Field Laboratory for Emerging Stacked Unconventional Plays (ESUP)

PI: NINO RIPEPI

CO-PIS: MICHAEL KARMIS, CHENG CHEN, ELLEN GILLILAND, BAHAREH NOJABAEI
Objective:
- Investigate and characterize the resource potential for multi-play production of emerging unconventional reservoirs in Central Appalachia.

Project Team
- Virginia Tech
- Virginia Center for Coal & Energy Research
- EnerVest Operating, LLC
- Pashin Geoscience, LLC
- Gerald R. Hill, PhD, Inc.

Funding: $11.1 million ($8 million federal)
- Cost-Share:
  - EnerVest - Lower Huron horizontal well ($2.2 million), plus personnel time (100K+)
  - Virginia Tech - personnel time (800K+)

Duration
- April 1, 2018 – March 31, 2023 (5 years)
**Objective and Goals**

- **Objectives:**
  - Investigate and characterize the resource potential for multi-play production of emerging unconventional reservoirs in Central Appalachia.
  - **Goal 1:** Drill and selectively core a deep vertical stratigraphic test well up to 15,000 feet to basement through Conasauga-Rome Petroleum System.
  - **Goal 2:** Drill at least one multi-stage lateral well in the Lower Huron Shale for completion using non-aqueous fracturing techniques, such as CO_2 or high rate N_2 with proppant.
  - Laboratory analysis, reservoir simulation, and monitoring observations will be integrated.
  - An assessment will be made of the multi-play resource potential and a recommended strategy advanced for prudent development that considers regional environmental and socioeconomic impacts.
Project Team
<table>
<thead>
<tr>
<th>Year</th>
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<th>Q4</th>
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### BP I

- **Task 1**: Project Management and Planning
  - Task 2: Data Mgmt. Plan
  - Task 3: Est. Advisory Board

### BP II

- **Task 4**: Risk Characterization, Management and Mitigation

### BP III

- **Task 5**: Project Reporting, Dissemination of Results, and Outreach
  - Task 6: Site Selection
  - Task 7: Geo. Characterization of ESUP Field Lab
  - Task 8: ESUP Field Lab Design, Const., and Ops.

### Additional Tasks
- **Task 9**: Post-operatons Data Analysis
- **Task 10**: Site Closure
BP I

**Task 1**  
Project Management and Planning
- 5/1/18: Project Management Plan

**Task 2**  
Data Mgmt. Plan
- 8/1/18: Data Management Plan

**Task 3**  
Est. Advisory Board
- 2/1/19: Risk Management Plan
- 3/1/19: Risk Register

**Task 4**  
Risk Characterization, Management and Mitigation
- 2/1/19: Outreach and Education Plan

**Task 5**  
Project Reporting, Dissemination of Results, and Outreach
- 10/1/18: Geo. Char. and Design Report
- 2/1/19: NEPA EQ

**Task 6**  
Site Selection
- 11/1/18: Site Sel. Report, Upd. AFE
- 2/1/19: GO/NO-GO 1
<table>
<thead>
<tr>
<th>Task</th>
<th>Description</th>
<th>Start Date</th>
<th>End Date</th>
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<td>12/1/19</td>
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<td>Geo. Characterization of ESUP Field Lab</td>
<td>4/1/19</td>
<td>12/1/19</td>
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**Timeline:**
- **4/1/19:** Sampling and Analysis Plan
- **12/1/19:** ESUP Field Lab Design and Plan, Compliance
- **3/1/2020:** Baseline Monitoring Report
- **4/1/19:** Drill Vertical Char. Well
- **12/1/19:** GO/NO-GO 2
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<th>Task</th>
<th>Description</th>
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<td>Task 8</td>
<td>ESUP Field Lab Design, Const., and Ops.</td>
<td>Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec</td>
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- 4/1/20: Drill and Complete Lower Huron Well(s)
- 6/1/20: Drilling and Completion Reports
- 6/1/20: GO/NO-GO 3
<table>
<thead>
<tr>
<th>Task 1</th>
<th>Project Management and Planning</th>
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<td>Task 4</td>
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<tr>
<td>Task 9</td>
<td>Post-operations Data Analysis</td>
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<tr>
<td>Task 10</td>
<td>Site Closure</td>
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</table>
**BP III**

**Task 1**
Project Management and Planning

**Task 4**
Risk Characterization, Management and Mitigation

- **4/1/2023:** Submit Data to EDX

**Task 5**
Project Reporting, Dissemination of Results, and Outreach

- **4/1/2023:** ESPU Field lab Report

**Task 9**
Post-operations Data Analysis

**Task 10**
Site Closure
Advisory Stakeholder Group (ASG)

- High priority task
- Membership discussion with individuals has commenced
- Plan for approximately 8 Board Members
  - Technical Experts with experience in geology and shale development in the region
  - Environmental community representatives
  - Local Community leaders, including elected officials
Big Sandy Field Summary

Discovery: 1915
Location: E Kentucky – SW West Virginia
Wells Drilled: >10,000
1st Hz Well: 2006 (IHS Data)
Hz Wells Drilled: ~950 (IHS Data)
Cum Prod: >2.5 Tcfg (estimated)
Target(s): Lower Huron Sh., Cleveland Sh.
Reservoir: Naturally Fractured Black Shale
Huron Thickness: 100-300 ft.

Source: The Atlas of Major Appalachian Gas Plays

Nora Area Summary

Discovery: 1948
Location: W Virginia
Wells Drilled: ~700 (IHS Data)
1st Hz Well: 2007 (IHS Data)
Hz Wells Drilled: ~60
Target(s): Lower Huron Sh., Rhinestreet Sh.
Reservoir: Black Shale
Huron Thickness: 100-300 ft.
Nora Field - Stratigraphy

- Current Stacked Unconventional Plays
  - Coalbed Methane (Pennsylvanian)
  - Big Lime (Mississippian)
  - Weir Sand (Mississippian)
  - Berea Sand (Mississippian)
  - Lower Huron Shale (Devonian)
## Deep Targets for Vertical Characterization Well

<table>
<thead>
<tr>
<th>Layer</th>
<th>Contents</th>
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<tbody>
<tr>
<td><strong>Devonian</strong></td>
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<tr>
<td>Huron Shale</td>
<td></td>
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<tr>
<td>Okentangy Shale</td>
<td></td>
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<tr>
<td>Rhinestreet Shale</td>
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<tr>
<td>Marcellus Shale</td>
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<tr>
<td>Corniferous (Onondaga) Ls</td>
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<tr>
<td>Oriskany Ss</td>
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<tr>
<td><strong>Silurian</strong></td>
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<tr>
<td>Salina Dol / Ls</td>
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<tr>
<td>Keefer Ss / Big Six Ss</td>
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<tr>
<td>Clinton Group / Rose Hill Fm</td>
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<tr>
<td>Tuscarora Ss / Clinch Ss</td>
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<tr>
<td><strong>Ordovician</strong></td>
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<tr>
<td>Juniata / Sequatchie Shale</td>
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<tr>
<td>Trenton Ls</td>
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<tr>
<td>Black River Ls</td>
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<td>Beekmantown Grp / Knox Dol / Rose Run Ss</td>
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<tr>
<td><strong>Cambrian</strong></td>
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<tr>
<td>Copper Ridge / Conococheague Dol</td>
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<tr>
<td>Corasauca ( Nolichucky / Rogersville / Pumpkin Valley Shale)</td>
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<td>Rome Fm</td>
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<td>Basal Ss</td>
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<td><strong>PreCambrian Basement</strong></td>
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EnerVest, 2018
Conasauga/Conasauga-Rome Petroleum System
Geochemical evidence suggests Cambrian source rocks are present in the Rome Trough
- Correlated with oils in Homer Gas field, KY
- Rome Trough primarily in eastern KY, WV, and PA
- Floyd Embayment (red) extends system boundaries into SW VA
Magnetic and gravity anomalies are proxies for Rome Trough and Precambrian structure.

The borders of the Floyd Embayment are ambiguous and are poorly understood in Virginia.

Gravity and magnetic data suggests that the Floyd Embayment intersects western portions EnerVest acreage.
Oil and Gas Shows near VA
Recent Rogersville Shale Activity

- **Stevens J et al #LAW 1 Chesapeake Appalachia Vertical Strat Test**
  - TD Date: 5/19/2015
  - Fm @ TD: Rome Fm
  - TD: 11,651 ft.

- **Young S #1 Bruin Exploration (Cimarex) Vertical Strat Test**
  - TD Date: 5/30/2014
  - Fm @ TD: Rome Fm
  - TD: 12,169 ft.

- **EQT Prod Co #572360 H Horizontal Tech Energy Co (EQT) Horizontal Rogersville Test**
  - TD Date: 6/7/2015
  - Fm @ TD: Rogersville Shale
  - TD: 13,383 ft. MD
  - Shut In

- **JH Northrup Estates #LAW 1 Chesapeake Appalachia Vertical Strat Test**
  - TD Date: 9/3/2015
  - Fm @ TD: Shady Dolomite
  - TD: 15,950 ft.

- **Walbridge Holdings #1H Bruin Exploration (Cimarex) Horizontal Rogersville Test**
  - TD Date: 2/23/2017
  - Fm @ TD: Rogersville Shale
  - TD: 16,108 ft. MD
  - Temporarily Abandoned

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**Rogersville Shale Tests**

- **Nora Acreage**
Lower Huron Core Distribution

Core Inventory

- 4 Whole Cores
- 3 Sidewall Cores

Cores By State

- VA: 4
- KY: 2
- WV: 1

EnerVest, 2018
Nora Field - Petrophysical Summary

- Water Saturation
  - Reservoir has high Vclay (30-50%), all non-swelling clays that are typical of higher maturity reservoirs
  - Reservoir is “dehydrated” - contains less water than would be anticipated in a high clay content reservoir
  - The above factors (along with pressure) contribute to issues with water based completions

- Maturity - directly related to depth
  - Kentucky wells are less mature (shallower); Virginia wells are more mature (deeper)
  - The Virginia Lower Huron play is within the dry gas window of Huron play

- TOC
  - Fairly high at 2-3% average (up to 8% in areas)

- Porosity
  - Fairly low 4-6% total (2-3% gas-filled porosity)

- Desorbed & Adsorbed Gas
  - Adsorbed gas likely accounts for 30-60% of total GIP – important consideration in regards to completion methodology
## Lower Huron Petrophysical Cutoffs

<table>
<thead>
<tr>
<th></th>
<th>2% TOC</th>
<th>3% TOC</th>
<th>4% TOC</th>
<th>5% TOC</th>
<th>6% TOC</th>
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<tr>
<td>Gamma (API)</td>
<td>216</td>
<td>264</td>
<td>312</td>
<td>360</td>
<td>407</td>
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<tr>
<td>Rhob (g/cc)</td>
<td>2.68</td>
<td>2.64</td>
<td>2.59</td>
<td>2.55</td>
<td>2.50</td>
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<tr>
<td>Resistivity (Ohmm)</td>
<td>37</td>
<td>61</td>
<td>99</td>
<td>160</td>
<td>259</td>
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- A series of maps were generated for each of the above petrophysical cutoffs for each of the following intervals:
  - Lower Huron Undifferentiated
  - “Lower” Lower Huron
  - “Middle” Lower Huron
  - “Upper” Lower Huron

- Combination maps were also generated combining multiple cutoffs
  - i.e. 264 API & 2.64 g/cc = 3% TOC

- Mapping was utilized to high grade Lower Huron potential with EnerVest’s acreage position
Lower Huron Delineation/Nomenclature

<table>
<thead>
<tr>
<th>Kentucky</th>
<th>Virginia</th>
<th>W. Virginia</th>
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Upper
Middle
Lower

EnerVest, 2018
“Lower” Lower Huron

Thickness exceeding 3% TOC (feet) vs. Normalized initial 2-year production (MMcf/1000’ lateral)

264 API = 3% TOC
2.64 g/cc = 3% TOC
61 Ohmm = 3% TOC

EnerVest, 2018
"Middle" Lower Huron
Thickness exceeding 3% TOC (feet) vs. Normalized initial 2-year production (MMcf/1000’ lateral)

264 API = 3% TOC
2.64 g/cc = 3% TOC
61 Ohmm = 3% TOC

EnerVest, 2018
“Upper” Lower Huron
Thickness exceeding 3% TOC (feet) vs. Normalized initial 2-year production (MMcf/1000’ lateral)

- 264 API = 3% TOC
- 2.64 g/cc = 3% TOC
- 61 Ohmm = 3% TOC

EnerVest, 2018
Well Log TOC Correlation

Gamma, Rhob, Resistivity Interpolation = 3% TOC
Focus Area Determination

Combined Gamma/Rhob Cutoff Mapping (264 API & 2.64 g/cc = 3% TOC)
Potential Test Locations

Normalized EUR (MMcf/1000’ lateral)

- Petrophysics suggests optimal location for Lower Huron horizontal well
- Gravity and magnetic data suggests location is also suitable for deep vertical well
- Both wells in close proximity is optimal for ESUP Field Laboratory studies
Land Overview

Potential Test Locations

- Potential site (440 ac.) favorable with respect to road access and cultural impact

- 2nd Potential site (400 ac.) favorable with respect to land control issues

- Both sites are favorable with respect to geology and infrastructure availability
Land Overview

Potential Test Locations: Road Access, Cultural Impact

- 5.2 Miles
- 2.9 Miles

EnerVest, 2018
Land Overview

Potential Test Locations: Infrastructure Availability

530555
Deep Test

530556
L. Huron Test

Fork Ridge Compressor
Suction: 3 Psi
Discharge: 1000 Psi
Available Capacity: 9.4 MMCFPD
Distance to Compression: 5.3 Miles

4" Pipeline
6" Pipeline
8" Pipeline
12" Pipeline

EnerVest, 2018
Nora Field - Reservoir Pressure

- Reservoir pressure gradient significantly lower than any of the major US shale plays

- Low reservoir pressure significantly limits completion options
  - Historic completions dominated by N₂ fracs and limited ability to place proppant
  - Water fracs – Can fluid from large scale SW jobs be recovered in low pressure environment? Artificial lift requirements?
  - Foam fracs in cemented completions difficult to initiate

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<td>Marcellus</td>
<td>0.50 - 0.80</td>
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<td>Eagle Ford</td>
<td>0.7</td>
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<td>Barnett</td>
<td>0.4 - 0.52</td>
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<td>Fayetteville</td>
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<td>Antrim</td>
<td>0.35</td>
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<td>Lower Huron</td>
<td>0.22</td>
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Core Analysis Workflow

Digital Rock Analysis
- X-ray CT and SEM scanning
- Visualization of microfractures
- Rock density variation
- Nano-scale shale structure
- Pore-scale flow modeling

Geomechanical Analysis
- Poisson’s ratio and Young’s modulus
- Confined and unconfined compressive strength
- Brinell hardness number
- Brazilian tensile strength
- These properties are critical for fracturing design

Petrophysical Analysis
- RockEval tests for total organic carbon (TOC)
- X-ray Diffraction Analysis (XRD) for mineralogy
- Permeability measurement using pulse decay permeameter (PDP-200), NanoK, and SMP-200 (all equipment from CoreLab)
- Fracture Conductivity Cell
- These properties are critical for finding the “sweet spots”
Core Analysis Workflow

Lattice Boltzmann (LB) Method is used for pore flow simulation based on the CT images.

It is a meso-scale numerical method to recover macroscopic hydrodynamics.

3D, multiscale X-ray CT scanning from core to nm scales.
Optimization of Fracturing and Proppant Placement

Proppant pumping optimization to achieve the highest return on fracturing investment (ROFI) (Gu et al., 2017, SPE-185071).
Optimization of Fracturing and Proppant Placement

Regular sand proppant:
Fast settlement near the well

Ultra-light-weight proppant:
Uniform placement along fracture
Optimization of Fracturing and Proppant Placement

Regular sand proppant:
Fast settlement near the well

Ultra-light-weight proppant:
Uniform placement along fracture

Fracture modeling gives **proppant concentration** (lb/ft²) distribution in fracture length and height directions
Optimization of Fracturing and Proppant Placement

Regular sand proppant:
Fast settlement near the well

Ultra-light-weight proppant:
Uniform placement along fracture

Fracture modeling gives proppant concentration (lb/ft²) distribution in fracture length and height directions

Pore-scale, DEM/LB-coupled modeling gives “fracture conductivity vs proppant concentration” curves under various closure pressures (Fan et al., 2018)
Optimization of Fracturing and Proppant Placement

Regular sand proppant:
Fast settlement near the well

Ultra-light-weight proppant:
Uniform placement along fracture

Fracture modeling gives proppant concentration (lb/ft²) distribution in fracture length and height directions

Pore-scale, DEM/LB-coupled modeling gives “fracture conductivity vs proppant concentration” curves under various closure pressures (Fan et al., 2018)

These two pieces of information are combined to obtain fracture conductivity distribution in the hydraulic fracture for larger-scale reservoir simulation
Reservoir Simulation Model

- Simulations will be used to design the ESUP Field Laboratory, including designs for drilling, completions, and monitoring.

- The modeling effort will include the use of a commercial reservoir simulator (if applicable) and the development of an in-house simulation tool.

- The in-house simulation model includes diffusion and nano-porous media confinement effects, and that can simulate reservoir response to hydraulic fracturing with non-aqueous fluids such as CO2.

- Fast, yet accurate, compositionally-extended black oil models will be developed that can incorporate the complexities associated with shale reservoirs during treatment and production.
Monitoring Program

- Monitoring + Operations Timeline
  - Historical data → Simulations → Define Area of Review (AOR)
  - Baseline data acquisition
  - Monitoring while Drilling
  - Characterization data → HF design
    - Non-aqueous fluid
    - Alternative/multiple proppants
  - Monitoring of HF treatment
  - Post-operations monitoring

Schematic Overview of ESUP Field Lab

Deep Characterization Well
Target depth: 15,000 ft

20-stage Completion
Lateral Gas Production Well
Lower Huron Shale

Reservoir Permeability
(mD)

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Monitoring Program

- Potential Methods: Atmospheric, Near-surface, Subsurface, Sub-reservoir Technologies
  - Offset gas and water sampling
  - Tracer studies
  - Reservoir imaging (e.g., microseismic monitoring)
  - Deep monitoring installation in Deformation monitoring
  - Production monitoring

- Deliverables: Sampling and Analysis Plan, Initial (Baseline) Monitoring Report, Final Scientific/Technical Report, NETL-EDX Final Project Files

Schematic Overview of ESUP Field Lab

- Deep Characterization Well Target depth: 15,000 ft
- 20-stage Completion Lateral Gas Production Well Lower Huron Shale
- Reservoir Permeability (mD)
Questions and Acknowledgments

- Nino Ripepi
  - nino@vt.edu
  - 540-231-5458

Acknowledgments

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