, Q., 2016, Origin and characterization of the lithofacies and dual micropore/macropore network in Pennsylvanian (early Desmoinesian) Caddo shelf-buildup complexes, Stephens County, north-central Texas: *GCAGS Journal*, v. 5, p. 1-24.
- Loucks, R. G., and Reed, R. M., 2016, Natural microfractures in unconventional shale-oil and shale-gas systems: real, hypothetical, or wrongly defined?: *GCAGS Journal*, v. 5, p. 64-72.
- Loucks, R. G., Frébourg, G., and Rowe, H. D., 2017, Upper Cretaceous (Campanian) Ozan and Annona Chalks in Caddo-Pine Island Field, northwestern Louisiana: depositional setting, lithofacies, and nanopore/micropore network: *GCAGS Journal*, v. 6, p. 73-91.
- Loucks, R. G., Kerans, C., Zeng, H., and Sullivan, P. A., 2017, Documentation and characterization of the Lower Cretaceous (Valanginian) Calvin and Winn carbonate shelves and shelf margins, onshore northcentral Gulf of Mexico: *AAPG Bulletin*, v. 101, no. 1, p. 119-142, <http://doi.org/10.1306/06281615248>.
- Ogiesoba, O. C., and Ambrose, W. A., 2017, Seismic attributes investigation of depositional environments and hydrocarbon sweet-spot distribution in Serbin field, Taylor group, central Texas: *SEG Technical Program Expanded Abstracts*, p. 2274, <http://doi.org/10.1190/segeab.36>.

- Ogiesoba, O. C., 2016, Application of the instantaneous quality factor (Q) in the characterization of the Austin Chalk and Eagle Ford Shale, South Texas: AAPG Search and Discovery Article #41781, 31 p.
- Ogiesoba, O. C., 2017, Application of thin-bed indicator and sweetness attribute in the evaluation of sediment composition and depositional geometry in coast-perpendicular subbasins, South Texas Gulf Coast: Interpretation, v. 5, no. 1, p. T87-T105, <http://doi.org/10.1190/INT-2015-0213.1>.
- Ogiesoba, O. C., and Klovov, A., 2017, Examples of seismic diffraction imaging from the Austin Chalk and Eagle Ford Shale, Maverick Basin, South Texas: Journal of Petroleum Science and Engineering, v. 157, p. 248-263, <http://doi.org/10.1016/j.petrol.2017.07.040>.
- Olariu, M. I., and Ambrose, W. A., 2016, Process regime variability across growth faults in the Paleogene Lower Wilcox Guadalupe Delta, South Texas Gulf Coast: Sedimentary Geology, v. 341, p. 27-49, <http://doi.org/10.1016/j.sedgeo.2016.05.013>.
- Olariu, M. I., Ambrose, W. A., Clift, S. J., Clayton, A., Shunli, L., Olariu, C., Steel, R. J., Zeng, H., and Zhang, J., 2016, Architectural variability and depositional trends in the Wilcox Group in Texas: Bureau of Economic Geology, 75 p.
- Olariu, M. I., and Zeng, H., 2018, Prograding muddy shelves in the Paleogene Wilcox deltas, south Texas Gulf Coast: Marine and Petroleum Geology, v. 91, p. 71-88, <http://doi.org/10.1016/j.marpetgeo.2017.12.027>.
- Phelps, R., Kerans, C., and Loucks, R. G., 2017, Reply to the discussion by Rose of Phelps et al. (2014) "Oceanographic and eustatic control of carbonate platform evolution and sequence stratigraphy on the Cretaceous (Valanginian-Campanian) passive margin, northern Gulf of Mexico," Sedimentology, 61, 461-496: Sedimentology, v. 64, p. 858-870, <http://doi.org/10.1111/sed.12324>.
- Reed, R. M., 2017, Organic-matter pores: new findings from lower-thermal-maturity mudrocks: GCAGS Journal, v. 6, p. 99-110.
- Zeng, H., Ambrose, W. A., and Xu, W., 2016, Sediment dispersal patterns of the outer shelf to upper slope Paleocene-Eocene Wilcox Group, south-central Texas coast: GCAGS Journal, v. 5, p. 215-237.
- Zhang, J., Steel, R., and Ambrose, W., 2016, Greenhouse shoreline migration: Wilcox deltas: AAPG Bulletin, v. 100, no. 12, p. 1803-1831.
- Zhang, J., Covault, J., Pyrcz, M., Sharman, G. R., Carvajal, C., and Milliken, K., 2018, Quantifying sediment supply to continental margins: applications to the Paleogene Wilcox Group, Gulf of Mexico: AAPG Bulletin, doi: 10.1306/01081817308.

APPENDIX C

STARR Presentations

One of the major goals of Project STARR is to disseminate results and new concepts developed by the program. During the first eighteen months of the current reporting biennium (2016–2018), STARR researchers gave a variety of presentations and workshops to oil and gas operators, a vital outreach activity impacting new oil and gas production in Texas.

Ambrose, W. A., 2016, Depositional systems, facies variability, and their relationship to reservoir quality in the Eocene Upper Wilcox Group in Fandango field, Zapata County, Texas: presented at 66th Annual GCAGS Convention, Corpus Christi, Texas, September 19.

Ambrose, W. A., 2016, Carl No. 1 Gillette and Apache No. 1-B Tips cores, Bee County, Texas: presented at Bureau of Economic Geology, Jackson School of Geosciences, and Austin Geological Society core workshop, Austin, Texas, October 20.

Ambrose, W. A., 2017, Depositional history of the upper Wilcox Group and lower Reklaw Formation, northern Bee County, Texas: presented to South Texas Geological Society, San Antonio, Texas, March 8.

Ambrose, W. A., 2017, Regional depositional framework of the southern part of the Eastern Shelf of the Permian Basin: presented to San Angelo State University undergraduate students, presented at Bureau of Economic Geology, Austin, Texas, April 7.

Ambrose, W. A., 2017, Stratigraphic framework and depositional systems of the Canyon and Cisco Group, Eastern Shelf of the Permian Basin: presented to Abilene Geological Society, Abilene, Texas, April 20.

Ambrose, W. A., 2017, STARR oil and gas program overview: presented to The University of Texas, Geology Foundation Advisory Council, presented at Bureau of Economic Geology, Austin, Texas, April 28.

Ambrose, W. A., 2017, Oil and gas in Texas: new life from old plays, new frontiers: presented to TCEQ Trade Fair, Austin, Texas, May 16.

Ambrose, W. A., 2017, STARR oil and gas program overview: presented to members and staff of the Texas State Government, presented at Bureau of Economic Geology, Austin, Texas, June 6.

Ambrose, W. A., 2017, The BEG STARR program: oil and gas for Texas: presented to SIPES, Corpus Christi Chapter, Corpus Christi, Texas, September 26.

- Ambrose, W. A., 2017, Slope channel and levee systems: Texaco No. 1-D Sterling, Sterling County, Texas: presented to Austin Geological Society, presented at BEG-STARR and Austin Geological Society core workshop: Shelf-to-Basin Architecture, Depositional Systems, and Facies Variability of the Southern Eastern Shelf of the Permian Basin, Austin, Texas, October 24.
- Ambrose, W. A., 2017, Depositional systems, facies variability, and their relationship to reservoir quality in the Jurassic Cotton Valley Group, Texas, Louisiana, and Mississippi onshore Gulf Coast: presented at the annual GCAGS convention, San Antonio, Texas, November 3.
- Ambrose, W. A., 2018, State of Texas advanced oil and gas resource recovery program: presented at the 9th East Texas Energy Symposium, Kilgore, Texas, May 1.
- Ambrose, W. A., 2018, Oil and Gas Resources and Challenges: Local and Global Perspectives: presented at the TCEQ Trade Fair and Conference, Austin, Texas, May 15.
- Ambrose, W. A., 2018, Depositional history and shoreline evolution of the upper Wilcox Group and lower Reklaw Formation, Northern Bee County, Texas: presented at the 2018 Annual AAPG Convention, Salt Lake City, Utah, May 23.
- Ambrose, W. A., 2018, State of Texas advanced oil and gas resource recovery program: presented to staff members of Texas State Representative Four Price, Austin, Texas, May 25.
- Hentz, T. F., 2016, Depositional and stratigraphic perspectives of the King, Lower Hope, Upper Hope, and Tannehill sandstones, Upper Pennsylvanian and Lower Permian strata of the southern half of the Eastern Shelf: presented to Williston Basin Exploration, Austin, Texas, September 2.
- Hentz, T. F., 2016, Texas field, New interpretations of reservoir architecture of the Upper Cretaceous Woodbine Group in East: Sequence stratigraphic and depositional perspectives: presented to SIPES, San Antonio Chapter, San Antonio, Texas, October 20.
- Hentz, T. F., 2016, Depositional framework of the Canyon and Cisco Groups (Upper Pennsylvanian –Lower Permian), southern part of the Eastern Shelf of the Midland Basin: presented to Pioneer Energy, Austin, Texas, October 27.
- Hentz, T. F., 2017, Cleveland and Marmaton tight-gas sandstones: sequence framework, depositional facies, and production trends, northwest Anadarko Basin: presented to the Panhandle Geological Society, Amarillo, Texas, April 5.
- Hentz, T. F., 2017, Stratigraphic framework and depositional systems of the Canyon and Cisco Groups, Eastern Shelf of the Permian Basin: presented to SIPES (Austin Chapter), Austin, Texas, May 4.

- Hentz, T. F., 2017, Depositional history and sequence framework of the Upper Pennsylvanian Cleveland Formation, Anadarko Basin, Texas: presented to Latigo Petroleum, LLC, Austin, Texas, October 6.
- Hentz, T. F., 2017, Depositional systems and architecture of the Canyon and Cisco Groups, Eastern Shelf of the Permian Basin: presented at core workshop sponsored by the Bureau of Economic Geology and the Austin Geological Society, Austin, Texas, October 24.
- Hentz, T. F., 2017, Depositional facies of the Cleveland and Marmaton Groups: a core study: presented to Latigo Petroleum, LLC, Austin, Texas, November 10.
- Hentz, T. F., 2017, Upper Pennsylvanian and Lower Permian shelf-to-basin facies architecture and trends, Eastern Shelf of the southern Permian Basin, West Texas: presented to SIPES, San Antonio Chapter, San Antonio, Texas, November 16.
- Hentz, T. F., 2018, High-resolution facies distribution, structural controls on sedimentation, and production trends of the Pennsylvanian Bend Conglomerate, Boonsville field, Fort Worth Basin, Texas: presented to the Abilene Geological Society, Abilene, Texas, April 19.
- Loucks, R. G., 2017, Fractures, faults, and karst caverns: architecture of the non-matrix reservoir elements, Longhorn Caverns, Texas, Mountjoy Carbonate Research Conference, Marble Falls, Texas, June 27.
- Ogiesoba, O. C., 2016, Seismic multiattribute analysis for shale gas/oil within the Austin Chalk and Eagle Ford Shale in a submarine volcanic terrain, Maverick Basin, South Texas: presented at Sanchez Oil and Gas Corporation, Houston, Texas, December 1.
- Ogiesoba, O. C., 2017, Seismic attributes investigation of depositional environments and hydrocarbon sweet-spot distribution in Serbin field, Taylor group, Central Texas: presented to Society of Exploration Geophysicists, presented at 87th SEG International Exposition and Annual Meeting, Houston, Texas, September 27.
- Olariu, M. I., 2016, Process regime change from wave-modified and tidally-Influenced to wave-dominated deltas across growth faults in the Paleogene Lower Wilcox Guadalupe Delta, South Texas Gulf Coast: presented to Bureau of Economic Geology, presented at Annual Bureau Research Symposium, Austin, Texas, September 16.

ADDITIONAL PROGRAM ELEMENTS

STARR WATER/ENERGY NEXUS

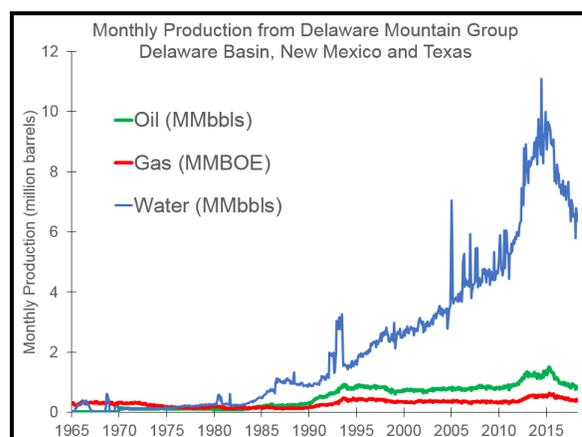
OVERVIEW AND GOALS OF PROJECT

For the last several years, the water/energy research by the BEG in State of Texas has focused on several specific areas, including water use in drilling and hydraulic fracturing operations and disposal of wastewater through UIC Class II wells. Wastewater management is a significant issue in Texas. Disposal of salt water through wells is the dominant management option, versus treatment and/or transport; but, large-scale disposal has been identified as triggering earthquakes, and this requires significant research to understand where and how this occurs, and how to reduce risks by carefully assessing and modifying disposal practices, where appropriate. The STARR Water/Energy project has provided support to more broadly participate on the seismicity (water/energy) issue, and to study landscape (land/energy) research as well. In addition to helping to create the robust research program funded under Center for Integrated Seismicity Research (CISR), STARR funds were also leveraged to create the Regional Induced Seismicity Collaborative (RISC), a consortium of five states (TX, OK, KS, NM, AR) addressing seismicity within their borders. RISC was funded to support collaborative activities across the southern midcontinent of the US. STARR also leveraged externally funded research focused on reducing land impacts from installation of field equipment for the energy industry (including oil and gas, wind and solar). STARR augmented a grant from the Cynthia and George Mitchell Foundation to study the Permian Basin, primarily the Delaware Basin.

DESCRIPTION OF RESULTS AND FINDINGS

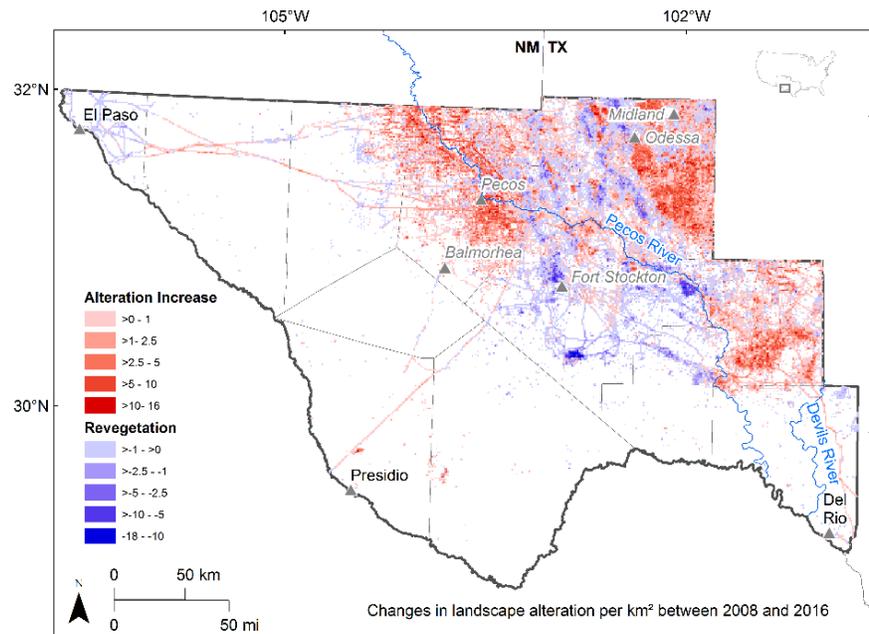
Water/Energy

- The earthquake research program at BEG, funded by private operators, and by the State of Texas, has led to a robust research program that spans subsurface geological characterization to the well-by-well analysis of water production at nearly every play in Texas.
- Water production rates generated for a 50-year span (see graph at right from Lemons et al., unpublished) is determined using data from the Railroad Commission of Texas and other sources.
- Though water production is not tracked directly from source to treatment and disposal, these volumes are used to create a rough, statewide water budget, which is checked against records of disposal volumes obtained from the RRC.
- These data are combined with disposal intervals and geological interpretation of subsurface architecture to understand where and when disposal is occurring. Along with estimates of fault characteristics, the results can provide a more complete picture of whether disposal is occurring above capacity and if faults are in local proximity to disposal wells. With this data and information, both operators and regulators can make better informed decisions.



Land/Energy

- With analysis of the 27-county footprint of the Eagle Ford play completed and published, focus was placed on the Delaware Basin in West Texas.
- Area of 113,000 km² was assessed for land use changes from all energy sources, but mostly from oil and gas infrastructure (e.g., pads and pipelines).
- Oil and gas development is the dominant source of landscape alteration in the region, though some landscape revegetation occurred between 2008 and 2016. See graph to the right (Pierre et al., unpublished)
- Future landscape impacts could be substantial, especially when considering recent O&G discoveries.
- Warm desert & semi-desert scrub & grasslands are most impacted by development, followed by temperate grassland and shrubland.



PRODUCTS AND OUTCOMES (PARTIAL LIST)

- Pierre, J.P., M.H. Young, B.D. Wolaver, J.R. Andrews, C.L. Breton. 2017. Time series analysis of energy production and associated landscape fragmentation in the Eagle Ford shale play. *Env. Mgmt.* 60:852-866. doi:10.1007/s00267-017-0925-1.
- Reible, D., M.H. Young, D. Bullard. 2017. Water Quality and Quantity, in: *The Academy of Medicine, Engineering and Science of Texas, 2017. Environmental and community impacts of shale development in Texas.* Austin, TX: The Academy of Medicine, Engineering and Science of Texas. doi: 10.25238/TAMESTstf.6.2017.
- Young, M.H., J.P. Pierre. 2017. Time Series Analysis of Energy Production and Associated Landscape Fragmentation in the Eagle Ford Shale Play. Presented at the South Texas Geological Society Meeting, San Antonio, TX. Invited.
- Young, M.H., D. Reible, D. Bullard. 2016. *The Water Side of Unconventionals.* University of Houston Energy Symposium. Houston, TX. Invited.
- Young, M.H., A. Savvaidis, P.H. Hennings, E. Rathje. 2016. *TexNet and CISR: Seismicity Monitoring and Research In Texas.* Presented at the Industry Council on the Environment, Austin, TX. Invited.

CONNECTION TO NEUTRALITY AND VALUE TO TEXAS

Funds have been used to match external grants in two different programs. In the water/energy program, 17 companies have sponsored the CISR consortium at a total of \$1,275,000 per year, and the US Dept. Energy sponsored the RISC program at \$250,000 per year. In the land/energy program, the Cynthia and George Mitchell Foundation underwrote a study at \$200,000 to assess potential impacts to land resources from all energy infrastructure in the Delaware Basin. In this aspect of water/energy research, the Bureau of Economic Geology has focused primarily on water disposal practices to manage earthquakes in Texas and on land use practices to improve land quality. Together, these programs represent a leveraging of 7.63:1, and they remain vital for maintaining the quality of resources for current and future Texans.

STARR HAZARDS MAPPING AND RESPONSE

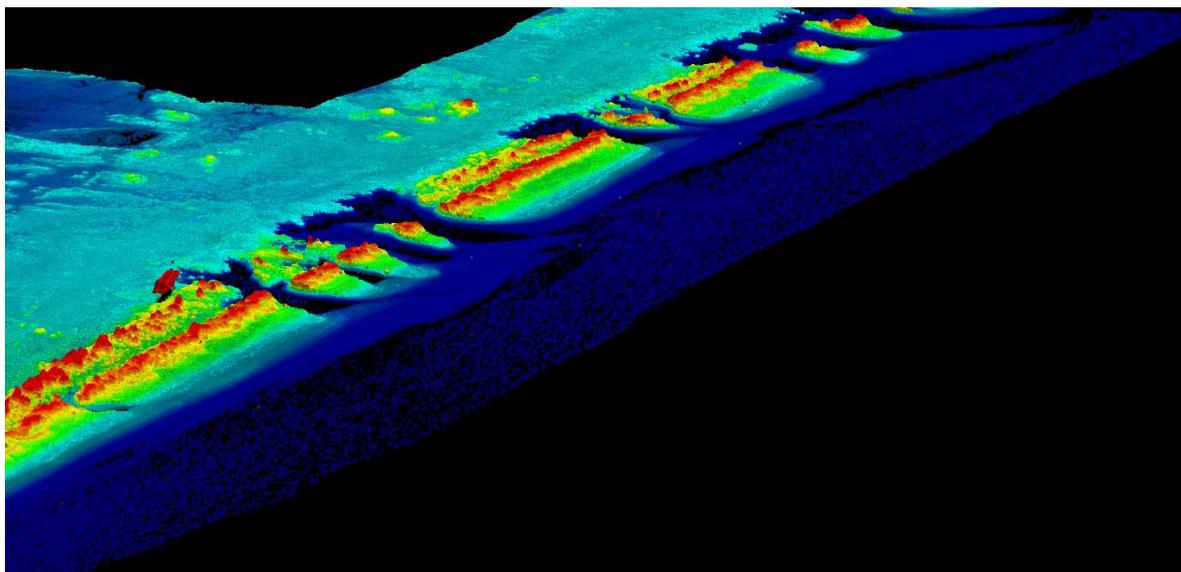
OVERVIEW AND GOALS

Multiple geologic hazards impact Texas citizens, infrastructure, and economic development. Principal among these are coastal erosion, tropical-cyclone impact, sinkhole development, and landslides. Goals of the STARR Hazards program are to prepare the state to respond to hazards by understanding their location and severity, assessing the threat they pose, and ultimately producing an atlas of geologic hazards that is accessible to emergency responders, planners, and citizens.

DESCRIPTION OF RESULTS AND FINDINGS

Efforts in this biennium were focused on coastal-hazard mapping in response to Hurricane Harvey (2017). Major activities fully or partly supported by STARR Hazards include

- An airborne lidar survey of the entire Texas Gulf shoreline beach and dune system, bay areas on the middle Texas coast, and selected bird rookeries to assess the impact of Hurricane Harvey, a Category 4 hurricane that struck the Texas coast in late August and early September 2017. Lidar and imagery acquired during this effort were used by emergency responders and state agency staff to identify hazards on the beach and in the bays, document beach and dune damage caused by storm surge and waves, assess damage to waterbird rookeries, and establish baseline coastal conditions to allow monitoring of recovery from the storm. STARR support allowed the survey to be flown within days of storm landfall, capturing data in the critical early post-storm phase.



- Airborne lidar- and ground-based mapping on the Texas coastal plain to assess onshore sand resources that will be needed to support coastal resilience and restoration projects in response to sea-level rise, tropical cyclone impacts, and shoreline erosion. STARR funds are used as required matching funds for externally funded projects, allowing us to conduct airborne lidar and ground-based investigations that complement project objectives on the Texas coast. Sand deposits identified during these activities are potential resources for future energy extraction, beach nourishment, and coastal habitat restoration. STARR-supported surveys have identified previously unknown surface faults and enhanced subsidence areas on the Texas coast and are being used to conduct geoenvironmental mapping associated with the development of Powderhorn Ranch, a 17,000+ acre parcel of land recently purchased for the State of Texas for development as a State Park and Wildlife Management Area.

PRODUCTS

Principal products from STARR-supported activities include presentations at conferences and stakeholder meetings, maps available to the public, interviews, reports, articles, and interactive websites showing historical coastal erosion rates on the Texas Gulf and bay shorelines. For the 2016-2018 biennium, these include:

- Four quadrangle-scale maps showing sand distribution in the Matagorda Bay area. These maps are jointly produced from STATEMAP, STARR mapping, and General Land Office projects and are listed in the STARR Mapping section.
- Fourteen presentations on effects of Hurricane Harvey, coastal erosion, and sinkholes at the following venues:
 - Hurricane Harvey impacts to the General Land Office of Texas, the Texas Chapter of the American Shore & Beach Preservation Association in Corpus Christi, Texas, the Geological Society of America in Seattle, Washington, and to several other public groups.
 - Coastal erosion hazards to the General Land Office of Texas, the National Coastal Conference, the General Land Office, and the Gulf Coast Association of Geological Societies in San Antonio, Texas.
 - Coastal mapping and sand resources to the Geological Society of America in Seattle, Washington, the Gulf Coast Association of Geological Societies, Corpus Christi, Texas, and the Symposium on the Application of Geophysics to Engineering and Environmental Problems in Denver, Colorado.
 - Wink sinkholes to San Antonio Geophysical Society, San Antonio, Texas.
- Ten reports, articles, and abstracts on coastal and geologic hazards:
 - Four articles on coastal erosion monitoring, mapping sand deposits on the Texas coastal plain, and identifying water resources in west Texas.
 - Three contract reports to state agencies on coastal erosion studies, sensitive habitat mapping and two to the U.S. Geological Survey on coastal mapping in the Matagorda Bay area.
 - Three conference abstracts on Hurricane Harvey impacts, coastal erosion monitoring, and coastal mapping efforts.

- Two interactive websites on coastal erosion hazards:
 - Texas Gulf Shoreline Change Project (<https://coastal.beg.utexas.edu/shorelinechange2016/>)
 - Measurement and Characterization of Bay Shoreline Change (https://coastal.beg.utexas.edu/shorelinechange_bays/)

CONNECTION TO NEUTRALITY AND VALUE TO TEXAS

Coastal hazards, sinkholes, and active faults threaten citizens, infrastructure, and economic development across Texas. Studies of geologic hazards benefit Texans by quantifying the impact of natural disasters, highlighting areas of heightened risk, and assessing risk and magnitude of future events. Knowing the context and distribution of geologic hazards helps maximize effective response when an event (like Hurricane Harvey) does occur and minimize its impact through better planning and avoidance of high-risk areas. STARR hazards funds supplement industry sources of funds that are being used to conduct sinkhole hazard studies in West Texas, and numerous State and Federal grants (GLO and National Oceanic and Atmospheric Administration primarily) that support coastal erosion studies on the Texas coast.

Sand resources on the Texas coastal plain will become an increasingly valuable commodity as offshore and dredged-channel sources are consumed in current and planned coastal restoration projects intended to offset chronic coastal erosion and land loss. STARR Hazards funds help supplement existing projects, allowing sand-resource assessments to be conducted in association with other funded coastal projects, leveraging both STARR and project funds.

MAPPING AND MINERAL/EARTH RESOURCES OF TEXAS

OVERVIEW AND GOALS OF PROJECT

This project produces geologic maps and related products to support the development and management of Texas' natural resources. The diverse geologic formations of Texas provide many industrial rocks and minerals used by Texas' industries and inhabitants. Minerals are produced across Texas and are mostly related to construction and industrial activities. Demand for earth materials that are used in the construction, chemical, and hydrocarbon exploration and production industries increases with population and economic growth. Geologic maps are a basic data set used by professionals to aid in exploration and evaluation of earth resources. Maps and related materials foster economic development and support the ability to locate and develop mineral and water resources, to identify and plan for potential hazards, to assess change in sensitive environments, and to properly plan and permit major construction projects. This project supports the development and management of Texas' mineral/earth resources by providing basic geologic information, such as geologic maps, to the public.

The STARR Geologic Mapping and Mineral/Earth Resources of Texas project complements the STARR Hazards Mapping and Response project and Texas STATEMAP project, which is partly supported by the National Geologic Mapping Cooperative Program administered by the U.S. Geological Survey. Possible mapping areas in Texas are prioritized by an advisory committee composed of representatives from the Texas Water Development Board, Texas Natural Resources Information System, Railroad Commission of Texas, Texas General Land Office, and Texas Parks and Wildlife Department, with coordination from the Bureau of Economic Geology. Geologic mapping and resource assessment activities during the September 2016-August 2018 biennium were conducted on the Texas Gulf of Mexico Coastal Plain, South-Central Texas, North-Central Texas, and the Trans-Pecos area of West Texas.

DESCRIPTION OF RESULTS AND FINDINGS

Three geologic maps produced for areas in south-central Texas with geologic units of potential sand and aggregate resources that are vitally important to the cement, construction, and oil and gas industries. Co-mapping for Texas STATEMAP Program and STARR.

One geologic map produced for the central Texas area with geologic units of potential industrial or hydraulic fracturing sand resources and limestone aggregate resources. Co-mapping for Texas STATEMAP Program and STARR.

Four geologic maps produced for middle Texas Gulf of Mexico Coast area of sensitive coastal environments, potential sand resources, and coastal land loss. Co-mapping for Texas STATEMAP Program and STARR.

Three geologic maps for the Central Texas area produced for geologic data applicable to earth and water resources and engineering projects of population corridors. Co-mapping for Texas STATEMAP Program and STARR.

Continued to develop and update a mineral resources map of Texas through the BEG website <http://igor.beg.utexas.edu/txmineralresources/>

Developed a Texas aggregate resource map for type, characterization, and quality of road and construction materials through the BEG website that can be used by industry professionals to explore regional aggregate material access: http://coastal.beg.utexas.edu/txdot_aggregate/#/

Promoted industry connections and fostered relationships with organizations and agencies that maintain resource-related data, as well as individual company operations, including U.S. Geological Survey, Department of Energy, Department of Interior, Texas Mining and Reclamation Association, Texas Aggregate and Concrete Association, Texas Cement Association, Texas Water Development Board, Texas Department of Transportation, Texas Railroad Commission, Texas Commission on Environmental Quality, and Texas Workforce Commission.

Provided assistance for more than 100 inquiries concerning mineral occurrences, deposits, data and available publications, many from companies and consultants looking for resource location information. Common inquiry topics included rocks and minerals, regional and local geology, engineering geology, geologic hazards, and resource-specific questions concerning uranium, sand and gravel, hydraulic fracturing sand and high quality industrial sands, natural clay materials, rare earth elements, silver, molybdenum, and vanadium resources, zeolite resources, gypsum, sulfur and graphite deposits, crushed limestone, trap-rock and other aggregate resources, heavy sands with possible titanium, zirconium, and niobium associations, and lithium and potash resources.

Research poster and oral presentations at regional and national Society of Economic Geology meetings, the Forum on the Geology of Industrial Minerals annual meeting, which was hosted in Austin at the BEG, Geological Society of America meetings, and Society of Mining and Engineering Meetings, and at the BEG-hosted Industry Day.

LIST OF PRODUCTS

Principal STARR mapping- and minerals-focused products completed during the 2016-2018 biennium include 4 articles and reports, 9 geologic maps, 2 web resource pages, and 13 public presentations at venues that included

Collins, E. W., 2017, Geologic Map of the Shingle Hills-Dripping Springs-Driftwood-Rough Hollow-Henly-Hammetts Crossing Area, Central Texas: The University of Texas at Austin, Bureau of Economic Geology Open-File Map No. 231, map scale 1:50,000.

Collins, E. W., and Paine, J. G., 2017, Project 1: Geologic mapping of the middle Texas Gulf of Mexico Coast and Coastal Plain (Port Lavaca East and Seadrift NE Quadrangles), in Collins, E. W., Paine, J. G., Elliott, B. A., and Woodruff, C. M., Jr., Texas STATEMAP Program Final Report FY16 (2016-2017): The University of Texas at Austin, Bureau of Economic Geology, Final Report prepared for U.S. Geological Survey, under contract no. G16AC00194, 2016.

Collins, E. W., Paine, J. G., and Costard, L., 2018, Project 1: Geologic mapping of the middle Texas Gulf of Mexico coast and coastal plain (Kamey and Point Comfort quadrangles), 1:24,000, in Collins, E. W., Paine, J. G., Elliott, B. A., Woodruff, C. M., Jr., and Costard, L., Texas STATEMAP Program FY17 (2017-2018): The University of Texas at Austin, Bureau

of Economic Geology, Final Report prepared for U.S. Geological survey, under contract no. G17AC00253, 2017, 8-15 p.

- Elliott, B. A., 2017, Geologic map of the Pontotoc Quadrangle, Texas: The University of Texas at Austin, Bureau of Economic Geology, Open File Map, 1:24000.
- Elliott, B. A., 2018, Geologic map of the Somerset Quadrangle, Texas: The University of Texas at Austin, Bureau of Economic Geology, Open File Map, 1:24000.
- Elliott, B.A., 2018, Petrogenesis of heavy rare earth element enriched rhyolite: Source and magmatic evolution of the Round Top laccolith, Trans-Pecos, Texas. *Minerals* 8 (10), 423, <https://doi.org/10.3390/min8100423>
- Elliott, B.A., 2018, The West Texas Sand Rush, Fifty-Fourth Forum on the Geology of Industrial Minerals, Austin, TX, Bureau of Economic Geology, the University of Texas at Austin.
- O'Neill, L.C., Elliott, B.A., and Kyle, J.R., 2017, Mineralogy and crystallization history of a highly differentiated REE-enriched hypabyssal rhyolite: Round Top laccolith, Trans-Pecos, Texas: *Mineralogy and Petrology*, v. 111, no. 4, p. 569-592, <http://doi.org/10.1007/s00710-017-0511-5>.
- Paine, J. G., and Collins, E. W., 2017, Geologic map of the Port Lavaca East Quadrangle, Texas Gulf of Mexico Coast: The University of Texas at Austin, Bureau of Economic Geology, Open-File Map, no. 0233, 1:24,000.
- Paine, J. G., and Collins, E. W., 2017, Geologic map of the Seadrift NE Quadrangle, Texas Gulf of Mexico Coast: The University of Texas at Austin, Bureau of Economic Geology, Open-File Map, no. 0232, 1:24,000.
- Paine, J. G., Collins, E. W., and Costard, L., 2018, Geologic map of the Kamey Quadrangle, Texas Gulf of Mexico Coast, Sheet 1: The University of Texas at Austin, Bureau of Economic Geology, Open-File Map, no. 0234, 1:24,000.
- Paine, J. G., Collins, E. W., and Costard, L., 2018, Geologic map of the Point Comfort quadrangle, Texas Gulf of Mexico Coast, Sheet 1: The University of Texas at Austin, Bureau of Economic Geology, Open-File Map, no. 0235, 1:24,000.
- Woodruff, C.M., Jr., and Collins, E.W., 2016, Geologic map of the upper Lake Travis area, Texas: The University of Texas at Austin, Bureau of Economic Geology, Miscellaneous Map No. 52, scale 1:50,000.
- Woodruff, C. M., Jr., and Collins, E. W., 2018, Geologic map of the Mansfield Dam, Jollyville, Austin West, and Bee Cave quadrangles, Central Texas (Lower Lake Travis and Lake Austin vicinity): The University of Texas at Austin, Bureau of Economic Geology, Open-File Map, no. 237, 1:50,000.

CONNECTION TO NEUTRALITY AND VALUE TO TEXAS

STARR Mapping and Earth/Mineral Resources of Texas work integrates much of its effort with the ongoing BEG Texas STATEMAP program, an established, ongoing geologic mapping program that began in 1992. Integrating work for this program allows for some State dollars to be matched with Federal dollars, increasing the productivity (and budgets) of the programs. The Texas STATEMAP program also complements ongoing studies of geologic hazards affecting Texas and studies of the status and trends of wetland environments and aquatic habitats.

STARR funds accounted for most of the required cost share for Federal funds awarded in the amount of \$463,123 for the STATEMAP Program in the 2016, 2017, and 2018 fiscal years.

STARR funds accounted for most of the required cost share for externally sponsored project funds (\$65,768) from mining industry interests in developing an inventory for oilfield brine chemistry and its potential to produce critical mineral resources from August 2017-August 2019.

Geologic maps and related charts, diagrams, and texts, are a type of product that has been documented to have immense economic and societal value (Bhagwat and Ipe, 2000; GSA Geology & Public Policy Committee, 2012). For example, one analysis calculated the value of the geologic maps to be 25 to 30 times the cost of map preparation. Geologic maps and their related materials foster economic development and support the ability to locate and develop mineral and water resources, to identify and plan for potential hazards, to assess changes in sensitive coastal environments, and to properly plan and permit major construction projects.

REFERENCES

Bhagwat, S.B., and Ipe, V.C., 2000, Economic benefits of detailed geologic mapping to Kentucky: Illinois State Geological Survey, Special Report No. 3, 48 p.
<http://library.isgs.illinois.edu/Pubs/pdfs/specialreports/sp-03.pdf> ;
<http://isgs.illinois.edu/kentucky-geologic-mapping-program>

GSA Geology & Public Policy Committee, 2012, The value of geologic mapping: The Geological Society of America, Position Statement,
http://www.geosociety.org/positions/pos3_mapping.pdf.

GEOLOGIC MAPPING AND MINERAL/EARTH RESOURCES OF TEXAS

OVERVIEW AND GOALS OF PROJECT

This project produces geologic maps to support the development and management of Texas' resources. The diverse geologic formations of Texas provide many industrial rocks and minerals used by Texas' industries and society. Mineral production exists throughout Texas and is mostly related to construction and industrial activities. Demand for earth materials that are used for construction materials, minerals used in the chemical industries, as well as earth materials used in the hydrocarbon exploration/production industry increases with population and economic growth. Geologic maps are one of the most basic data sets used by professionals to aid in exploration and evaluation of earth resources. Maps and their related materials foster economic development and support the ability to locate and develop mineral and water resources, to identify and plan for potential hazards, to assess changes in sensitive coastal environments, and to properly plan and permit major construction projects. This project supports the development and management of Texas' mineral/earth resources by providing basic geologic information, such as geologic maps, to the public.

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DESCRIPTION OF RESULTS AND FINDINGS

- 3 geologic maps produced for areas in south-central Texas with geologic units of potential sand and aggregate resources that are vitally important to the cement, construction and oil and gas industries (**B. Elliott**). Co-mapping for Texas STATEMAP Program and STARR.
- 1 geologic map produced for Central Texas area with geologic units of potential industrial and/or hydraulic fracturing sand resources and limestone aggregate resources (**B. Elliott**). Co-mapping for Texas STATEMAP Program and STARR.
- Continued development and update to the Mineral resources map of Texas through the BEG website <http://igor.beg.utexas.edu/txmineralresources/> (**B. Elliott**).
- Developed a Texas aggregate resource map for type, characterization and quality of road and construction materials through the BEG website that can be used by industry professionals to explore regional aggregate material access: http://coastal.beg.utexas.edu/txdot_aggregate/#/ (**B. Elliott**).

- Promoted industry connections and foster relationships with organizations and agencies that maintain valuable resource related data, as well as individual company operations, including United States Geological Survey, Department of Energy, Department of Interior, Texas Mining and Reclamation Association, Texas Aggregate and Concrete Association, Texas Cement Association, Texas Water Development Board, Texas Department of Transportation, Texas Railroad Commission, Texas Commission on Environmental Quality and Texas workforce Commission (**B. Elliott**).
- Provided information and assistance to more than 100 inquiries on mineral occurrences, deposits, data and available publications, many from companies and consultants looking for resource location information. These inquiries ranged from public questions on rocks and minerals, regional and local geology questions, to resource specific questions concerning, uranium, sand and gravel, hydraulic fracturing sand and high quality industrial sands, natural clay materials, rare earth elements, silver, molybdenum and vanadium resources, zeolite resources, gypsum, sulfur and graphite deposits, crushed limestone, trap-rock (gabbro/diabase) and other aggregate resources, heavy sands with possible titanium, zirconium and niobium associations, to lithium and potash resource possibilities (**B. Elliott**).
- Research posters and oral presentations at regional and national Society of Economic Geology meetings, Forum on the Geology of Industrial Minerals annual meeting – hosted in Austin at the BEG for the 2018 annual meeting, Geological Society of America meetings, and Society of Mining and Engineering Meetings, and at the Bureau of Economic Geology hosted Industry Day (**B. Elliott**) (**E. Collins**) (**C. Woodruff**). Some presentations relate to JSG student supervision and training (**B. Elliott**).

LIST OF PRODUCTS

- Elliott, B. A., 2019, Geologic map of the Leming Quadrangle: The University of Texas at Austin, Bureau of Economic Geology, Open File Map, 1:24000.
- Elliott, B. A., 2019, Geologic map of the Rossville Quadrangle: The University of Texas at Austin, Bureau of Economic Geology, Open File Map, 1:24000.
- Elliott, B. A., 2018, Geologic map of the Somerset Quadrangle, Texas: The University of Texas at Austin, Bureau of Economic Geology, Open File Map, 1:24000.
- Elliott, B. A., 2017, Geologic map of the Pontotoc Quadrangle, Texas: The University of Texas at Austin, Bureau of Economic Geology, Open File Map, 1:24000.
- Ugurhan, M., Elliott, B.A., and Kyle, J.R., 2019, Whole-rock Geochemistry and U-Pb Geochronology of highly evolved, REE-enriched, the Cave Peak Porphyry Mo System, Culberson County, TX, Economic Geology, (in preparation).
- Piccione, G., Rasbury, E.T., Elliott, B.A., Kyle, J.R., Jaret, S.J., Acerbo, A.S., Lanzirotti, A., Northrup, P., Wooton, K., and Parrish, R.R., 2019, Vein Fluorite U-Pb Dating Demonstrates Post-6.2 Ma Rare Earth Element Mobilization Associated with Rio Grande Rifting. *Geochemistry, Geophysics, and Geosystems Journal*, (submitted).
- Kyle, J.R. and Elliott, B.A., 2019, Past, Present, and Future of Texas Industrial Minerals. *Mining, Metallurgy & Exploration Journal* (accepted).
- Elliott, B.A., 2018, Petrogenesis of heavy rare earth element enriched rhyolite: Source and magmatic evolution of the Round Top laccolith, Trans-Pecos, Texas. *Minerals* 8 (10), 423, <https://doi.org/10.3390/min8100423>

Elliott, B.A., 2018, The West Texas Sand Rush, Fifty-Fourth Forum on the Geology of Industrial Minerals, Austin, TX, Bureau of Economic Geology, the University of Texas at Austin.

O'Neill, L.C., Elliott, B.A., and Kyle, J.R., 2017, Mineralogy and crystallization history of a highly differentiated REE-enriched hypabyssal rhyolite: Round Top laccolith, Trans-Pecos, Texas: Mineralogy and Petrology, v. 111, no. 4, p. 569-592, <http://doi.org/10.1007/s00710-017-0511-5>.

Presented “Characterization of the Marble Canyon granitoids and Cave Peak Rhyolite in Trans-Pecos, Texas: Insights into the Petrogenesis of High-Silica Y+REE-Enriched Magmas” at the 2019 combined north central, south central, and rocky mountain Geological Society of America meeting in Manhattan, KS

Presented “Geochemistry and U-Pb dating of fluorite and nacrite from the Round Top rhyolite: Constraints on magmatism and Tectonism in Trans-Pecos Texas” at the 2019 combined north central, south central, and rocky mountain Geological Society of America meeting in Manhattan, KS

Presented “Physical properties and characteristics of Permian Basin frac sand: When is frac sand “good Enough?” at the 2019 annual Society for Mining, Metallurgy and Exploration Meeting in Denver, CO

Presented “Permian Basin Frac Sand: A case study for unprecedented growth” at the 2019 annual Society for Mining, Metallurgy and Exploration Meeting in Denver, CO

Presented “The West Texas Sand Rush” at the 2018 annual Texas Mining and Reclamation Association meeting in Bastrop, TX

Presented “The West Texas Sand Rush” at the 2018 annual Forum on the Geology of Industrial Minerals meeting in Austin, TX

Presented “Aggregate Resources of Texas” at the 2017 Civil Engineering Conference in San, Marcos, TX

Presented “Qualitative analysis of sand resources in Texas for hydraulic fracturing” at the 2017 Association of Environmental and Engineering Geologists meeting in Colorado Springs, CO

CONNECTION TO NEUTRALITY AND VALUE TO TEXAS

- STARR funds accounted for most of the required Cost Share for the externally sponsored projects funds (\$65,768) from mining industry interests in developing an inventory for oilfield brine chemistry and its potential to produce critical mineral resources from August 2017-August 2019.

STARR WATER/ECONOMICS

OVERVIEW AND GOALS OF PROJECT

Recognizing the importance of water issues in Texas related to economic development, particularly considering that the state is continually subjected to floods and droughts, BEG has focused research on water issues with large economic impacts in the State. Our work on water and economics has focused on approaches to improve water resource management to reduce adverse impacts on economic development and the environment. Within the past year we have concentrated on managing water issues related to (1) floods and droughts and water issues related to (2) energy development.

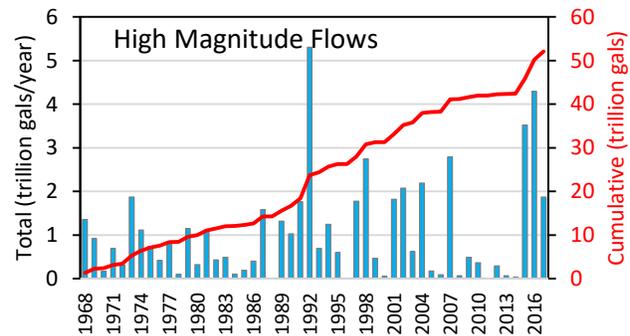
Texas was subjected to the most extreme flooding on record in Aug/Sep 2017 from Hurricane Harvey, concentrated in the vicinity of Houston. Rainfall was up to 60 inches (5 feet) and totaled about 275 trillion gallons extending along south central Texas and into Louisiana. Economic losses from the flooding in Houston and surrounding region were estimated to total ~ \$100 billion. At other times Texas has been subjected to intense droughts, with the 2011 drought being the most extreme drought on record for many regions of the state. These climate extremes pose huge challenges for water resource managers. Our work has focused on assessing the potential for capturing high magnitude streamflows and storing this water in depleted aquifers for use during drought periods. We quantified the magnitude, duration, and frequency of high magnitude flows (>95th percentile) in major rivers that discharge to Gulf of Mexico from Texas. We also considered water rights and instream flows.

The second major focus of our work relates to water issues linked to tight oil and shale gas development in the state. The major tight oil plays in Texas (Eagle Ford and Permian Basin) are in semiarid regions with limited groundwater availability. Increasing water intensity of hydraulic fracturing could be constrained by limited water supplies if industry continues to rely heavily on fresh and brackish groundwater resources. Tight oil plays also produce large volumes of water with oil and gas, termed produced water. Produced water is mostly managed through subsurface disposal using saltwater disposal wells. Managing this produced water is becoming challenging with increased frequencies of seismicity clustered in the Pecos region of the Permian Basin and in the Eagle Ford plays. Our work has focused on evaluating the potential of resolving both water issues by assessing the potential to reuse produced water for hydraulic fracturing of new wells, reducing groundwater depletion and also produced water management.

DESCRIPTION OF RESULTS AND FINDINGS

Managing Water Resources for Floods and Droughts

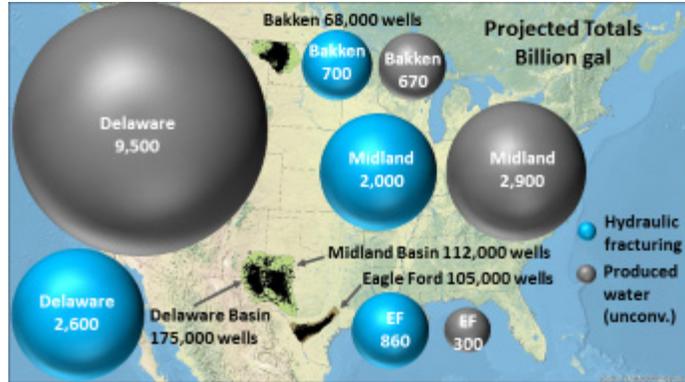
- High magnitude flows in the Texas Gulf Coast total ~10 trillion gallons within the past 3 years (2015 – 2017) and ~50 trillion gallons over the past 50 years.
- These high magnitude flows exceed the water rights; therefore, capturing these flows would not impact current water rights.
- Preliminary evaluation of instream flow studies from the Texas Water Development Board suggest that the volume of water that could be captured from high magnitude flows would have to be reduced by ~35% in the San Antonio and Brazos river basins to minimize impacts on aquatic ecosystems.
- Long duration, low frequency events contribute most of the volume of the high magnitude flows, with events ≥ 20 d contributing 35% of the volume over the past 50 years.
- Groundwater depletion in the Gulf Coast region would provide sufficient capacity to store ~70% of the high magnitude flows recorded between 2015 and 2017; however, interim storage, such as off channel reservoirs, would be required because of low aquifer injectivity.



Water/Economic Issues related to Hydrocarbon Extraction

- We published an analysis of water use and produced in the Permian Basin describing the current water issues within the context of water management related to conventional oil and gas production over decades. These results indicate that conventional reservoirs produce about 15 barrels (bbl) of water per bbl of oil but it is managed by water flooding with little negative impacts on seismicity or groundwater depletion. Although the current shale gas reservoirs produce about 3 bbl of water per bbl of oil, it cannot be reinjected into the reservoirs and subsurface disposal could be linked to seismicity.
- We evaluated water scarcity concerns for hydraulic fracturing with water use for hydraulic fracturing markedly increasing by up to almost 10 times in the Permian Basin in recent years. Groundwater depletion is recorded in the Eagle Ford play but much less in the Permian Basin to date.
- We examined why we see much less seismicity in the Permian and Eagle Ford plays relative to Oklahoma and show that the lower seismicity may be primarily linked to shallow disposal in the Permian and Eagle Ford that is far from basement rock relative to deep disposal in Oklahoma.

- We developed projections of produced water working with the Tight Oil Resource Assessment consortium people to determine if produced water management will be an issue in the future. Projections for the Permian Basin, particularly the Delaware Basin, are extremely high (9,500 billion gallons) over the life of the play. We show that water issues related to oil production could be partially alleviated by reusing produced water for hydraulic fracturing; however, the Delaware Basin is projected to generate much more water than is required for hydraulic fracturing. Subsurface disposal capacity will need to be quantified and other approaches to managing this produced water will need to be considered.
- Dr. Scanlon also participated in a National Academy of Sciences study evaluating the approaches used by the U.S. Geological Survey for resource assessments.



PRODUCTS AND OUTCOMES (PARTIAL LIST)

- Yang Q and Scanlon BR., How much water can be captured from flood 1 flows to store in depleted aquifers for drought times? Case study Texas, U.S. in review in *Env. Research Letters*.
- Scanlon BR, Reedy RC, Male F, & Walsh M (2017) Water Issues Related to Transitioning from Conventional to Unconventional oil Production in the Permian Basin. *Environmental Science & Technology* 51(18):10903-10912.
- Scanlon BR, Weingarten MB, Murray KE, & Reedy RC (2018) Managing Basin-Scale Fluid Budgets to Reduce Injection-Induced Seismicity from the Recent U.S. Shale Oil Revolution. *Seismological Research Letters*.

Presentations

- Reedy RC, Scanlon BR, Male F, & Walsh M (2017) Water Issues Associated with Increasing Unconventional Oil Production in the Permian Basin *H53A-1422 presented at 2017 Fall Meeting, American Geophysical Union, New Orleans, LA, 11-15 Dec.*
- Scanlon B, R.(2017) Managing water risks related to oil and gas production in the Permian Basin. *Presentation at Univ. of Texas El Paso, Sep. 11, 2017.*
- Scanlon B, R., (2017) Water budget of the Permian Basin: Implications for groundwater quality. *Presentation to the Texas Groundwater Protection Committee, Sep. 12, 2017, at the Texas Commission of Environmental Quality.*
- Scanlon BR (2017) Changing Water Budget Related to Transitioning from Conventional to Unconventional Oil Production in the Permian Basin, *Society of Petroleum Engineers, Houston, March 29, 2017.*
- Scanlon BR (2018) Water Challenges in the Permian Basin. *Presentation to Research Institute of Petroleum Exploration and Development, Jan. 9, 2018.*

- Scanlon BR (2018) Water Issues in Unconventional Resource Development in the Permian Basin. *Keynote presentation at Houston Geological Society Conference: Integrated Approaches of Unconventional Reservoir Assessment and Optimizaiton, Mar. 7, 2018, Houston, Texas. .*
- Scanlon BR (2018) Managing Water Issues related to Unconventional Oil and Gas Development in the Permian Basin. *Presentation at the Permian Basin Water in Energy Conference, Feb. 21, 2018.*
- Scanlon BR (2018) Will Water Issues Constrain Energy Production in the Permian Basin? *Hart Energy Executive Oil Conference, Water Forum, Nov. 6, 2018, Midland Texas.*

CONNECTION TO NEUTRALITY AND VALUE TO TEXAS

Funds have been used to match external grants in two different programs.

Sloan Mitchell Exxon

In the water/energy program, 17 companies have sponsored the CISR consortium at a total of \$1,275,000 per year, and the US Dept. Energy sponsored the RISC program at \$250,000 per year. In the land/energy program, the Cynthia and George Mitchell Foundation underwrote a study at \$200,000 to assess potential impacts to land resources from all energy infrastructure in the Delaware Basin. In this aspect of water/energy research, the Bureau of Economic Geology has focused primarily on water disposal practices to manage earthquakes in Texas and on land use practices to improve land quality. Together, these programs represent a leveraging of 7.63:1, and they remain vital for maintaining the quality of resources for current and future Texans.