Technology & the Global Energy Transition

Scott W. Tinker
Outline

• Global Energy
• Shale
• CCS
• Subsurface Sensors
• Energy Storage
Energy Mix

Source: United States basins from U.S. Energy Information Administration and United States Geological Survey; other basins from ARI based on data from various published studies.
Global Population and Energy

Forecast

Asia

Africa

Rest of World

Source: From the UN, as appeared in The Economist, August 23, 2014
Energy Demand

Source: United States basins from U.S. Energy Information Administration and United States Geological Survey; other basins from ARI based on data from various published studies.
Global Oil Production

OECD  Non-OECD

Source: BP Statistical Review 2012
Global Oil Production

- OPEC
- Non-OPEC
- FSU

Source: BP Statistical Review 2012
Global Oil Production

- Total North America
- Total S. & Cent. America
- Total Europe & Eurasia
- Total Middle East
- Total Africa
- Total Asia Pacific

Source: BP Statistical Review 2012

30.5 BBY

Source: BP Statistical Review 2012
Liquids
Future Transportation Mix

Long-Term Oil Supply

Resources and Cost

- Global Consumption: 31 Bby

- Resources (billion barrels):
  - Coal to liquids
  - Gas to liquids
  - Oil shales
  - Shale oil
  - Ultra-deepwater
  - Oil sands & bitumen
  - Heavy oil & bitumen
  - Other conventional oil
  - Gas to liquids

- Production cost (2008 $):
  - Low: 0-20
  - Medium: 40-80
  - High: 100-140

- Total resources: ~200 year total resource

Annual US Oil Production

2010 U.S. SHALE LIQUIDS PROJECTION

United States Consumption ~ 7 Bby

~ 1.4 Bby from shale by 2022

After Morse et. al., 2012, Energy 2020: North America, the new Middle East: Citi GPS: Global Perspectives & Solutions, figure 14, p. 17.
Annual US Oil Production

~ 50% of U.S. Production from Shale by 2022

U.S. Production ~ 3.1 Bby 2014

Annual US Oil Production
Options to Oil

I. Unconventional Oil Reservoirs

II. Biofuels

- Land, water, conversion, scale

IV. Natural Gas (CNG, LPG, LNG)

- Deliverability and access

IV. Electricity (Batteries)

- Charging today means coal, natural gas, nuclear...

v. Hydrogen (fuel cells)

- Just ten years away!

after Tinker, et.al. GSA Special Pub, 2013
Global Natural Gas Production

Source: BP Statistical Review 2012
Global Natural Gas Production

Source: BP Statistical Review 2012

Total North America
Total S. & Cent. America
Total Europe & Eurasia
Total Middle East
Total Africa
Total Asia Pacific

115 Tcfy
Global Natural Gas

Resources v. Cost

Global Consumption
115 TcFy

~ 300 year total resource

U.S. Natural Gas

Production and Reserves

Data: BP World Energy 2012
U.S. Natural Gas

Production (TcF)

An Anticipated Evolution

From a 2004 Tinker Talk to the IPAA
US Natural Gas 2004 forecast

- Total Natural Gas
- Conventional Gas
- Unconventional Gas


http://www.eia.gov/energy_in_brief/about_shale_gas.cfm
Forecast vs. Actual

Model: Rice University, Medlock, 2012

Actual
Options to Natural Gas for Power

I. Coal
   - Available, affordable to generate, reliable
   - Dirty, expensive to build

II. Nuclear
   - Efficient, no emissions, affordable generation
   - Expensive to build, waste, safety

III. Wind
   - Simple, affordable, no emissions
   - Intermittent, land and visual, transmission

IV. Solar
   - Simple, no emissions, local
   - Intermittent, land, transmission

V. Hydro
   - Efficient, affordable to generate, no emissions
   - Water, land, drought

VI. Geothermal
   - Affordable where concentrated, no emissions
   - Geology

after Tinker, et.al. GSA Special Pub, 2013
The Economy and Energy

**U.S. Economy and Oil Price**

Data: BP Statistical Analysis; US Department of Commerce

1970-1983 Arabian Light  
1984 Brent dated

Year

GDP Growth (% change on 2000 chained dollars)

Oil Domestic Wellhead Price (2013 $)
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Shale

- Reserves and Production
- Water
- Induced Seismicity
- Characterization
What is the total resource base in place?

What portion is technically recoverable?

What potion is economically recoverable?

What is the long-term production outlook?
Barnett

Monte Carlo Production Distribution

Relative Frequency

Cumulative Production (Tcf)

OGIP 444 TcF

35 Tcf

56 Tcf

Browning, J. et al. 2013. SPE Econ & Mgmt
Fayetteville
Monte Carlo Production Distribution

Relative Frequency

Cumulative Production (Tcf)

OGIP 80 TcF

13 TcF

23 TcF

BEG Shale Reserves and Production Project
Environmental Impact

Not to Scale!

After JP Nicot, Bureau of Economic Geology
Environmental Impact

1000’s of Feet of Rock

Drawn to Scale
Shale3

- Reserves and Production
- Water
- Induced Seismicity
- Characterization
Industry and Water

Companies* that have experienced water-related problems that affect their business, 2014

<table>
<thead>
<tr>
<th>Industry</th>
<th>% of respondents by industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utilities</td>
<td>50</td>
</tr>
<tr>
<td>Consumer staples</td>
<td>40</td>
</tr>
<tr>
<td>Materials</td>
<td>30</td>
</tr>
<tr>
<td>Energy</td>
<td>20</td>
</tr>
<tr>
<td>Consumer discretionary</td>
<td>10</td>
</tr>
<tr>
<td>Industrials</td>
<td>0</td>
</tr>
<tr>
<td>Healthcare</td>
<td>0</td>
</tr>
<tr>
<td>IT</td>
<td>nil</td>
</tr>
</tbody>
</table>

*Largest 500 companies in FTSE Global Equity Index

Source: CDP; The Economist, November 8, 2014
Texas Water Use

- 2011 water use for thermoelectricity: 0.41 maf
- 2010 water withdrawal for other sectors: 14 maf

Source: Scanlon et al., 2013
Texas Water Use

2011 water use for thermoelectricity: 0.41 maf
2010 water withdrawal for other sectors: 14 maf

Source: Nicot and Scanlon, 2012, ES&T

Source: Scanlon et al., 2013
Water and Fracking

- Use of Brackish or De-sal water
- Recycle
- Reuse
- Alternate fluids
- Dry Fracks
Shale

- Reserves and Production
- Water
- Induced Seismicity
- Characterization
Historical Earthquakes (>M3.0)

- 1978 Snyder M4.6
- 2013 Azle M3.6
- 2012 Timpson M4.8
- 1992 Andrews M4.6
- 1995 Marathon M5.7
- 2011 Fashing M4.8
Disposal Wells in Texas

Seismometers for Texas

Source: Data from IHS database, 2014

Injection well depth (ft)
- < 1,000
- 1,000 - 2,500
- 2,500 - 5,000
- 5,000 - 10,000
- < 10,000
Irving, Texas Recent Events

Source: DeShon, Stump, et.al, SMU, 2015
TexNet

Proposal
- Install 22 new permanent seismograph stations in Texas
- Acquire ~36 portable seismographs
- Create a BEG-housed facility to deploy and maintain the network

Goal
- Locate/catalog Texas earthquakes
- Provide information and education

Why Texnet?
- Currently, no Texas organization is responsible for providing information about seismicity, or investigating/evaluating earthquakes
- Railroad Commission now requires summary information about nearby seismicity to accompany permit applications
- U.S. Geological Survey routinely locates earthquakes in Texas, but reliably only events with M>3, & location errors 5-15 km
Hope to Improve…

- Pre-Disposal Characterization
- Baseline Seismicity
- Risk/Impact Understanding
- Event Reaction Time
- Public Education
- Freedom to Operate
Shale

- Reserves and Production
- Water
- Induced Seismicity
- Characterization
Environmental Impact

Barnett Shale Mapped Frac Treatments/TVDS

Source: Fisher and Warpinski SPE, 2012
To describe anisotropy, one needs at least 4 elastic parameters, but only 3 of those can be estimated reliably from either surface seismic measurements or borehole measurements.

[Yanadet and Fomel] discovered an alternative set of 4 parameters, such that two of them (q1 and q3) are strongly correlated and can be reduced to one.

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\[ q_1 = 0.83734 q_3 + 0.15810 \]

\[ R^2 = 0.98771 \]
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- Subsurface Sensors
- Energy Storage
Climate and Carbon

- Climate Modeling
- Emissions
- Tax, Cap and Trade
- CCS
Climate Modeling

Wall Street Journal

*Climate Science Is Not Settled*

Dr. Steve Koonin

September 2014
Global CO2 Emissions

Developed nations make products for the world.

Kyoto Protocol Ratified

Developing nations make products for the world.

Source: http://edgar.jrc.ec.europa.eu/#QAe3387
The Future Electricity Mix

Electricity Generation by Fuel

North America

Quadrillion BTUs

Europe

Asia Pacific

The Future Electricity Mix

The Unintended Consequences of "Political Will"

Source: EIA Data

U.S. Electricity Generation

<table>
<thead>
<tr>
<th>Year</th>
<th>Coal</th>
<th>Natural gas</th>
<th>Nuclear</th>
<th>Hydroelectric</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>1162</td>
<td>346</td>
<td>251</td>
<td>279</td>
<td>252</td>
</tr>
<tr>
<td>1990</td>
<td>1594</td>
<td>373</td>
<td>577</td>
<td>293</td>
<td>201</td>
</tr>
<tr>
<td>2000</td>
<td>1966</td>
<td>601</td>
<td>754</td>
<td>276</td>
<td>206</td>
</tr>
<tr>
<td>2010</td>
<td>1847</td>
<td>988</td>
<td>807</td>
<td>260</td>
<td>216</td>
</tr>
<tr>
<td>2013</td>
<td>1586</td>
<td>1114</td>
<td>789</td>
<td>269</td>
<td>292</td>
</tr>
</tbody>
</table>

Source: EIA Data
The Future Electricity Mix

U.S. First Quarter Total Carbon Dioxide Emissions

Million metric tons

Source: EIA
The Future Electricity Mix

Electricity Generation by Fuel

North America

- Nuclear
- Coal
- Gas
- Renewables

Europe

- Nuclear
- Coal
- Gas
- Renewables

Asia Pacific

Quadrillion BTUs

1980
1990
2000
2010
2020
2030

The Future Electricity Mix

ETS carbon price (EUA) (Euro per tonne)

Coal consumption OECD Europe (million tonnes)

Sources: Thompson Reuters, IEA
The Future Electricity Mix

Electricity Generation by Fuel

North America

Europe

Asia Pacific

The Future Electricity Mix

Energy-related carbon-dioxide emissions by geography, and net change since 2005

<table>
<thead>
<tr>
<th>Country/area</th>
<th>2011 emissions</th>
<th>Net change in annual emissions from 2005 to 2011, million metric tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>8715 million metric tons</td>
<td>3252</td>
</tr>
<tr>
<td>India</td>
<td>1726</td>
<td>544</td>
</tr>
<tr>
<td>Russia</td>
<td>1788</td>
<td>201</td>
</tr>
<tr>
<td>Japan</td>
<td>1181</td>
<td>-61</td>
</tr>
<tr>
<td>Canada</td>
<td>553</td>
<td>-71</td>
</tr>
<tr>
<td>UK</td>
<td>497</td>
<td>-86</td>
</tr>
<tr>
<td>Germany</td>
<td>748</td>
<td>-99</td>
</tr>
<tr>
<td>Europe</td>
<td>4305</td>
<td>-370</td>
</tr>
<tr>
<td>US</td>
<td>5491</td>
<td>-509</td>
</tr>
</tbody>
</table>

Sources: US DOE, The Wall Street Journal
The Future Electricity Mix

Average national electricity prices (in 2011 US cents/kWh)

Data: average prices from 2011 converted at mean exchange rate for that year

Sources: IEA, EIA, national electricity boards, OANDA, shrinkthatfootprint.com
Offshore CO₂ Storage

- Match emissions sources and sinks
- Future global energy needs
- Nationally-owned & managed resource
- Reduces geopolitical aspects

Source: Meckel, BEG
Outline

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Advanced Energy Consortium
Mission Space

High Resolution
Low Resolution

Short Range
Range of investigation
Long Range

Seismics
Crosswell
Nanosensors
Micro and Nano Subsurface Sensors

Well logs/core data

Ref: Harris & Langan, AAPG Explorer, 1997

Source: BEG AEC
More 250 Academics from 30 different Universities & Research Institutions

Source: BEG AEC
AEC Research Portfolio

1) MOBILITY

2) CONTRAST AGENTS

3) NANOMATERIAL SENSORS

4) MICRO-FABRICATED SENSORS

Source: BEG AEC
AEC Fabricated Sensor

Source: BEG AEC
Research to Application Pipeline

AEC Research Thrust Engine

AEC Filtering and Integration of Ideas

Member Driven Use Cases

Nano Concepts

Research Thrusts

Building Blocks

Application Ideas

Pre Competitive

Prototypes

Experiments and Demos

Hydrofrac

EOR

Waterflood

Source: BEG AEC
Use cases will be an added dimension to our research strategy, the scientific thrusts remain and our projects managers will continue to lead our projects.
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ERCOT Power Curve

ERCOT load vs. actual wind output 8/17/2011 – 8/24/2011

Source: International Gas Union
The Demand Curve

ERCOT

Actual integrated wind output (MW)

Integrated load (MW)

Source: International Gas Union

Tinker, 2015
Global Investment in Clean Energy

New investment*, $bn

*Excludes corporate and government R&D
Source: Bloomberg New Energy Finance, The Economist, April 26, 2014
Energy Storage

- Compressed Air
- Pumped Water
- Molten Salt
- Advanced Capacitors
- Chemical Batteries
- Flywheels
- Buildings
- Grid Storage
A Final Thought
After: Rice World Gas Trade Model
Medlock, 2012

TPER = Total Primary Energy Requirement. Energy needed to facilitate Total Final Consumption (TFC does not include conversion and transmission losses).
Energy and the Economy

TPER = Total Primary Energy Requirement. Energy needed to facilitate Total Final Consumption (TFC does not include conversion and transmission losses).

After: Rice World Gas Trade Model
Medlock, 2012

~3 billion people

United States
Australia
Korea
Japan
Brazil
India
China
Australia
United States
The Global Energy Paradox

TPER = Total Primary Energy Requirement. Energy needed to facilitate Total Final Consumption (TFC does not include conversion and transmission losses).

Developed Nations
- Balance of Trade
  - Exports
  - Imports
- Regulation and Planning
  - Infrastructure
  - Resources
  - Permitting
- Emissions, Climate, Environment
- Energy Security

Developing Nations
- Food
- Housing
- Clothing
- Education
- Healthcare
- Electricity

GDP per capita

TPER per capita

Tinker, 2015