APPALACHIAN STORAGE HUB (ASH) FOR LIQUID ETHANE

QUARTERLY REPORT

August 2016 – October 2016

Submitted By

APPALACHIAN OIL & NATURAL GAS RESEARCH CONSORTIUM

National Research Center for Coal & Energy

Ohio Geological Survey

Pennsylvania Geological Survey

West Virginia Geological Survey

NOVEMBER 2016

Quarterly Progress Report

1.0 INTRODUCTION

State officials in Pennsylvania, Ohio and West Virginia, with the support of their respective Governors, are promoting a high-technology program to enhance economic development by expanding the market for ethane production from the liquids-rich Marcellus Shale gas fields in southwestern Pennsylvania and Utica Shale fields in eastern Ohio and northern West Virginia. Their vision is to link these gas fields to end users in southern West Virginia and northeastern Kentucky via a pipeline that essentially follows the Ohio and Kanawha rivers. However, because the production of ethane may not occur at a consistent rate, and the need by consumers is for a steady, dependable supply, underground storage for liquid ethane at some point along the pipeline route is essential. Ethane can then be injected into storage at irregular rates, but withdrawn at consistent volumes and transported to the end users. Without this underground ethane storage facility, the entire program cannot go forward.

Therefore, it was necessary that the project to locate a storage facility of sufficient volume be completed. Under this project, numerous geologic formations along the proposed pipeline route are being evaluated to determine their potential to store the required volume of liquid ethane. Options being considered include: creating cavities in the Salina F-4 Salt through solution mining; deep mining (below 2,000 feet) of the Greenbrier Limestone; and injecting liquid ethane into saline reservoirs in depleted and abandoned gas fields.

The successful completion of the project will require mapping and identification of areas where the Salina F salt is at least 100 feet thick and suitable for solution mining; mapping and identification of areas of the Greenbrier Limestone that are at least 40 feet thick and suitable for hard-rock mining; and mapping the thickness and extent of sandstone reservoirs in depleted gas fields and estimating their capacity for storing and delivering liquid ethane.

The following stratigraphic units are being investigated for their potential for ethane storage:

- Middle Mississippian Greenbrier Limestone
- Lower Mississippian Sandstones (Keener to Berea interval)
- Upper Devonian Sandstones (Bradford, Venango, Elk interval)
- Lower Devonian Oriskany Sandstone
- Upper Silurian Salina Formation (Salina F4 salt and Newburg sandstone)
- Lower Silurian Clinton-Medina Sandstones
- Lower Silurian Tuscarora Sandstone
- Lower Ordovician Rose Run Formation
- Upper Cambrian Gatesburg Formation (Upper Sandy member)

This Appalachian Storage Hub (ASH) for Liquid Ethane Study is being conducted by participating members of the Appalachian Oil & Natural Gas Research Consortium, a program within the National Research Center for Coal and Energy (NRCCE) at West Virginia University. Consortium members participating in this study include the State Geological Surveys of Ohio (OGS), Pennsylvania (PAGS) and West Virginia (WVGES), as well as NRCCE. The research is divided into six strategies, each of which has a

lead state geological survey. A seventh strategy, Management and Technology Transfer, is being led by NRCCE.

Milestones for the first quarter of this one-year project (August 2016-July 2017) were to:

- Initiate Data Collection (Strategy 1)
  - Identify and assemble well log and core data
  - Identify previous studies of interest
  - Create a project database (format, prototype)
- Initiate Stratigraphic Correlation of Key Units (Strategy 2)
  - Initiate development of cross sections of all stratigraphic intervals of interest

All milestones were met during the initial calendar quarter of the project. Details follow in the Research Section.

2.0 RESEARCH

2.1 Data Collection & Database Creation

First quarter project efforts focused on identifying and assembling well log and core data for the project's Area of Interest (AOI; see Appendix 5.1) into a "Master PETRA® Project." OGS was tasked with compiling these data from their own archives as well as those of the WVGES and PAGS. A total of 1,948 wells with depth-registered raster logs and 112 wells with digital curves were loaded into the Master Project during the first quarter. Additional well header, raster logs, digital curves and subsurface formation tops data will be compiled during the second quarter, and will be used to generate cross sections and maps of thickness, extent and structure of potential storage units in the AOI as part of Strategies 2 and 3 (see Appendix 5.2).

The research team identified previous studies relevant to this project and loaded the associated well data into the Master Project. These studies include the Appalachian Tight Gas Reservoirs project; the regional geologic characterization work performed for the Midwest Regional Carbon Sequestration Partnership (MRCSP); the Subsurface Brine Disposal Framework in the Northern Appalachian Basin project; the Utica Shale Appalachian Basin Exploration Consortium's project entitled *A Geologic Play Book for Utica Shale Appalachian Basin Exploration*; and the Ohio Coal Development Office (OCDO)'s project entitled *Conducting research to better define the sequestration options in eastern Ohio*. Data from these projects include digital log curves, formation tops, regional structure/isopach maps, core data and formation pressure. These data provide the foundation for interpreting the regional stratigraphic framework and reservoir characterization specific to project requirements.

2.1.1 Project Website

A prototype website has been created for the project. Access to the website is password-protected, and login credentials will be sent to Industry and Advisory groups via their respective listservs once successful communication is established. The URL for the project website is: https://gisonline.wvgs.wvnet.edu/ASH/

Figure 2.1.1. Login screen for the ASH project.

The project website is designed to allow Industry and Advisory Groups access to project data sources, and is directly linked to the root files uploaded, organized and developed by the research team and managed by WVGES. Project data are accessed via the DATA tab at the top of the login screen.

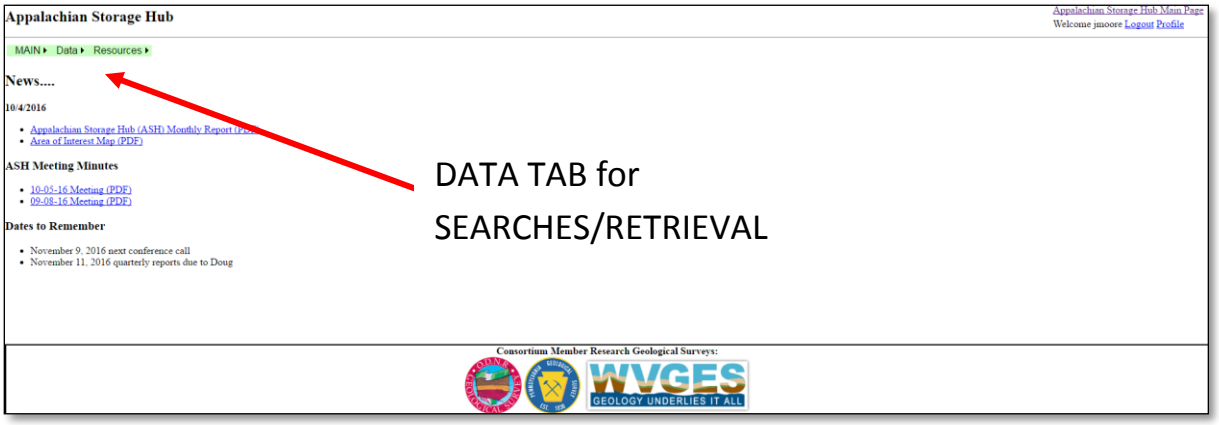


Figure 2.1.2. Data tab for searches and retrieval.

ASH project data sources are queried and retrieved by using a set of drop-down menus populated with the following information (see Figure 2.1.3 below).

API #: American Petroleum Institute 10-digit code. A list of API state and county codes is provided in Figure 2.1.4.

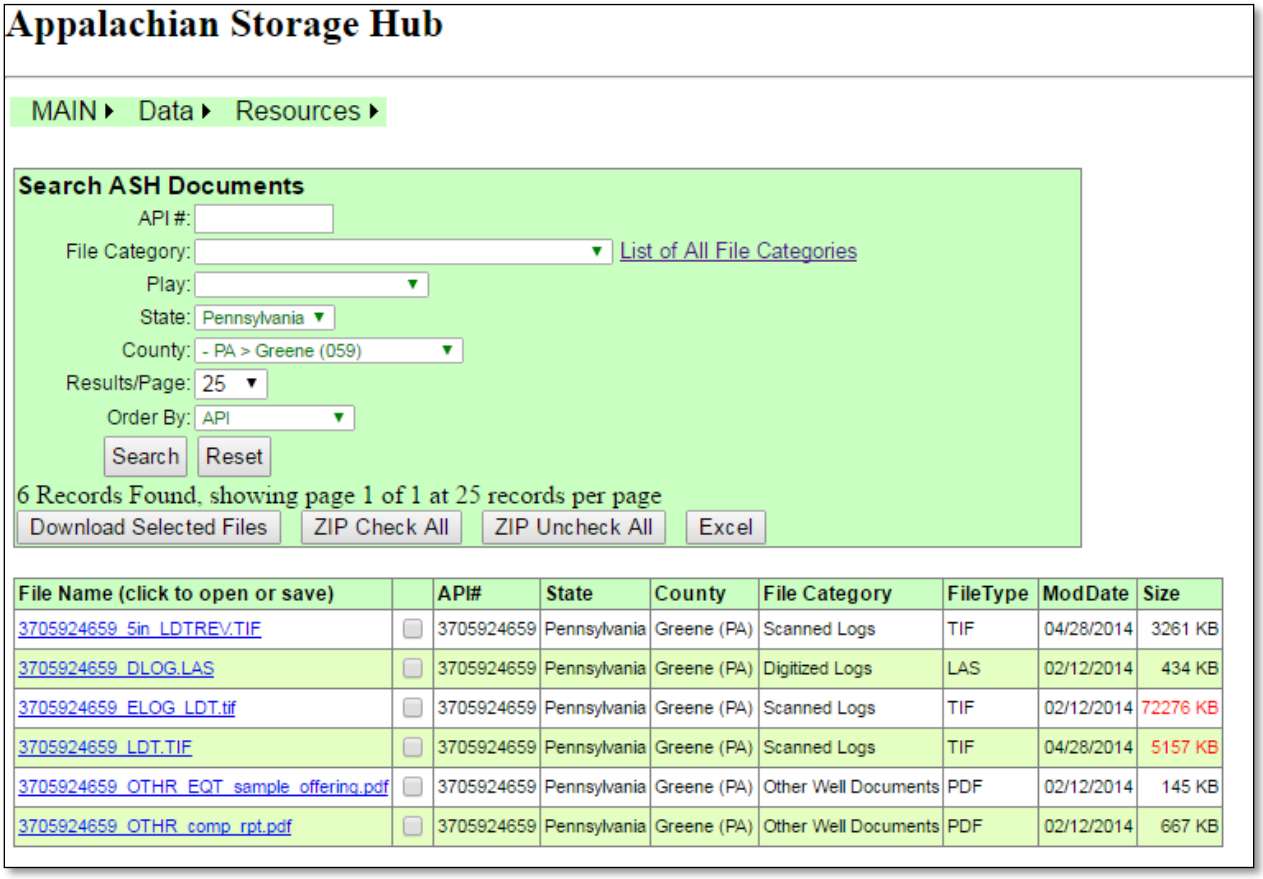
FILE CATEGORY: Type of data/document. The list is designed to be inclusive of the broad range of categories, and not all types will be available for any given state/county/reservoir. The category abbreviation is coded into the file name for ease of identification. Figure 2.1.5 lists the individual file categories.

PLAY: Select from Salina (SLNA), Greenbrier (GRBR), or Depleted Gas (DGAS). This list is under construction and will be populated as the project progresses.

STATE: Select from Ohio, Pennsylvania, or West Virginia.

COUNTY: Select from counties included in the AOI (see Figure 2.1.4).

The search results may be downloaded individually or zipped into a bulk download. A list of results with embedded hyperlinks can be exported to Excel.



File Name (click to open or save)		API#	State	County	File Category	FileType	ModDate	Size
3705924659_5in_LDTREV.TIF	☐	3705924659	Pennsylvania	Greene (PA)	Scanned Logs	TIF	04/28/2014	3261 KB
3705924659_DLOG.LAS	☐	3705924659	Pennsylvania	Greene (PA)	Digitized Logs	LAS	02/12/2014	434 KB
3705924659_ELOG_LDT.tif	☐	3705924659	Pennsylvania	Greene (PA)	Scanned Logs	TIF	02/12/2014	72276 KB
3705924659_LDT.TIF	☐	3705924659	Pennsylvania	Greene (PA)	Scanned Logs	TIF	04/28/2014	5157 KB
3705924659_OTHR_EQT_sample_offering.pdf	☐	3705924659	Pennsylvania	Greene (PA)	Other Well Documents	PDF	02/12/2014	145 KB
3705924659_OTHR_comp_rpt.pdf	☐	3705924659	Pennsylvania	Greene (PA)	Other Well Documents	PDF	02/12/2014	667 KB

Figure 2.1.3. ASH project data document example search results.

ASH Region Counties

State: OH — API Code: 34

Athens	009
Belmont	013
Carroll	019
Columbiana	029
Gallia	053
Guernsey	059
Harrison	067
Jackson	079
Jefferson	081
Lawrence	087
Mahoning	099
Meigs	105
Monroe	111
Morgan	115
Noble	121
Scioto	145
Vinton	163
Washington	167

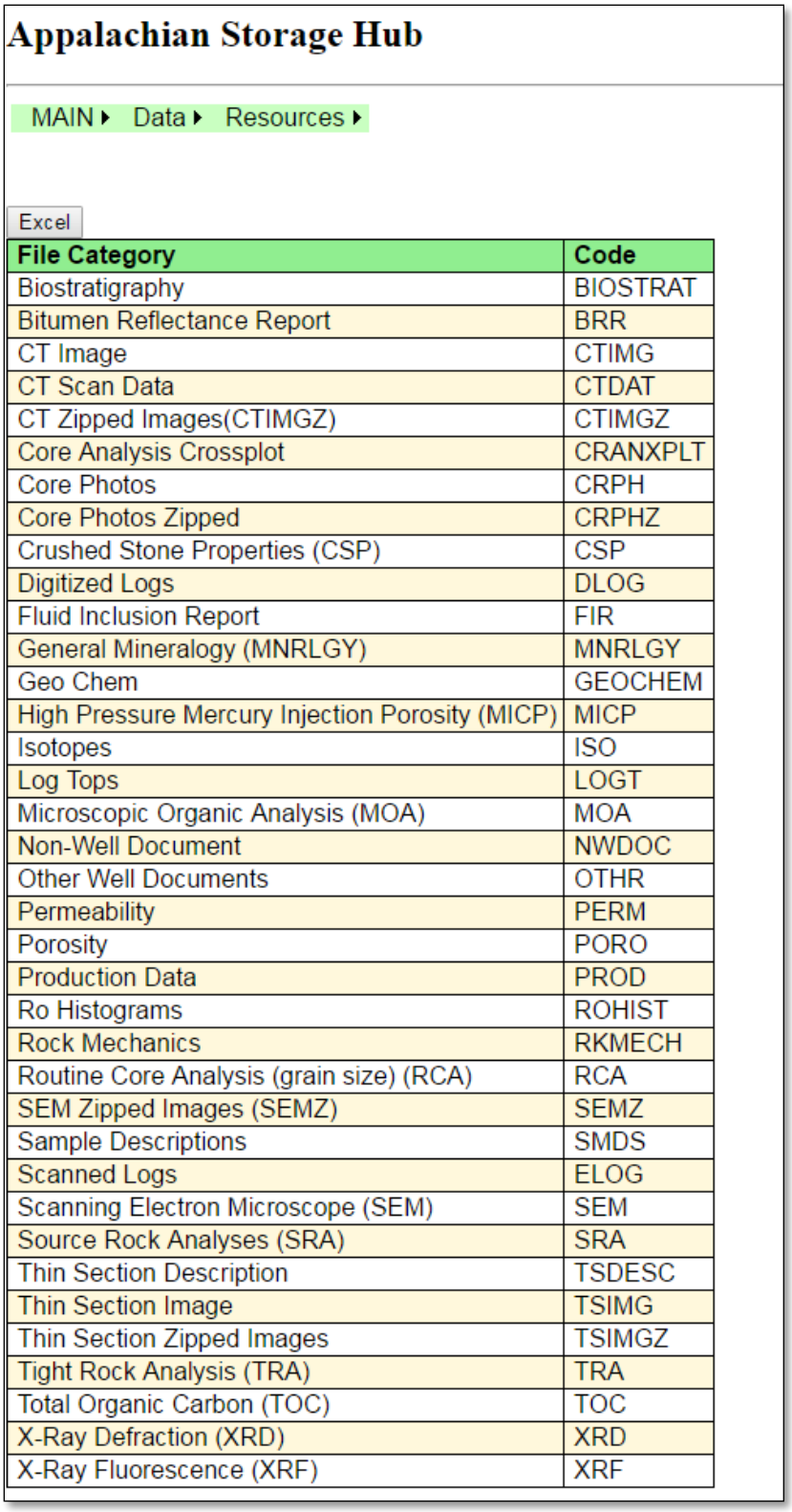
State: WV — API Code: 47

Boone	005
Brooke	009
Cabell	011
Doddridge	017
Hancock	029
Jackson	035
Kanawha	039
Lincoln	043
Marion	049
Marshall	051
Mason	053
Monongalia	061
Ohio	069
Pleasants	073
Putnam	079
Ritchie	085
Roane	087
Tyler	095
Wayne	099
Wetzel	103
Wirt	105
Wood	107

State: PA — API Code: 37

Allegheny	003
Beaver	007
Butler	019
Greene	059
Lawrence	073
Washington	125

Figure 2.1.4. State and county codes for the AOI.



Appalachian Storage Hub

MAIN ▸ Data ▸ Resources ▸

Excel

File Category	Code
Biostratigraphy	BIOSTRAT
Bitumen Reflectance Report	BRR
CT Image	CTIMG
CT Scan Data	CTDAT
CT Zipped Images(CTIMGZ)	CTIMGZ
Core Analysis Crossplot	CRANXPLT
Core Photos	CRPH
Core Photos Zipped	CRPHZ
Crushed Stone Properties (CSP)	CSP
Digitized Logs	DLOG
Fluid Inclusion Report	FIR
General Mineralogy (MNRLGY)	MNRLGY
Geo Chem	GEOCHEM
High Pressure Mercury Injection Porosity (MICP)	MICP
Isotopes	ISO
Log Tops	LOGT
Microscopic Organic Analysis (MOA)	MOA
Non-Well Document	NWDOC
Other Well Documents	OTHR
Permeability	PERM
Porosity	PORO
Production Data	PROD
Ro Histograms	ROHIST
Rock Mechanics	RKMECH
Routine Core Analysis (grain size) (RCA)	RCA
SEM Zipped Images (SEMZ)	SEMZ
Sample Descriptions	SMDS
Scanned Logs	ELOG
Scanning Electron Microscope (SEM)	SEM
Source Rock Analyses (SRA)	SRA
Thin Section Description	TSDESC
Thin Section Image	TSIMG
Thin Section Zipped Images	TSIMGZ
Tight Rock Analysis (TRA)	TRA
Total Organic Carbon (TOC)	TOC
X-Ray Defraction (XRD)	XRD
X-Ray Fluorescence (XRF)	XRF

Figure 2.1.5. File categories included in the searchable data tables. The list is designed as a broad categorization; data availability is highly variable.

2.1.2 FTP Site and Root File Maintenance

A file transfer protocol (FTP) site has been established for the ASH project. Login credentials were assigned to Research User Group members in October 2016. The FTP site will serve as the main data repository for the project, but due to the dynamic and iterative nature of the data sets during the project period, will be used solely for data sharing among research team members.

Data submitted by researchers will be sorted and coded to mirror the file structure of the web-based search. Initial organizational tasks included separating counties within the AOI from statewide datasets, adding codes for file category and play type and assembling well lists for multi-data files.

2.1.3 Other Project Resources

The ASH project website RESOURCES tab includes a link to the final website constructed for the Appalachian Tight Gas Reservoirs project. This comprehensive database of information for Pennsylvania and West Virginia provides well log data, core photos and project reports for many of the potential reservoir targets included in this project. A direct link to the project is also available on the WVGES website: http://www.wvgs.wvnet.edu/atg/

2.2 Stratigraphic Correlations and Mapping

PAGS has finalized the stratigraphic correlation diagram for this project (see Appendix 5.3). The research team will be using the nomenclature identified in this diagram to ensure consistent correlation and mapping of geologic intervals for this project within the Keener-Berea interval, Upper Devonian sandstones, Oriskany Sandstone, Clinton-Medina/Tuscarora interval and the Rose Run/Upper Sandy member of the Gatesburg Formation. Many target formation tops have already been identified and correlated on logs from multiple wells within the region (Table 2.2.1).

Potential Target Rock Units for Ethane Storage	# of wells interpreted
Salina Group members	577
Greenbrier Formation	
Keener sand to Berea Sandstone Interval	
Upper Devonian Sandstones	
Oriskany Sandstone	755
Clinton-Medina / Tuscarora Interval	750
Rose Run / Upper Sandy member - Gatesburg Formation	665

Table 2.2.1. Table displaying potential targets for ethane storage and the number of wells in which that formation has been identified to date.

Efforts in West Virginia focused on stratigraphic correlation of Lower Devonian to Lower Silurian targets, particularly the Lower Devonian Oriskany and Upper Silurian Newburg sandstones. Reservoir unit tops and bases were picked for 256 digital logs located in Kanawha, Jackson, Lincoln, Mason, Boone, Putnam and Boone counties. In order to ensure to constrain the accuracy of the correlations for the Newburg sandstone, 89 raster logs were digitized to LAS logs. The distribution of these data points provide robust data density for the Newburg with from geophysical logs collected from wells located within and adjacent to the Kanawha Forest, Rocky Fork, Copper Creek, North Ripley and South Ripley gas fields.

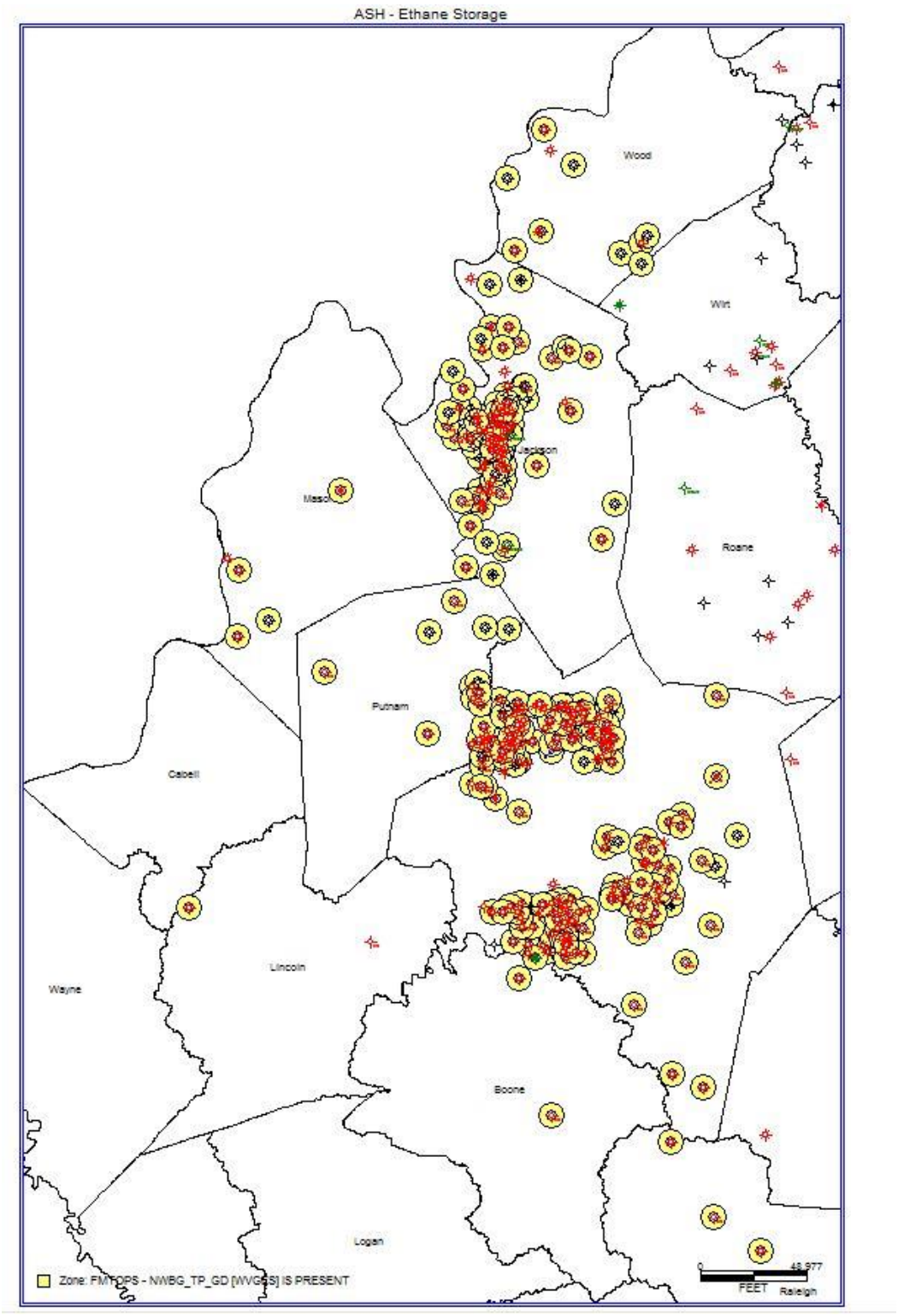


Figure 2.2.1. Wells used to correlate the Newburg sandstone. Yellow circles mark wells with digitized geophysical logs.

2.3 Reservoir Characterization

PAGS will take the lead role on this task, which is scheduled to begin in month 5 of the project (see Appendix 5.2).

2.4 Ranking & Recommendations

Determination of ranking criteria is scheduled to begin in month 8 and will be followed by ranking of potential storage sites, scheduled to begin in month 10 of the project.

3.0 ADMINISTRATION & TECHNOLOGY TRANSFER

3.1 Team Communication

3.1.1 User Groups

Communication within and among all Consortium member groups is essential to the success of this project, as is the efficient, yet secure, assembly and transfer of information. For the purposes of this project, lines of communication and data sharing are divided into three broad User Groups:

Research Group: Members of the Ohio, Pennsylvania and West Virginia Geological Surveys and the NRCCE

Industry Group: Representatives from organizations entered into agreement to support research efforts

Advisory Group: Small subset of individuals with professional experience that can be used to guide Research Group efforts. The Advisory Group is currently comprised of the following members:

Brian Anderson, WVU Energy Institute
Indrajit Bhattacharya, AEP
Ray Boswell, NETL
Dennis Carulli, DC Energy Consultants
Tom Eyermann, Mountaineer NGL
Michael Goodman, Chevron
Peter Swift, EQT

3.1.2 Email Communication

Email listservs for each User Group have been established through the WVGES email provider, WVNet. The Research Group listserv was distributed in October 2016 and is the primary communication method between researchers. The Industry and Advisory group listservs have been populated with member information and test emails are scheduled to be sent on Monday, November 14, 2016. WVGES will be responsible for maintenance and troubleshooting of the email groups.

3.1.3 Monthly Conference Calls

Research team members participate in monthly phone conferences, during which each member of the research team provides a status update on strategy progress to NRCCE.

3.2 Technology Transfer

3.2.1 Kickoff Meeting

The West Virginia University Foundation hosted a Project Kickoff meeting for research team members and representatives of the industry partners on August 18th at the WVU Erickson Alumni Center, Evansdale Campus, in Morgantown. Following an overview of the project, a research lead from each of the three geological survey team members presented a more detailed technical review of their respective roles in the project.

3.2.2 Breakfast Address to First United Bank & Trust Advisory Group Members

At the invitation of Jack Thompson, WVU Corporate Relations Manager, the project's Principal Investigator presented a summary of the project to members of the First United Bank & Trust Advisory Group during a breakfast meeting, August 18th at the Morgantown Hilton Garden Inn.

3.2.3 Public Release of Final Results

The primary technology transfer event will be a full-day workshop at the end of the project period, during which results will be made available to the public.

3.3 Reporting

3.3.1 Quarterly Reports

Written quarterly reports by all team members will be compiled and submitted to the Benedum and WVU foundations, the WVU Research Corporation and the WVU Energy Institute. These reports will be available to all industry members and members of the advisory board through the project website.

3.3.2 Final Report

A final report will be produced by the end of July 2017 and provided to our sponsors and partners, and eventually to the public following a technology transfer workshop for the formal release of the data.

4.0 FINANCIAL UPDATE

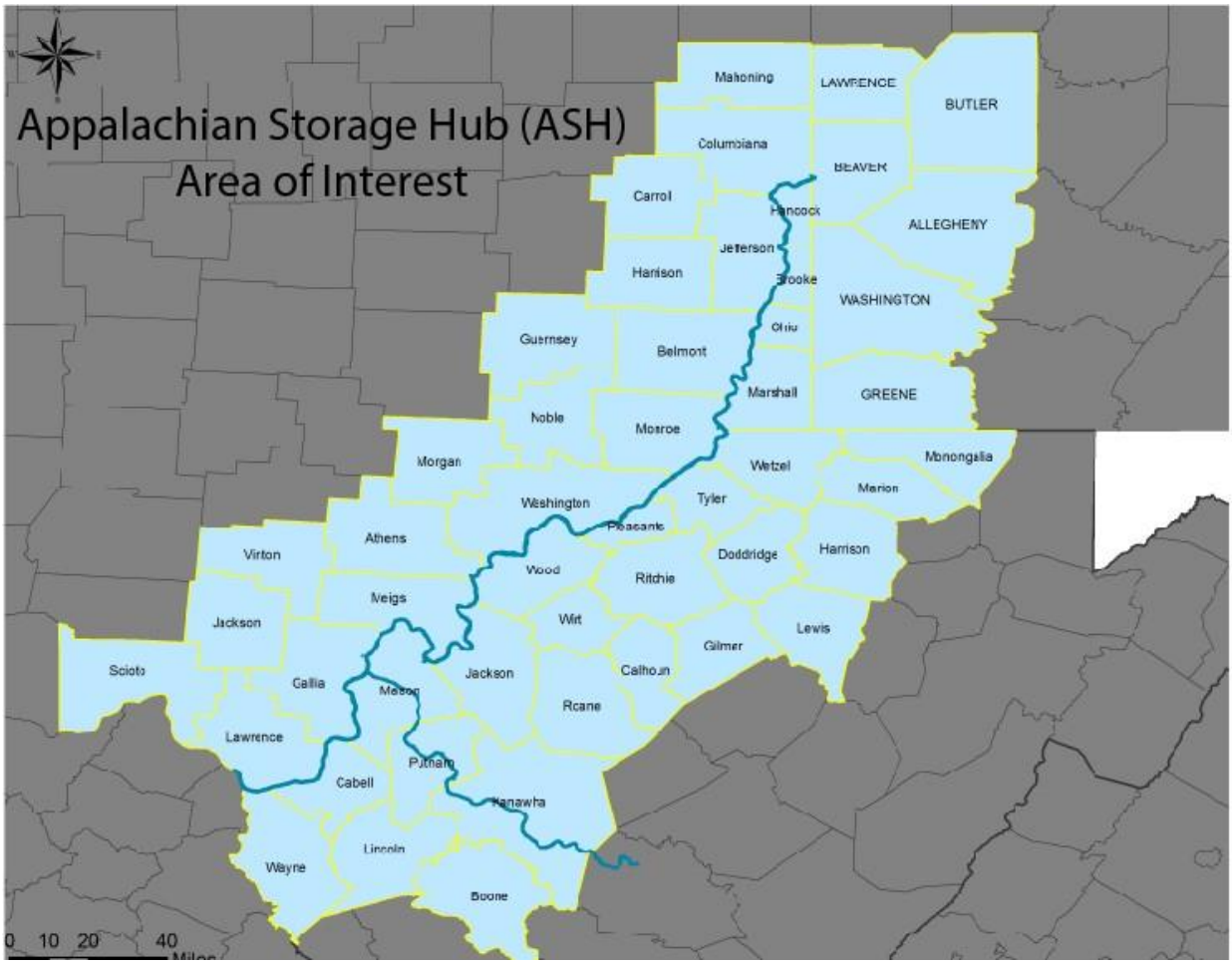
Expenditures during the initial quarter of this one-year project are documented in the following table.

CATEGORY	Funded	Expended	Remaining
Salaries/Fringe Benefits	$17,000		
Supplies	$200		
Travel – includes team meeting costs	$2,800		
Analytical			
Other - Subcontracts	$180,000	$852	$179,148
In-kind match	$60,000	$4,020	$55,128
Total	$260,000	$4,872	$255,128

5.0 APPENDICES

5.1 Appalachian Storage Hub (ASH) Area of Interest

OGS is building the Master PETRA Project, and Kyle Metz is the point of contact for submitting state-specific data in the Area of Interest (AOI). The AOI has been slightly modified to include several more counties in central West Virginia (see below).

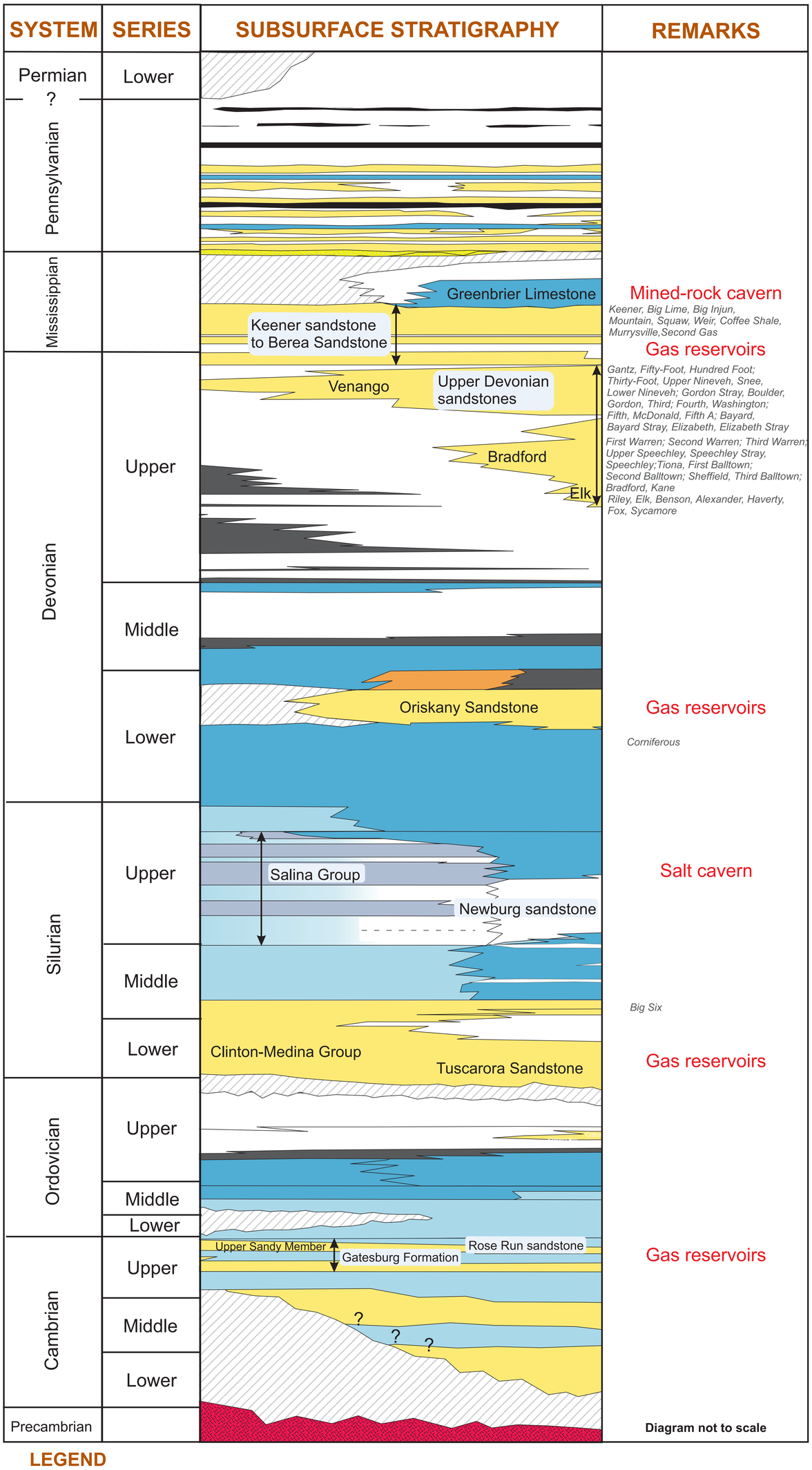


5.2 Project Milestone Chart (revised from initial proposal)

Strategy 1: Data Collection		
• Identify and assemble well log and core data	Month 1	Month 2
• Identify previous studies of interest	Month 1	Month 2
• Create a project database (format, prototype)	Month 1	Month 2
Strategy 2: Stratigraphic correlation of key units		
• Develop cross sections of the Salina Formation	Month 3	Month 8
• Develop cross sections of the Greenbrier Formation	Month 3	Month 8
• Develop cross sections of the Keener to Berea Interval	Month 3	Month 8
• Develop cross sections of the Upper Devonian Sandstones	Month 3	Month 8
• Develop cross sections of the Oriskany Sandstone	Month 3	Month 8
• Develop cross sections of the Clinton-Medina through Tuscarora Interval	Month 3	Month 8
• Develop cross sections of the Rose Run and Upper Sandy Member of the Gatesburg Formation	Month 3	Month 8
Strategy 3: Map the thickness, extent, and structure of potential storage units in the study area		
• Map the Salina Formation	Month 5	Month 7
• Map the Greenbrier Limestone	Month 5	Month 7
• Map the Keener-Berea, Upper Devonian, Oriskany, Clinton-Medina, and Gatesburg Formations	Month 5	Month 7
Strategy 4: Conduct studies of reservoir character		
• Characterize potential storage intervals in the Salina Formation	Month 5	Month 8
• Characterize potential storage intervals in the Greenbrier Formation	Month 5	Month 8
• Characterize potential storage pools in gas-depleted sandstone reservoirs	Month 5	Month 8
Strategy 5: Develop ranking criteria for potential storage zones		
• Determine criteria and weighted priority of potential storage zones	Month 8	Month 9
Strategy 6: Recommendations		
• Rank all candidates within each category	Month 10	Month 11
• Rank the top candidates in each category	Month 10	Month 11
Strategy 7: Suggestions for engineering follow-up study		
• Make suggestions for additional field and lab studies	Month 10	Month 11
Strategy 8: Project management and technology transfer		
• Project management	Month 1	Month 12
• Final Report	Month 11	Month 12
• Technology transfer		Month 12+ ongoing

5.3 Appalachian Storage Hub (ASH) stratigraphic intervals of interest (next page)

REGIONAL SUBSURFACE ROCK CORRELATION DIAGRAM
APPALACHIAN STORAGE HUB PROJECT



LEGEND

- Sandstone
- Siltstone and shale
- Organic-rich shale
- Coal
- Limestone
- Evaporite/salt
- Chert
- Dolostone
- Unconformity
- Crystalline basement rock

Murrysville — Drillers' Sand Names

Gas reservoir — Type of potential storage

5.4 Project Members

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*Advisory Board members, including several from partner companies