Despite of the widely publicized gains of PMMs, there is a general reluctance from E&Ps to adopt this new technology. Most of the reluctance is perceived cost. Adopting Permanent Magnet Motor technology involves a company paradigm shift along with a simple infrastructure change. With the initial investment lasting up to two years, are E&Ps going to reap the benefit for all that infrastructure change?

• Hear insight on the real power saving opportunities to ensure you’re getting your money’s worth
• Understand how these E&Ps made and justified investment decisions
• Evaluate the immediate payback and ROI of employing PMMs on ESPs

Dennis Harris, Well Reliability Optimization, Chevron Energy Technology Company
ESP with Permanent Magnet Motors for Well Profitability

Dennis Harris, Petroleum Engineer
Well Reliability Optimization / Artificial Lift Advisor
Chevron Energy Technology Company
Houston, Texas
What do tall ships have to do with Petroleum?

Left: (USA Sloop) Old Ironsides, USS Constitution;  Right: (Spanish Galleon) Revenge, King Philip V of Spain (Formerly)

During the course of this presentation clues will be given to answer the riddle. Hint: focus on technology and company habits.
• Short recap of what PMM technology is with 4 slides from the 2018 Permian Basin Congress.
• Next, economics will be examined for tangible gains in opex reductions.
• Several case histories will portray the PMM application and the power savings.

Key message is a company needs a desire to change its way of doing business for profitability.
Desired outcome is operators take action on proved technology now.
Permanent Magnet Motor (PMM) Technology
What is a Permanent Magnet Motor?

Similar to IM except ….

• Rare Earth Magnets replace the copper rotor bars in the rotor.
• Synchronous speed (no slip).
• VFD required. Why?
  To know the magnet/stator positions for alignment of the magnetic fields.

- In the rotor, copper bars are replaced with rare earth permanent magnets (PM) for reduced physical weight, electrical resistance, and heat rise. The PM motor has lower power consumption and lower operating temperature which theoretically leads to increased runlife.

- The term “rare earth” is a bit misleading because the metals are abundantly found but the process to make the alloys with high magnetic strength, measured in Tesla, was quite expensive to manufacture up until the 1990’s. Today the process is more affordable but the name has stuck.

- Curie temperature (Tc), or Curie point, is the temperature at which certain materials lose their permanent magnetic properties and need induced magnetism to maintain their magnetic field strength.

- Before 1966, ferrite or alnico magnets were used in the PMM industry. These had magnetic field strength in the range of 0.5 - 1 Tesla but had low Curie Temperatures. (ex: Refrigerator magnets are .3T)

- In the 1970s and 1980s, alloys such as Neodymium (Nd2Fe14B) and Samarium-Cobalt (SmCo5) were made with magnetic field strengths > 1.4 Tesla. The Curie Points of 300-400 °C for Neodymium and 720-800°C for Samarium-Cobalt is what coined the terminology of “permanent magnet”.

- Since 2010 the cost is greatly reduced to where the magnets make the PMM-ESP competitive and gaining in its acceptance.

[source: Wikipedia]
PMM vs. IM – physical difference

PMM & IM stators are similar:
both have 3-phase armature winding which generates rotating magnetic field.

The Stators are the same as we have used for years!

PMM & IM housings, heads & bases, shafts, and bearings are the same or similar

PMM & IM electromagnetic processes, which participate in energy generation, have significant differences

Stator is the stationary part of the motor and helps create an electrical magnetic field.
Rotor is the rotational part of the motor with a magnetic field created by electricity (induction motor) or magnets (permanent magnet motor).
The rotor magnetic field interacts with the stator EMF in an attract/repel fashion to rotate and create torque (a rotational force)

PMM essentially replace the copper bars found in an IM with permanent magnets. Less copper = less cost.
PMM Benefits

- Shorter and lighter.
- Can operate at higher RPM.
- May pass through higher DLS.
- May be alternatively deployed (rigless).
- ALS possibilities with well deepening to produce additional reserves.
- Well construction optimization.

Front end thinking is needed to focus on what you are attempting to achieve.
- Is the goal reduced capex?
- Is the goal to reduce well intervention cost?
- Is the goal to lower electric bills?
## PMM vs. IM Comparison

<table>
<thead>
<tr>
<th>Property</th>
<th>PMM vs IM</th>
<th>Property</th>
<th>Rated</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>-25%</td>
<td>Rated Voltage</td>
<td>+11%</td>
<td>+8%</td>
</tr>
<tr>
<td>Volume</td>
<td>-25%</td>
<td>Rated Current</td>
<td>-14%</td>
<td>-19%</td>
</tr>
<tr>
<td>Weight</td>
<td>-33%</td>
<td>Rated Heat Rise</td>
<td>-13%</td>
<td>-13%</td>
</tr>
<tr>
<td>Density</td>
<td>-9%</td>
<td>Rated Torque</td>
<td>+8%</td>
<td>+8%</td>
</tr>
<tr>
<td>Poles (PMM, IM)</td>
<td>4 vs. 2</td>
<td>Rated Power</td>
<td>+12%</td>
<td>+14%</td>
</tr>
<tr>
<td>Rated Frequency, Hz</td>
<td>120 vs. 60</td>
<td>Rated Efficiency</td>
<td>+6%</td>
<td>+8%</td>
</tr>
<tr>
<td>Rated Speed, rpm</td>
<td>3600 vs. 3484</td>
<td>Rated Power Factor</td>
<td>+14%</td>
<td>+23%</td>
</tr>
<tr>
<td>Slip (PMM, IM)</td>
<td>0% vs. 2%</td>
<td>Electrical Savings*</td>
<td>+10%</td>
<td>+18%</td>
</tr>
</tbody>
</table>

* Operating Window


A (-) means a PMM property savings vs. the IM. Example: PMM motors are 1/3 less in weight.

A (+) means a PMM property gain over the IM. Example: PMM motors have 11% more Rated Voltage.

The reduced Length, Volume and Weight are indicative of the general higher power density of PMM.

Note: not all PMM are designed the same.
Economic Considerations
In the petroleum industry your bank is underground. To make a withdrawal from your account you need technology.

Your bank statement (i.e. balance) is determined by your economic software with economic parameters.

You can influence your Decline Rate but you cannot empty your bank all at once.

You cannot control oil&gas price so you use escalation scenarios. Likewise, you escalate your future operating expense.

Taxes are a known and you cannot avoid them.

The only thing you can control is your technology via Capex and Opex.

What software cannot control or predict is company attitude, policies, and culture in embracing new technologies.

Companies vary with philosophies and it is reflected in NRI, ROI and NPV.

What we can examine is Payout, and that related only to power savings, which can influence NPV.
Energy Cost Savings

Actual industry example = 27%

Kay Electric Cooperative Blackwell, Oklahoma

<table>
<thead>
<tr>
<th></th>
<th>Oct'15 Pre-Work</th>
<th>2500 BFPD</th>
<th>kWh/BF</th>
<th>$0.122/BF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td></td>
<td></td>
<td>8.8 g</td>
<td>1.38 kWh</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>kW/BF</td>
</tr>
<tr>
<td>Savings</td>
<td></td>
<td></td>
<td></td>
<td>$0.096/BF</td>
</tr>
<tr>
<td></td>
<td>Dec'15 Post Work</td>
<td>2300 BFPD</td>
<td>9.1 g</td>
<td>1.05 kW/BF</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$0.026/BF</td>
</tr>
</tbody>
</table>

~Savings: 27% on dollar basis; 21% on $/BF; 29% on energy/BF

Actual industry example of PMM savings on power bill 27.6% on dollar basis; 21.3% on $/BF; 29.6% on energy/BF

(note: 2017 presentation had kWh/BF and $/BF too large; no division by 30 service days)

- Very high watercut well. Operator decided to take advantage of PMM ESP install and perform well workover.
- November ’15, high water zone was shut off to see if the oil cut would improve. PMM installed.
- 200 BFPD less after the workover but 200’ deeper pump depth.
- February ’16 equipment pulled to abandon the well and sell the lease.
- Operator impressed with power savings and decided to use PMM going forward.
Energy savings in second month  
(Note: fluid rate drop; 5% increase in $/BF saving)

You must know what you are measuring. In the previous slide we measure for conditions about the same, Time (n) vs. Time (n+1)

Recall the previous slide: 28.6% on dollar basis; 21.4% on $/BF ; 23.9% on energy/BF

Now we are comparing Time (n) with Time (n+2) but the well conditions have changed. If we just compared dollars you would have the wrong savings simply because you used less energy.

If we just compared the energy cost/BF you still would have the wrong answer because your well condition changed.

The correct yardstick is thus the cost per barrel of fluid lifted. Correct comparison is 26% $/BF vs. the 21.4%/BF.
PMM technology equipment cost - 2015 study

Oklahoma Field
Depth ~ 4000’
Flowline Pressure ~ 300’ (125 psi)
Friction ~ 50’
Total Dynamic Head ~ 4350’
Approximate Rate  600 - 800 BPD

- PMM is comparable to IM
- Competitively priced
- Affordable

<table>
<thead>
<tr>
<th>Normalized Cost</th>
<th>Vendor-1</th>
<th>Vendor-2</th>
<th>Vendor-3</th>
<th>Vendor-4</th>
</tr>
</thead>
<tbody>
<tr>
<td>IM</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>PMM</td>
<td>0.63</td>
<td>0.99</td>
<td>0.99</td>
<td>0.99</td>
</tr>
<tr>
<td>PMM</td>
<td>0.63</td>
<td>0.79</td>
<td>0.79</td>
<td>0.79</td>
</tr>
<tr>
<td>PMM</td>
<td>0.62</td>
<td>1.12</td>
<td>1.12</td>
<td>1.12</td>
</tr>
</tbody>
</table>

Subsurface equipment is competitive (M/S/P)
Surface is a variable
Total is competitive

Updated for 2019 show **no** significant change.
PM motor cost still ranges -20% to +10% versus the IM and are dependent upon the specific well application

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Actual quote in 2015 specified NEW condition on ESP equipment. Costs were normalized to the IM.
- Surface: ESP cable #4 AWG, J-Box, VFD 6 pulse, Step up transformers and miscellaneous
- Subsurface: Sensor, motor, seal/protector, intake, pump, and motor lead extension (MLE)
Vendors are adapting to make kits for GCS, Advantage drives. Almost all new drives come IM/PMM compatible. ALL NEW WELLS should have PMM with Current Drives.
Two ways to determine your payout from power savings.
1- Using Total Dynamic Head (TDH) and Vendor ESP Catalogues
2- Motor Nameplate and Power Factor
Leveraging the technology
PMM leveraging possibilities

1. Reduced operating expense through power savings.
2. Enables alternative deployments for lower intervention cost.
3. Deeper ESP deployment in high angle, high dogleg wells.
4. Reserves adds via well deepening and PMM through liners
5. Well construction (ex: 5” casing with narrow PMM)
6. *Slim Hole Drilling for Capex Reduction
7. Enabled AL technology: ES-Linear Reciprocating Pumps

* highly suggested read for the serious

To leverage the PMM we must do more up front engineering to examine what it is we wish to achieve
(Note: DOE report showed a 35%-50% savings on capex can be realized with slim holes.)
Seven areas listed, not all to be addressed.
PMM enables new AL technologies

1. Electric Submersible Reciprocating Rod Pump (ESRRP) Reciprocating Direct Drive ES Plunger Pump (RDD-ESPP)
   - Linear PMM driving a downhole sucker rod pump.
   - Low Productivity and low permeability wells
     - Vertical, directional and horizontal wells
     - Higher Efficiency (motor, pump, system)/ lower maintenance
     - VFD for advanced control and automation

2. Through Tubing 2.625 Lo/Mid Volume and 2.17 Low volume ESP
3. ESPCP with higher Torque and power savings
4. Mix and Match organization capability

1-PMM enables newer technology such as keeping the rod pump while eliminating the rods prone to failure and eccentric wear on tubing.
2-Slim ESP to fit inside existing tubing.
3-Energy Efficient ES-PCP
4-Ability to mix and match.
Newer technology: PMM driving rod pumps
China: AL Technology, Well Application and Power Savings

PE = Pump Efficiency, SE = System Efficiency

**Daqing oilfield**, 108 oil wells; (50% vertical, 40% deviated, ~0% horizontal,)
PE = 67% (63% increase) ; Power Savings = 45%

**Changqing oilfield (2007)**, 27 oil wells in low-permeability reservoirs
PE = 65% (24% increase) ; Power Savings of 22%

**Zhengting oilfield (2012)**, 5 deviated wells, low productivity
high eccentric wear, frequent intervention
PE = 60% (45% increase) ; Power Savings = 34%
Pump maintenance extended 46 days

**Jinli oilfield (2014)**, 11 oil wells,
PE = 80% (a 320% increase) ; Power Savings = 30% , SE = 17% (up 77%) 
The pump maintenance period extended 200 days

4 fields in China with proven history demonstrating the AL Technology in various well/reservoir conditions and the resultant power savings.
Examples of well construction issues or logistical issues.
### PMM enabling power savings

#### Argentina: high efficiency pump and power savings

<table>
<thead>
<tr>
<th>Power Factor</th>
<th>Novovent ESP</th>
<th>Original ESP</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>1.00</td>
<td>2.00</td>
<td>Measured</td>
</tr>
<tr>
<td>Voltage (GPM)</td>
<td>10350/10500</td>
<td>10350/10500</td>
<td>Measured</td>
</tr>
<tr>
<td>Current</td>
<td>17.4A</td>
<td>34.0amps</td>
<td>Measured</td>
</tr>
<tr>
<td>kW measured</td>
<td>48.9A</td>
<td>77.30A</td>
<td>Measured</td>
</tr>
<tr>
<td>Motor Load %</td>
<td>52.7%</td>
<td>84%</td>
<td>Calculated</td>
</tr>
<tr>
<td>Total Efficiency (Motor+Pump+Cable)</td>
<td>52.2%</td>
<td>62.3%</td>
<td>Calculated</td>
</tr>
</tbody>
</table>

**Notes:**
- Performance improvements of 47% in sending, the power factor was 1.00, a change of 2.00 to 2.00 was observed.
- **Conclusions:**
  - Measured ESP has a 77.30A, has energy consumption than the original ESP model.
  - Current, voltage, capacity, and power factor were evaluated to determine energy savings.

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**Power savings in Argentina**
PMM for increased production and MTBF
Ex: ESPCP-PMM in heavy oil

Technology Application for Heavy Oil
• Power saving;
• Well servicing and workover costs reduce;
• Stable flow and the technogenic influence reduce on the well bottom
PMM enabling savings …
in new pump technology to offset high burdens

Old wells from shallow to deep depths encumbered by high utility rate and high taxes. Need to extend economic limit by lowering opex.

USA-1:
• 28% power savings due to powder metallurgies and 380 days (still running)
• 49% reduction in length, increased clearance 1.49” to 1.68”.
• 9 yr. life extension, 42 MBO reserves, $1.2MM value

USA-2:
• 38% power savings with power cast metallurgy;
• 18% increase in production rate
  -> better gas handling for drawdown.
• 425 day runtime (still running) vs 125 with IM system.

USA Operator installed 33 more PMM and seeing average of 30% savings

Source: Novomet-USA
Who are the manufacturers of PMM?

1 Borets, RU
2 Novomet, RU
3 AccessESP, USA
4 Magnetic Pumping Solutions, UK
5 Schlumberger, Ukr
6 BakerHughesGE, USA
7 Coreteq, UK
8 ZILift, UK
9 Reynolds Technologies, USA
10 Triol, Ukr
11 Lex ESP, RU
12 Alnas, RU
13 Runaco, RU

Blue: 2015 tested & commercial
Black: 2019 beta / commercial

PMM is not a question of when, it is already here.
What actions to take?

1. Plan AL upfront for capitalization
2. Commit PMM on all new wells with artificial lift required
3. Upgrade brown fields VFD with kits or replace new or lease/rent newer models
4. Examine your time value of money; the longer you wait, the more you lose.
It’s not what your see but what you don’t see.

- The ship hull of the galleon draft heavy due to water friction; they are slow.
- The ship hull of the sloop draft light, less water friction; can maneuver quickly.

Big Oil Cos have big guns (resources) for research and technology development but react slow to adoption; heavy overhead and processes.
Small Oil Cos have less overhead, able to make decisions faster; can adopt technology quicker and free up savings for other investment/improvements.
Thank you for listening