Criteria for sustainable energy solutions

Solving three simultaneous equations:

\[ f(x_1) = \text{sound science and technology} \]
\[ f(x_2) = \text{consistency with policy which adequately addresses the welfare of society} \]
\[ f(x_3) = \text{financial viability to attract the interest of investors} \]

= complexity

multidisciplinary studies for interdisciplinary solutions
<table>
<thead>
<tr>
<th>Region</th>
<th>Gas Tcf</th>
<th>Oil Bbbl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barnett</td>
<td>~16,500</td>
<td>~63,000</td>
</tr>
<tr>
<td>Fayetteville</td>
<td>~6,000</td>
<td>~35,000</td>
</tr>
<tr>
<td>Haynesville</td>
<td>~6,500</td>
<td>~13,000</td>
</tr>
<tr>
<td>Marcellus</td>
<td>~75,000</td>
<td>~500,000</td>
</tr>
<tr>
<td>Permian Basin</td>
<td>~16,500</td>
<td>~90,000</td>
</tr>
<tr>
<td>Bakken/Three Forks</td>
<td>~18,000</td>
<td>~100,000</td>
</tr>
</tbody>
</table>

**Gas Production and Recovery**

- **Original In-Place**
  - Barnett: ~3100 Tcf
  - Fayetteville: ~10,500 Tcf
  - Marcellus: ~10,500 Tcf
  - Permian Basin: ~10,500 Tcf

- **Tech. Recoverable**
  - Barnett: 780 Tcf
  - Fayetteville: ~780 Tcf
  - Marcellus: ~6,500 Tcf
  - Permian Basin: ~75,000 Tcf

- **Production to date**
  - Barnett: 70 Tcf
  - Fayetteville: ~70 Tcf
  - Marcellus: ~6,500 Tcf
  - Permian Basin: in progress

- **Horizontal wells to date**
  - Barnett: ~75,000
  - Fayetteville: ~75,000
  - Marcellus: ~10,500
  - Permian Basin: in progress

- **Future wells (base case)**
  - Barnett: ~500,000
  - Fayetteville: ~500,000
  - Marcellus: ~200,000
  - Permian Basin: in progress
3,553 TCFG
Total Technically Recoverable Reserves are over 50 years current annual Consumption.
170 BBO Total
Technically Recoverable Reserves are over 23 years current annual Consumption.
Hydrocarbons account for two-thirds of the United States Energy Sources. The United States Economy and Economic Standing in the World has historically, continues to develop, and operates on clean, inexpensive energy. Developing Countries and those in Poverty need inexpensive energy sources to develop and compete.
Externalities of Oil & Gas Extraction:

U.S. Oil & Gas Industry accounts for 8% of national GDP and uses approximately 2% of U.S. water supply.

U.S. Oil & Gas Industry has reduced emissions 26% in the last several years while doubling production. A greater than 50% decrease per energy unit.
1. Innovators are Small Independents, individuals or small companies.
2. Fee (Private) Mineral Ownership.
3. Infrastructure.
   a. Fields, pipelines,
   b. Service Companies,
   c. Information,
   d. Technology
      (i). Drilling,
      (ii). Completions.
4. Marginal Economics per well and total CapEx.
What is a Super-basin?
More than 5 billion Boe cumulative production
More than 5 billion Boe remaining production
Multiple source rocks – petroleum systems
An assemblage of reservoirs and Stacked pays
Established infrastructure – access to markets
Established service sector & supply chains
Permian Basin – “super basin” prototype architecture onshore, unconventional, geology and engineering

1) Four source zones; three low in pile; 2) Maturation due to Permian subsidence for most of basin; 3) Late salt seal reduces leakage;

Argentina Neuquen Bains, Vaca Muerta

MAP

AGRO
Organic-rich shales.
Thickness: 50 to 400 m
TDC: 2-5%
Kerogen Type: II to II-III
Source Quality/Maturity: mostly oil prone

VACA MUERTA
Organic-rich shale and marls.
Thickness: 25 to 700 m
TDC: 3-17%
Kerogen Type: III; locally restricted type II-3 facies

LOS MOLLES
Organic-rich shales - initial sag stage of the basin.
Thickness: 100 to 800 m.
TDC: 1-5%
Kerogen Type: II-III.
Source Quality/Maturity: mixed for oil and gas.

Russia, W. Siberian Basin

Cross Section

Simple Basin, Super Basin

MAP

Data and maps from IHS as of January, 2018

Milkov (2018)
1) Three main sources, two low in section  
(Jurassic, mid-Cretaceous)  
2) Generation continuing at present  
3) Repetition of oil window by salt nappe(s)  
4) Strong vertical migration, no superseal; leaky basin

Courtesy Tom Ewing, 2018; Cindy Yielding 2018; Otaviano Pessoa 2018
Production Rejuvenation of “mature basin”
Permian 1958 to 2019+

Back to the Future!

1) Be a part of the Energy Solution
2) Be a lifelong learner
3) Be proactive in professional organizations, say yes!
Oil and gas advocacy

Colin Leyden
U.S. O&G Supply Chain
2015 Methane Emissions

- Drilling & Production: 7.6 Tg (1.3%)
- Gathering & Processing: 3.5 Tg (0.6%)
- Transmission & Storage: 3.3 Tg (0.6%)
- Local Distribution: 2.7 Tg (0.5%)
- Methane Synthesis: 1.8 Tg (0.3%)
- 2017 EPA GHG Inventory (For year 2015):
  - Drilling & Production: 1.3 Tg (0.2%)
  - Gathering & Processing: 1.4 Tg (0.2%)
  - Transmission & Storage: 0.44 Tg (0.1%)
  - Local Distribution: 0.44 Tg (0.1%)

Methane Synthesis
Alvarez et al 2018

2017 EPA GHG Inventory
(For year 2015)
Flaring In Texas

- 4.4% of all Permian gas in 2017
- 1 Trillion cubic feet 2012-2017 statewide
As I said at the oil & gas session @Davos today, the world will use oil & gas for several years to come, but much more needs to be done to reduce their emissions:

- Lower methane leaks
- Capture CO2
- Use renewables in operations
- Step up bio-methane & hydrogen

#wef19
7:15 AM - 23 Jan 2019
128 Retweets 228 Likes
Unconventional oil & gas development: environmental impacts

Sheila Olmstead
The University of Texas at Austin & Resources for the Future

Energy Week
February 5, 2019
U.S. unconventional production has generated significant benefits.

- Selected economic benefits of the boom in U.S. unconventional oil and gas production:
  
  - U.S. natural gas price dropped 47% compared to a counterfactual without new U.S. production, 2007-2013, generating $74 billion/year in benefits to U.S. consumers (Hausman and Kellogg 2015).

  - New oil and gas extraction increased aggregate US employment by up to 640,000, and decreased the unemployment rate by 0.43 during the Great Recession (Feyrer et al. 2017).

  - U.S. personal income increased in 2014 alone by $67 billion (0.5%) due to oil and gas royalty income (Brown et al. 2019).

  - Coal-to-gas switching in electricity generation (due to cheap gas) has reduced local air pollution concentrations, with associated health benefits of ~$17 billion/year (Johnsen et al. 2019).
What about environmental costs?

- Research has established links between fracking and local/regional air pollution, surface water pollution (Olmstead et al. 2012), groundwater contamination, greenhouse gas emissions, seismicity from waste disposal, increased accidents (Muehlenbachs et al. 2017), etc.

- Markets capitalize some risks:
  - In PA, groundwater-dependent homes within 1.5 km of a shale gas well lose 10-17% of their market value, relative to homes at the same distance that use municipal piped water (Muehlenbachs et al. 2015).
  - OK homes in seismically-active regions lose 3-5% of their market value at the onset of the earthquake boom from produced water injection (Metz et al. 2017).

- Which potential environmental costs from unconventional production are likely to be most significant, and what can communities, firms, and regulators do?