Teaching old wells new tricks:
Reserves for the modern grid

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Several presentations cover challenges of adding wind and solar

Storage duration (hours at rated power)

1. New forms of resource management, flexible inverters, etc.
2/3. New approaches for daily/weekly cycling
4. Geologic storage, other approaches

Fraction of annual energy from wind and solar in a large grid
Uncovering large, latent resources

>$60B valuation
>7M drivers

$52B in ad revenue
"Audience of one"

725k new jobs
Defeated peak oil
**Vast natural resources**
- More oil than Saudi Arabia (15M bbl/day, #1)
- More natural gas than Russia (80B ft³/day, #1)
- Impact ~ GDP of S. Korea ($1.3T/year)

**Vast manmade resources**
- 700k – 3.5M inactive wells
- 1-10T m³
- 900-9000 TWh (and growing)
"The United States of oil and gas," Washington Post, 2017
Fractracker.org; King and King, SPE Prod. & Ops., 2013; PwC; EIA; World Bank
Let’s unleash depleted wells as an energy storage resource

- Oil & gas know-how
- Storage concepts
- Creative adaptations

Second life as “electron reserve”
Oil & gas wells are large, premade containers

**Features:**
- ~1M-10B m³
- 10-100+ bar
- 15-30% porous
- Surveyed and drilled
- Infrastructure built
Goal: shed cost, keep efficiency

- Li-ion
- Flow batteries
- Compressed air
- Tank storage
- Geologic H₂
- Pumped hydro

<table>
<thead>
<tr>
<th>Technology</th>
<th>Round-trip efficiency</th>
<th>Installed cost ($/kWh)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Li-ion</td>
<td>100%</td>
<td>~140 Wh/L</td>
</tr>
<tr>
<td>Flow batteries</td>
<td>90%</td>
<td>~0.75 Wh/L</td>
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<tr>
<td>Compressed air</td>
<td>70%</td>
<td>~5 Wh/L</td>
</tr>
<tr>
<td>Geologic H₂</td>
<td>50%</td>
<td>~10 Wh/L</td>
</tr>
<tr>
<td>Pumped hydro</td>
<td>30%</td>
<td>~0.1 Wh/L</td>
</tr>
</tbody>
</table>

* Marginal installed capital cost of delivered energy
Geologic hydrogen: cheap and cheaper

Features:
- Free mining and infrastructure
- 5-year head start

Challenges:
- Parasitic processes
- Slow mass withdrawal
- NG/H₂ mixtures

$1.61/kg
$1.23/kg

~25% to work with

Salt cavern Depleted well

Total capital costs ($M)

Mining Compressor Cushion gas Other

Compressed air (CAES) has similar trade-offs

Challenges:
- Can residual NG be monitored and used for reheating?
- Is heat storage feasible long-term?
- How do you lower lower financial risk?
Underground pumped hydro: “down is up”

**Traditional**

- Upper reservoir
- Lower reservoir

**Underground concepts**

- “Upper” reservoir
- Deep storage shaft
- Pump-turbine
- Water flow
- Penstock

US ACE; Gravity Power; Quidnet Energy
Innovations needed

Interdisciplinary teams!

- Location optimization
  - Resource availability
  - Dimensions, state of repair
  - Messy input data
  - NG/oil
  - Water
  - Sulfur compounds
- Storage simulation
  - Cost projection
  - Loss minimization
  - Safety
- Forgiving power conversion
Thank you!

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