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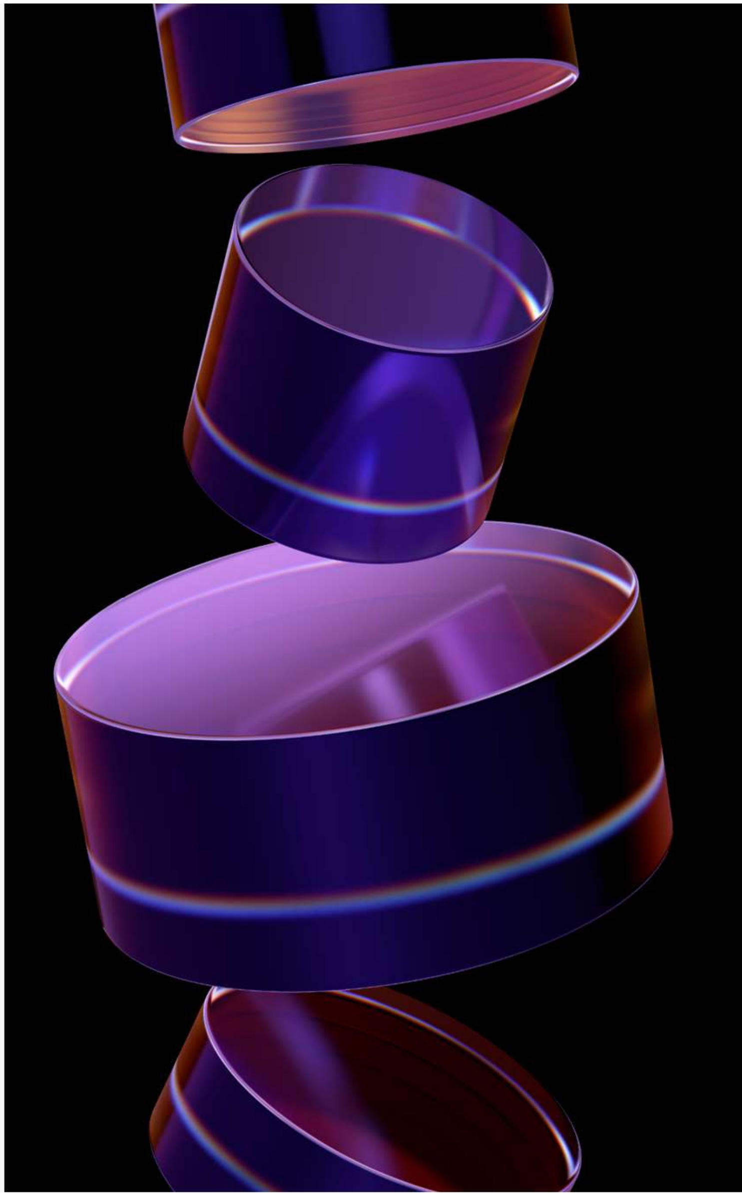
OKLAHOMA SOCIETY OF PROFESSIONAL ENGINEERS

Permanent Magnet Motors for Reduction of Carbon Emissions in Oil Well Applications

Oklahoma Engineering Conference
June 13-14, 2024

Walter Dinkins

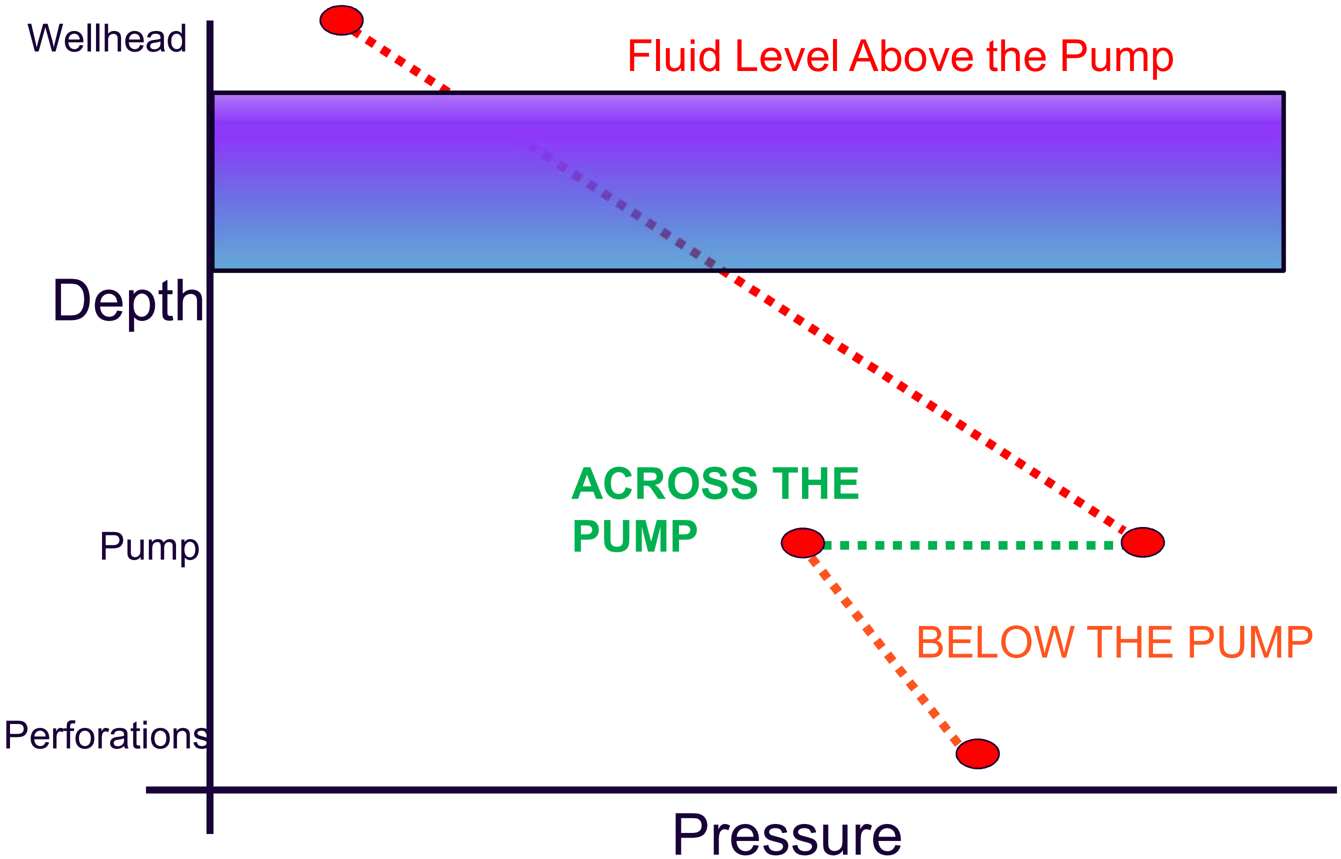


Types of Artificial Lift

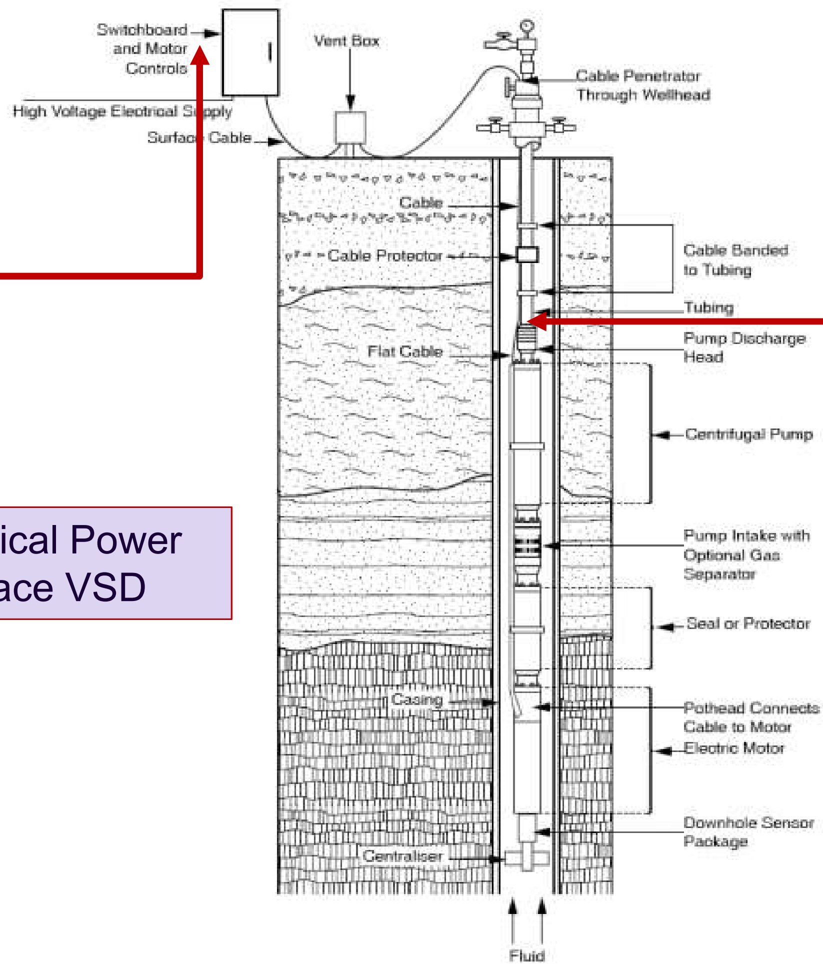
Electric Submersible Pumping (ESP) | Plunger Lift | Reciprocating Rod Lift | Gas Lift | Hydraulic Lift | Progressing Cavity Pumping (PCP)

ESP Conventional Equipment

Understanding ESP Operation



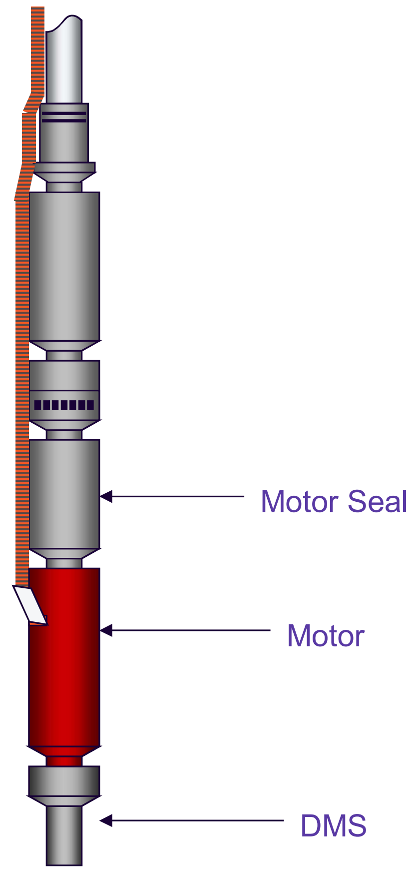
Overall Efficiency = <u>Output Power</u>
Input Power



Input Electrical Power To the Surface VSD

Output Fluid Hydraulic Power Leaving the ESP Pump

Motor



Induction & Permanent Magnet Motor

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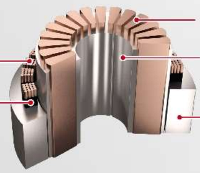
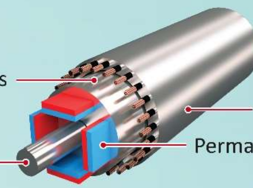
Induction Motor



- Rotor constructed using copper bars short-circuited by two copper end rings
- Rotor magnetic field is generated by current induced in the (rotor) copper bars
- Rotating magnetic field created in the stator when alternating current is applied to non-rotating stator windings
- Interaction of the rotor magnetic field and (rotating) stator magnetic field results in:
  - rotor torque
  - slip
- No special VSD control algorithm required

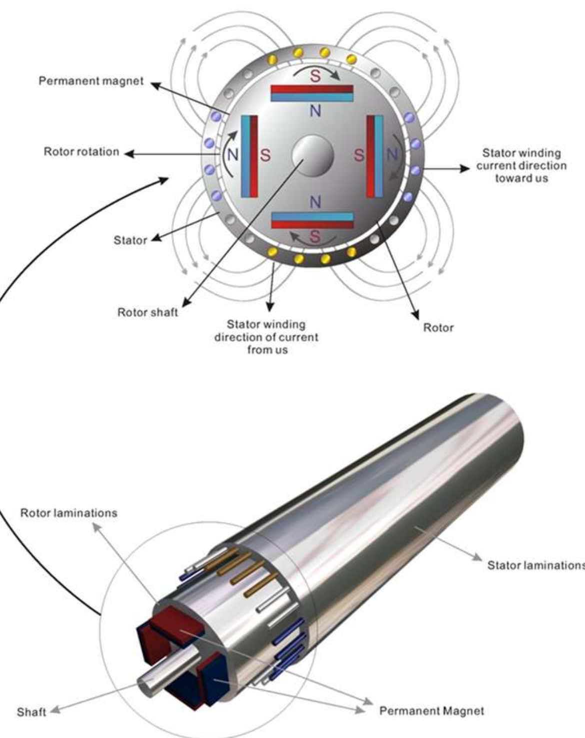
Permanent Magnet Motor



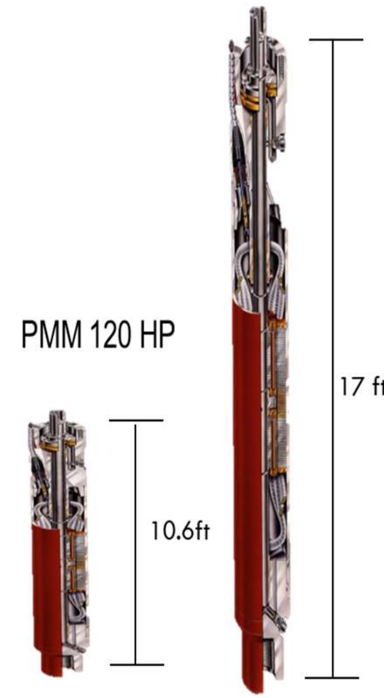
- Rotor constructed to include permanent magnets made from hard-sintered rare-earth metals
- (Constant) Rotor magnetic flux created by presence of permanent magnets
- Rotating magnetic field created in the stator when alternating current is applied to non-rotating stator windings
- Interaction of the rotor magnetic field and (rotating) stator magnetic field results in:
  - rotor torque
- Special control algorithm required

PMM Technological Advantages

- Up to 95% electrical efficiency
  - 10-20% increased efficiency at nominal power
  - Increased grid capacity to add additional ESP’s
  - Increased grid capacity to add additional GL Compressors
- 25% reduction in power cable costs
- Increased power density results in 40% shorter motor sections
- Lower idle amps
  - Power savings during gas interference
- Lower temperature rise
  - Longer insulation life
  - 77% PMM survivability rate compared to 45% for IM
  - Lower risk of scaling
- 15% higher power factor, up to 0.96
  - Less material
  - Better suited for higher doglegs
- Ability to operate efficiently at low motor loads
  - Wider operating range for later on in well life

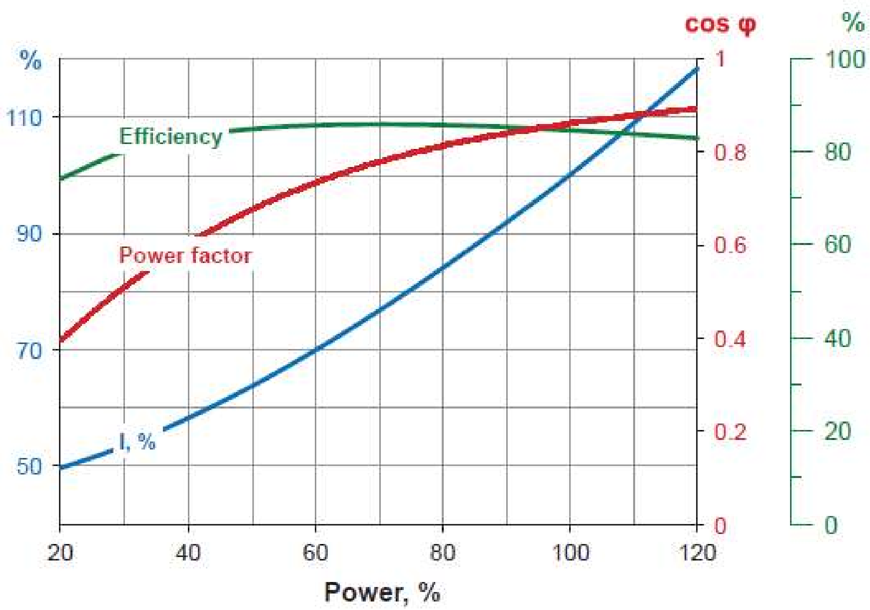


120 HP
Induction Motor

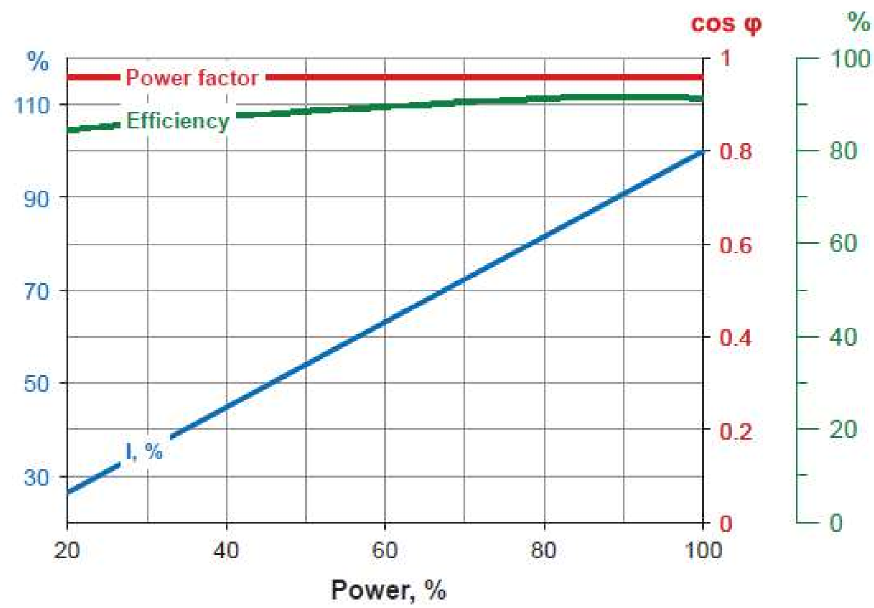


IM versus PMM

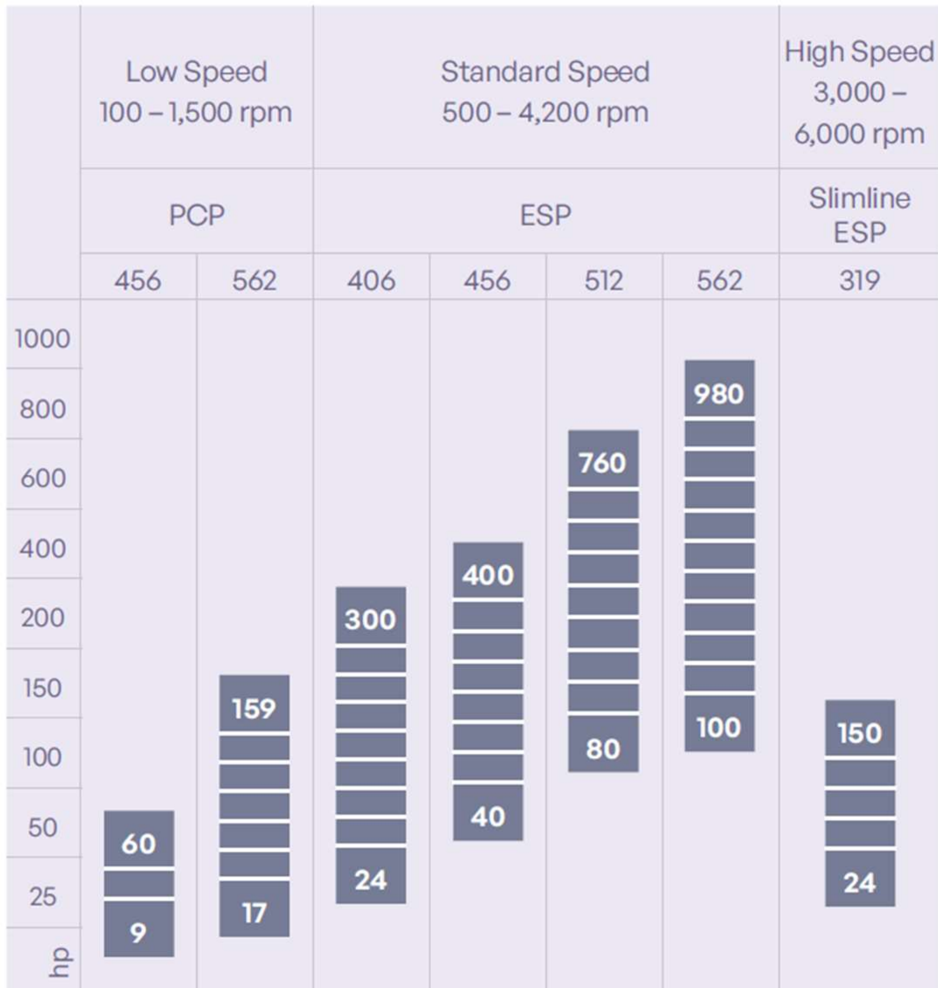
456 Series ESP Induction Motor



456 Series ESP Permanent Magnet Motor



PMM HP Rating for ESP, PCP & WR2



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Power Calculation

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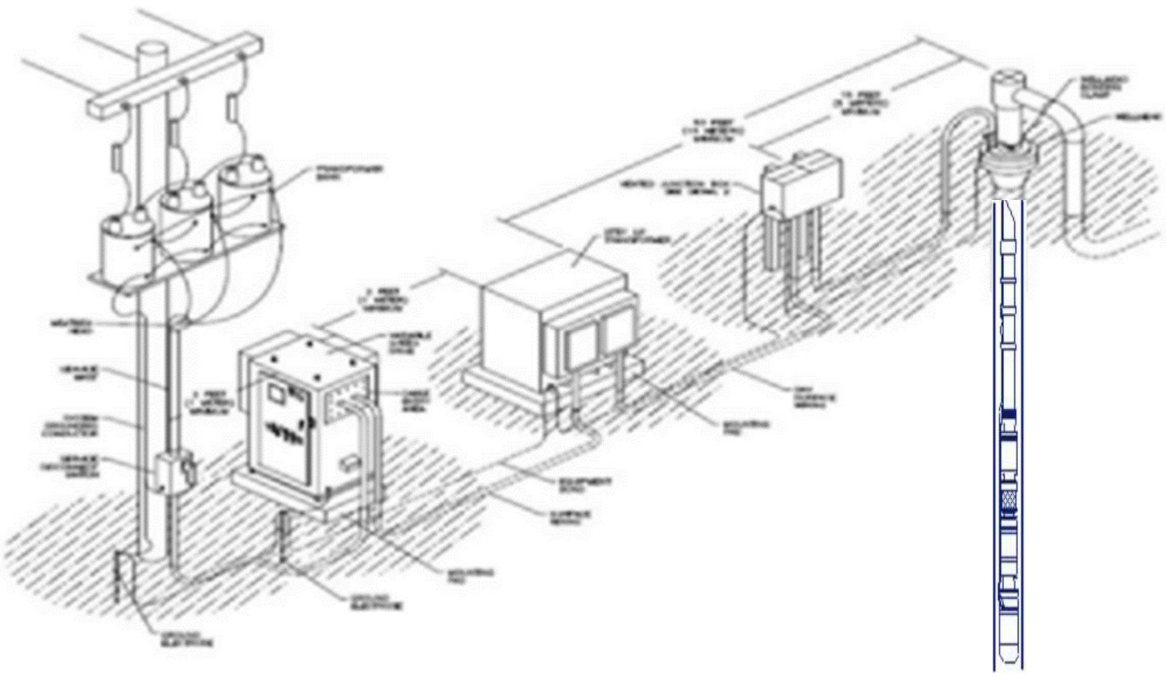
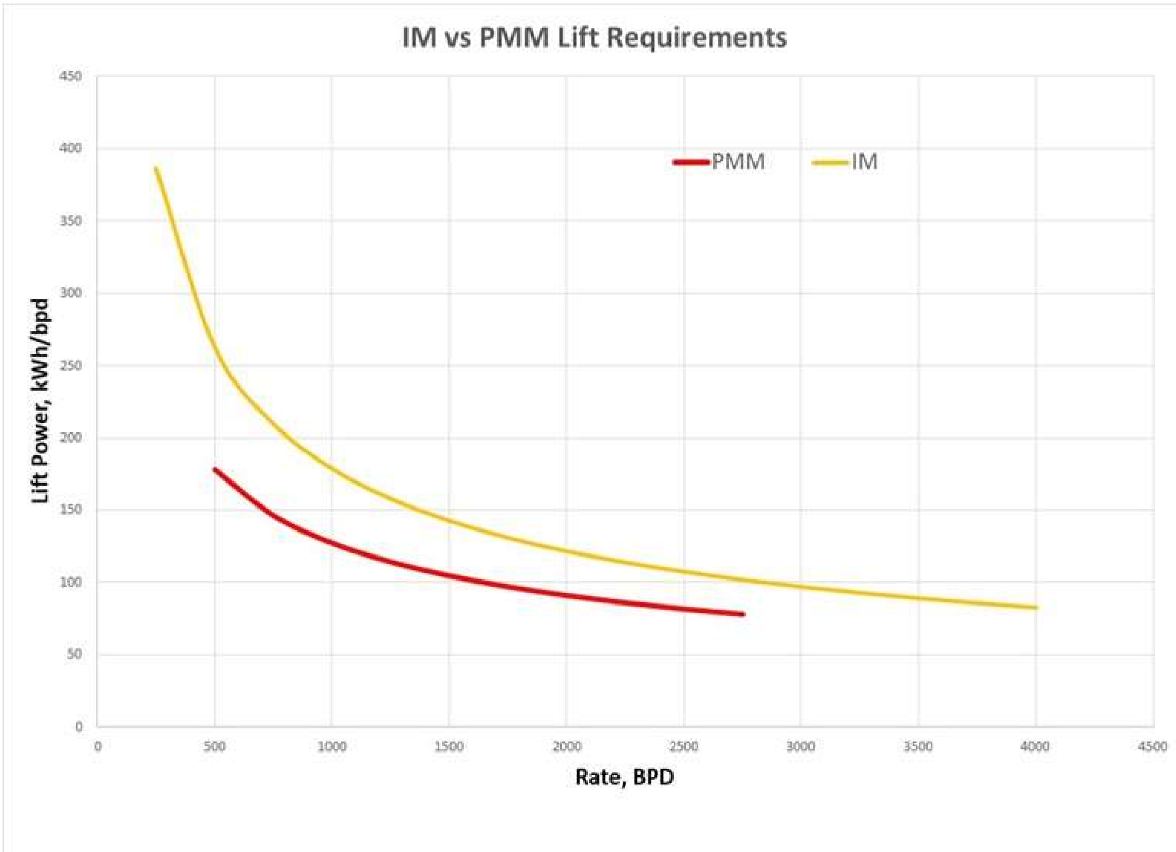
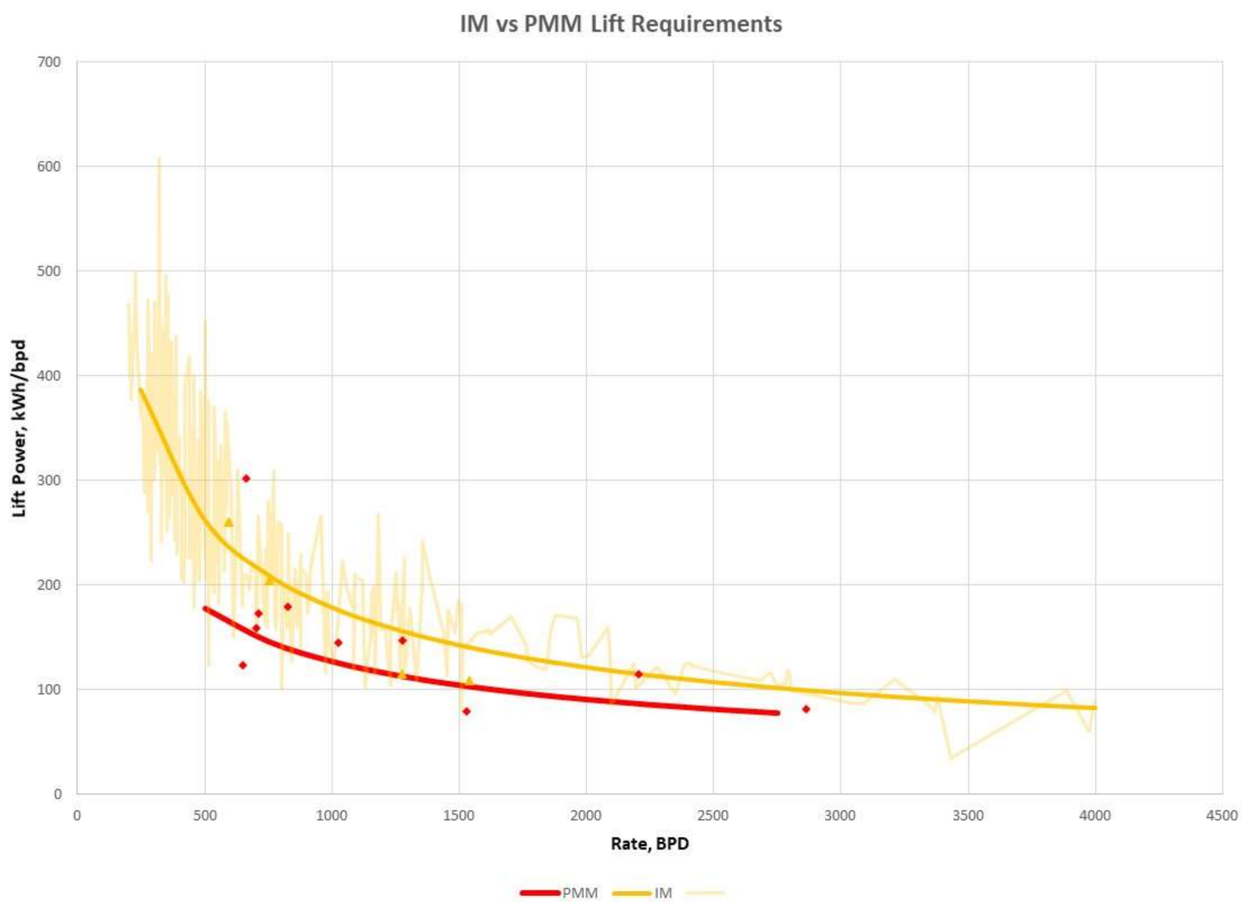


PMM Power Savings vs Rate



PMM Power Savings vs Rate



Case Example: IM vs PMM Howard County, Texas

Well

- TD: 7,725 ft
- TVD: 7,599 ft
- Casing OD: 5.5 in.
- Casing weight: 17# / ft
- Pump setting depth: 6,000 ft

Equipment Used in Test

- **Induction Motor (IM):** 456 Series, 240 hp, 2x1,295 V, 59 A (tandem)
- **Permanent Magnet Motor (PMM):** 117 mm, 266 hp, 2466 V, 62 A
- **Variable Frequency Drive (VFD):** Levare-VD250-300 Current Source Drive
- **ESP Cable:** 6,000' #4 AWG SL-450 Lead Flat
- **Motor Seals:** 400 Series Tandem
- **Pumps:** 400 Series, 3,000 bpd (285 stages, 3 sections)
- **Intake pressure measurement:** Levare Viewpoint ESP downhole sensor

Test 1: measure power consumption maintaining constant (surface) flow rate

Flow Rate (BPD)	IM (kW)	PMM (kW)	Delta	Delta (%)
2400	167.3	132.9	34.4	↓ **20.6**
3000	203.4	161.0	42.4	↓ **20.8**
3400	224.8	204.3	20.5	↓ **9.1**

Test 2: measure power consumption maintaining constant intake pressure

	Frequency (Hz)	Pump Intake (psi)	Motor Load (%)	Motor Winding Temp (°F)	Motor Efficiency (%)	Power Consumed – Meter (kW-Hr)	% Savings (kW-Hr)
IM	55.8	601	67	182	80.4	161.8	-
	61.6	545	83	187	82.9	211.3	-
	65.9	505	97	192	84	245	-
PMM	52.7	603	63	186	90.8	133.3	↓ **17.6**
	57.5	545	78	199	91.1	177	↓ **16.2**
	60.5	505	89	210	90.7	210.9	↓ **13.9**

Case Example: Test Well

Well

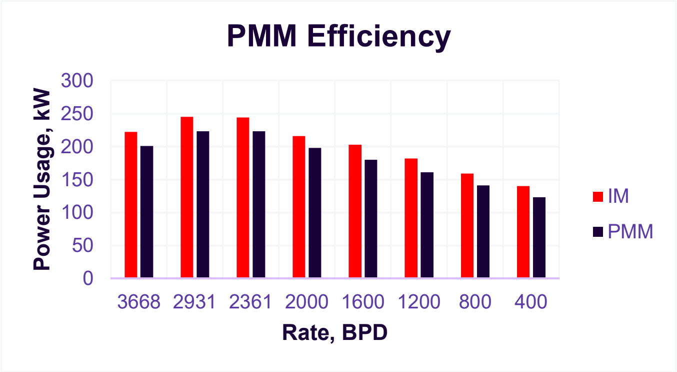
- TD: 8696 ft
- TVD: 8696 ft
- Casing OD: 5.5 in.
- Casing weight: 20# / ft
- Pump setting depth: 7500 ft

Equipment Used in Test

- **Induction Motor (IM):** 456, 400 hp, 3420 V, 72 A (3668 – 2000 bpd) | 270 hp, 3190 V, 60 A (1600 – 400 bpd)
- **Permanent Magnet Motor (PMM):** 456, 400 hp, 4045 V, 58 A (3668 – 2000 bpd) | 264 hp, 3260 V, 48.8 A (1600 – 400 bpd)
- **Variable Frequency Drive (VFD):** Levare-VD533-641 Current Source Drive
- **ESP Cable:** 7500' #4 AWG SL-450 Lead Flat
- **Motor Seals:** 400 Series Tandem
- **Pumps:** 400 Series, 3,000 bpd (297 stages, 3 sections, 56 stage, 3200 Vapro)
- **Intake pressure measurement:** Levare Viewpoint ESP downhole sensor

Test 1: measure power consumption maintaining constant (surface) flow rate

Flow rate	PIP	IM (kW)	PMM (kW)	kW Delta	Power Savings
3668	2472	222	201	21	↓ 10%
2931	1970	245	223	22	↓ 10%
2361	1088	244	223	21	↓ 9%
2000	900	216	198	18	↓ 9%
1600	800	203	180	23	↓ 13%
1200	700	182	161	21	↓ 13%
800	600	159	141	18	↓ 13%
400	500	140	123	17	↓ 14%



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Carbon Footprint Reduction

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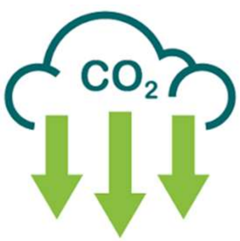
- Currently spending **$97,270** per well on electricity alone for a total of **$48 MM** annually
- 481 wells account for **324,087** metric tons of carbon emissions
- With a full PMM takeover client could save **~$7.2 MM** annually (**$15,045** per well) on electrical costs alone

Annual Power Consumption / CO2 Emissions							
ASSET	**ESP's**	**TOTAL KWH ANNUAL**	**ENERGY RATE**	**TOTAL ELEC COST ANNUAL**	**CO2 EMMISIONS (TONNES)**	**SAVINGS PER YEAR**	**CARBON REDUCTION**
Area1	41	43,504,703	$0.085	$3,697,900	24,841	$554,685	3,726
Area2	64	65,244,271	$0.085	$5,545,763	37,254	$831,864	5,588
Area3	118	122,491,080	$0.085	$10,411,742	69,942	$1,561,761	10,491
Area4	133	181,961,509	$0.085	$15,466,728	103,900	$2,320,009	15,585
Area5	125	154,376,927	$0.085	$13,122,039	88,149	$1,968,306	13,222
Total	481	567,578,490	$0.085	$48,244,172	324,087	**$7,236,626**	**48,613**

Ability to reduce carbon footprint by 48,613 tons per



9,459
homes' electricity use for one year

10,475
Passenger vehicles driven for one year

13.2
Wind turbines installed

5,470,125
gallons of gasoline consumed

Power savings based on 15% increase in electrical efficiency w/ 100% runtime

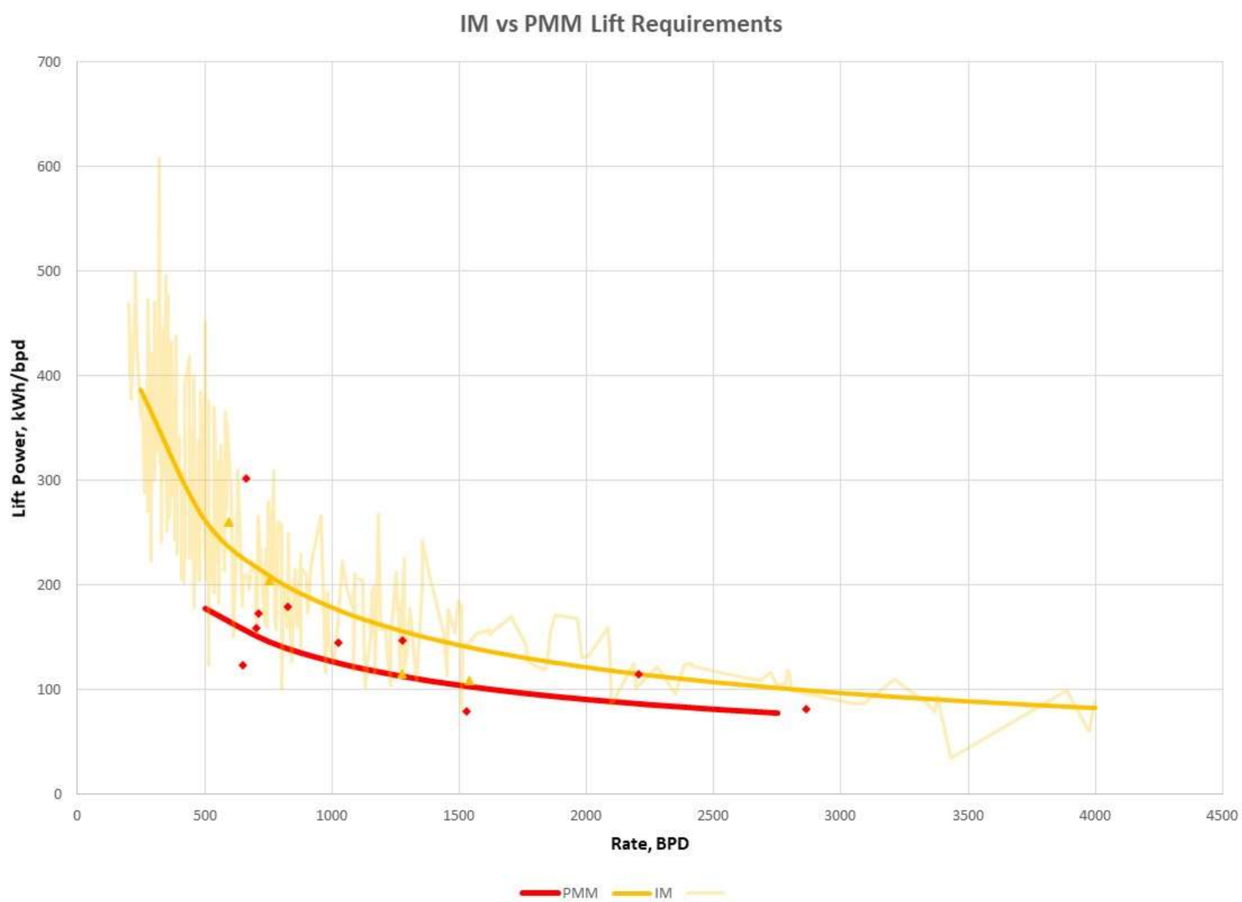
PMM Progression Plan

Potential to reduce electrical costs and carbon emissions by **$11 MM** and **75,682** metric tons over a span of 5 years based on current progression plan

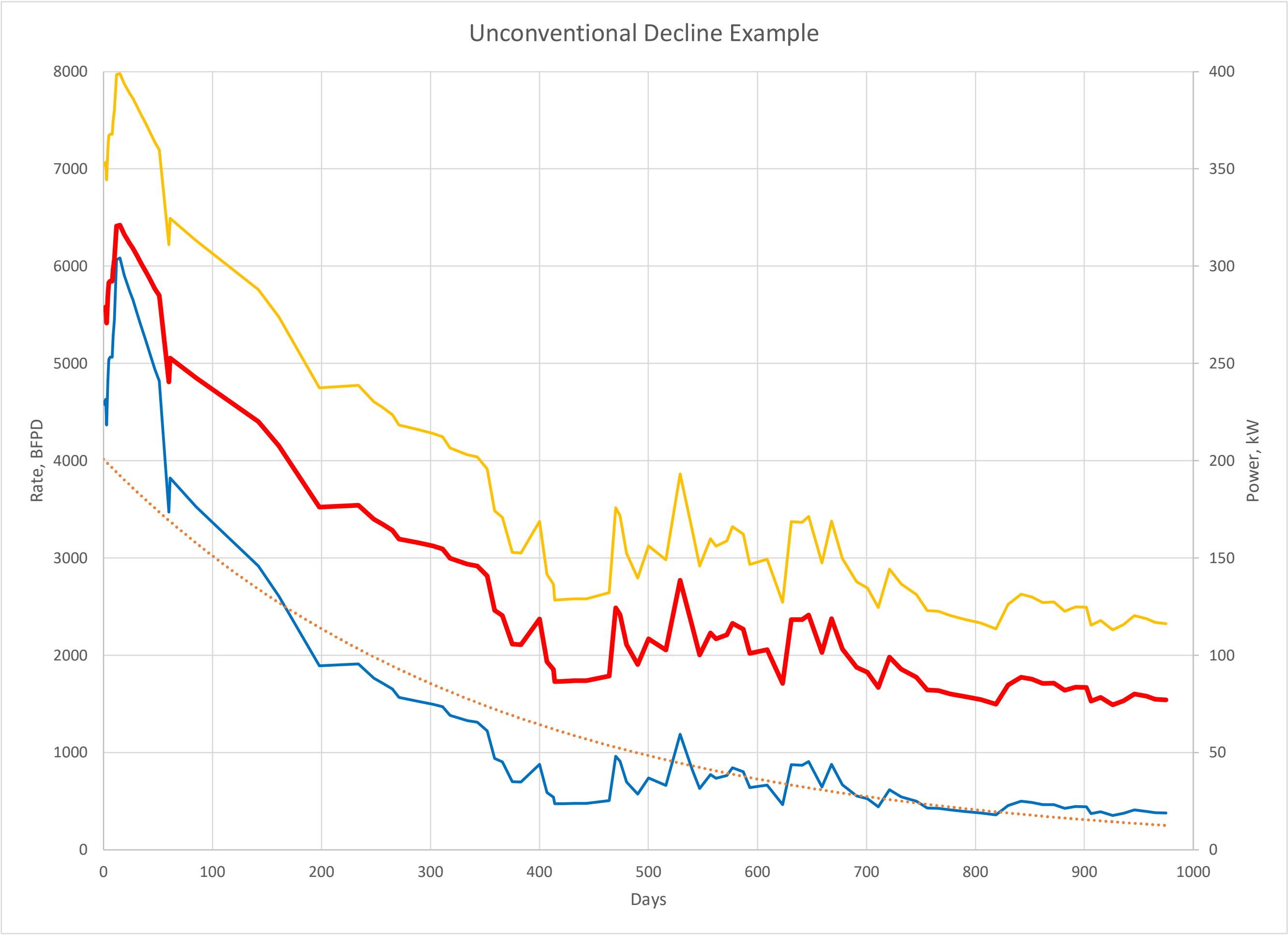
YEAR	2024	2025	2026	2027	2028
NEW PMM INSTALLS	20	45	65	90	115
TOTAL ACTIVE PMMS	20	65	130	220	335
ANNUAL POWER SAVINGS	$291,810	$948,383	$1,896,765	$3,209,910	$4,887,818
ACCUMALITIVE POWER SAVINGS		$1,240,193	$3,136,958	$6,346,868	**$11,234,685**
ANNUAL CARBON REDUCTION	1,966	6,389	12,778	21,623	32,927
ACCUMALITIVE CARBON REDUCTION		8,355	21,132	42,756	**75,682**

Power savings based on 15% increase in electrical efficiency w/ 100% runtime

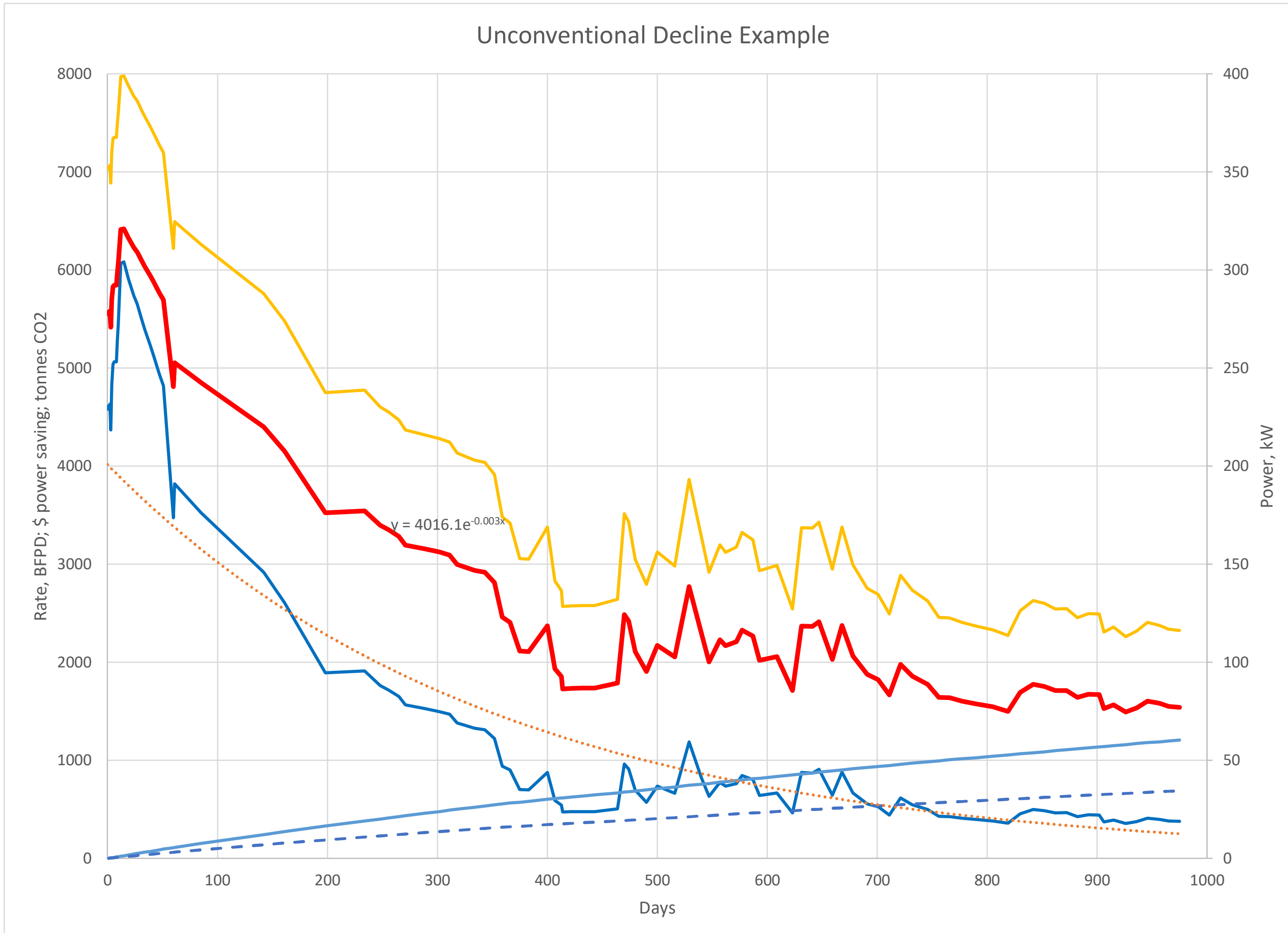
PMM Power Savings & Carbon Reduction



PMM Power Savings & Carbon Reduction



PMM Power Savings & Carbon Reduction



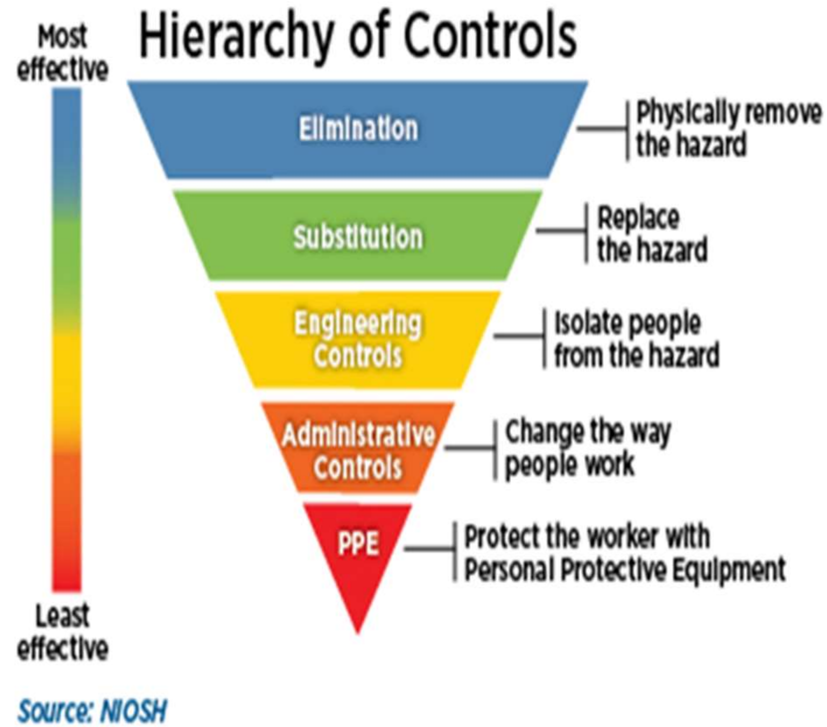
Risk Mitigation and Monitoring

Elimination:

- No Simultaneous Operations.
- Inspection & Test

Engineering Controls:

- Warning signs/labels/markings/signals
- Use of continuous monitoring devices
- Distancing when working with energized equipment;
  - remote read-out
  - non-contact instrumentation
- Barriers
  - Access – barricade (restrict the unqualified)
  - Downhole - prevent unplanned rotation
- Use of Shorting Box and Blocking Caps
- Test Meters

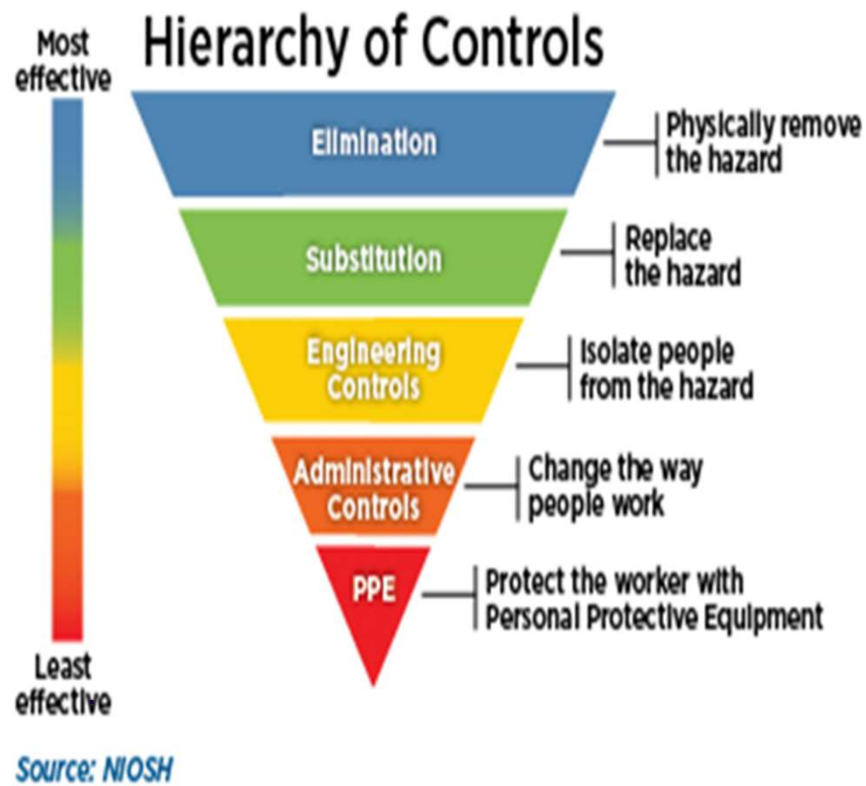


Administrative Controls:

- Creating an Electrically Safe Work Condition
- Lock-out/Tag-out for 2 sources
- Training and certification of personnel
- Regular Audits – Compliance verification
- Certification of equipment
- Grounding – Establish Equipotential Zone (EPZ)
- JSA/Risk assessment
  - Guidelines
  - Procedures

PPE & Tools:

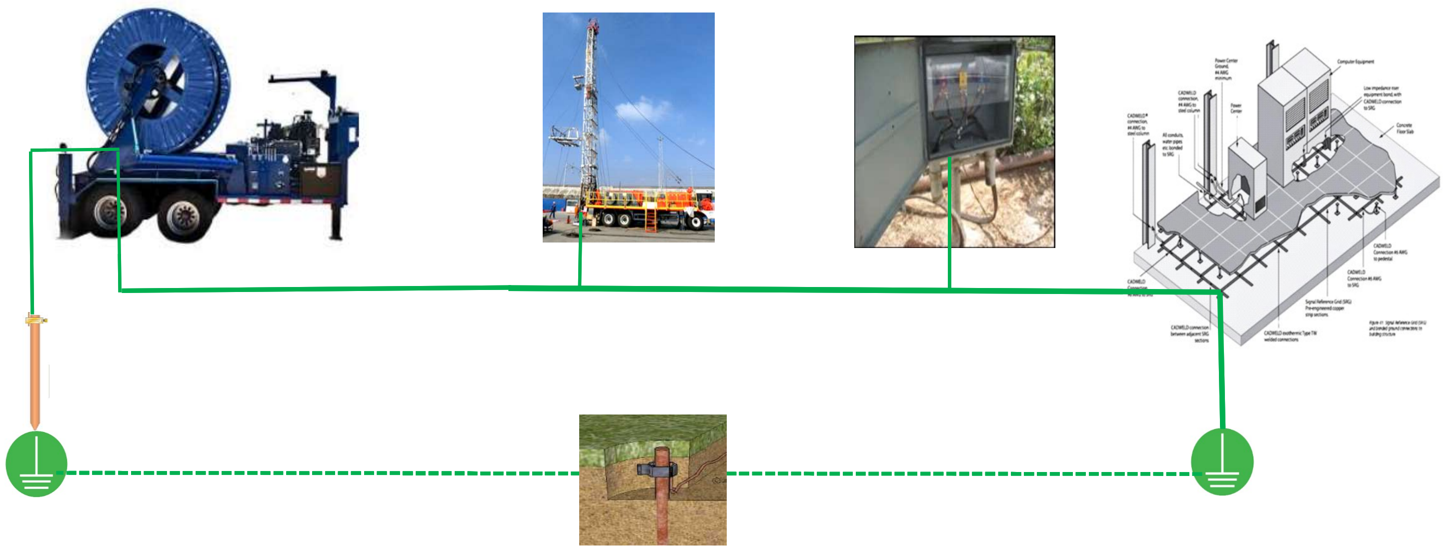
- Use task-suitable PPE
- Use task-suitable tools
- Use task-suitable instrumentation



Training / Procedures

- Field Service (FS) Training School
- PMM FS HSE Awareness
- PMM Safety Guideline Document HSE GLB-1100
- API 11S9 PMM Safety Recommended Practice
- NFPA 70E
- Auditing and Continuous Improvement
- Recertification

<u>Grounding – Creating an EquiPotential Zone (EPZ)</u> – Administrative Controls:



- Check ground continuity. Cable spooler, rig, vent box and surface equipment must be properly grounded and bonded to wellhead. Use an external cable if required.
- **<u>Ground resistance should be less than 10 Ohms</u>. Create Equipotential Zone (EPZ).**

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Hierarchy of Controls – PPE & Tooling

- PPE & Tooling
  - All PPE & Tooling to be certified / calibrated as per manufacturer's recommendation
  - Inspected and maintained per a defined schedule

Shorting Box – Engineering Controls

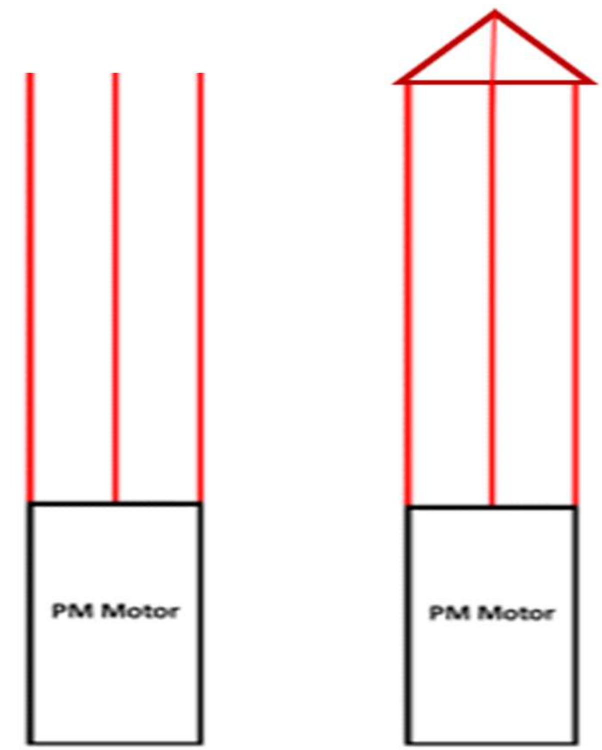
PMM Generated voltage is observed at the power cable leads

ESP vendor recommendation is to short circuit the phases at the Shorting Box and isolated from Ground.

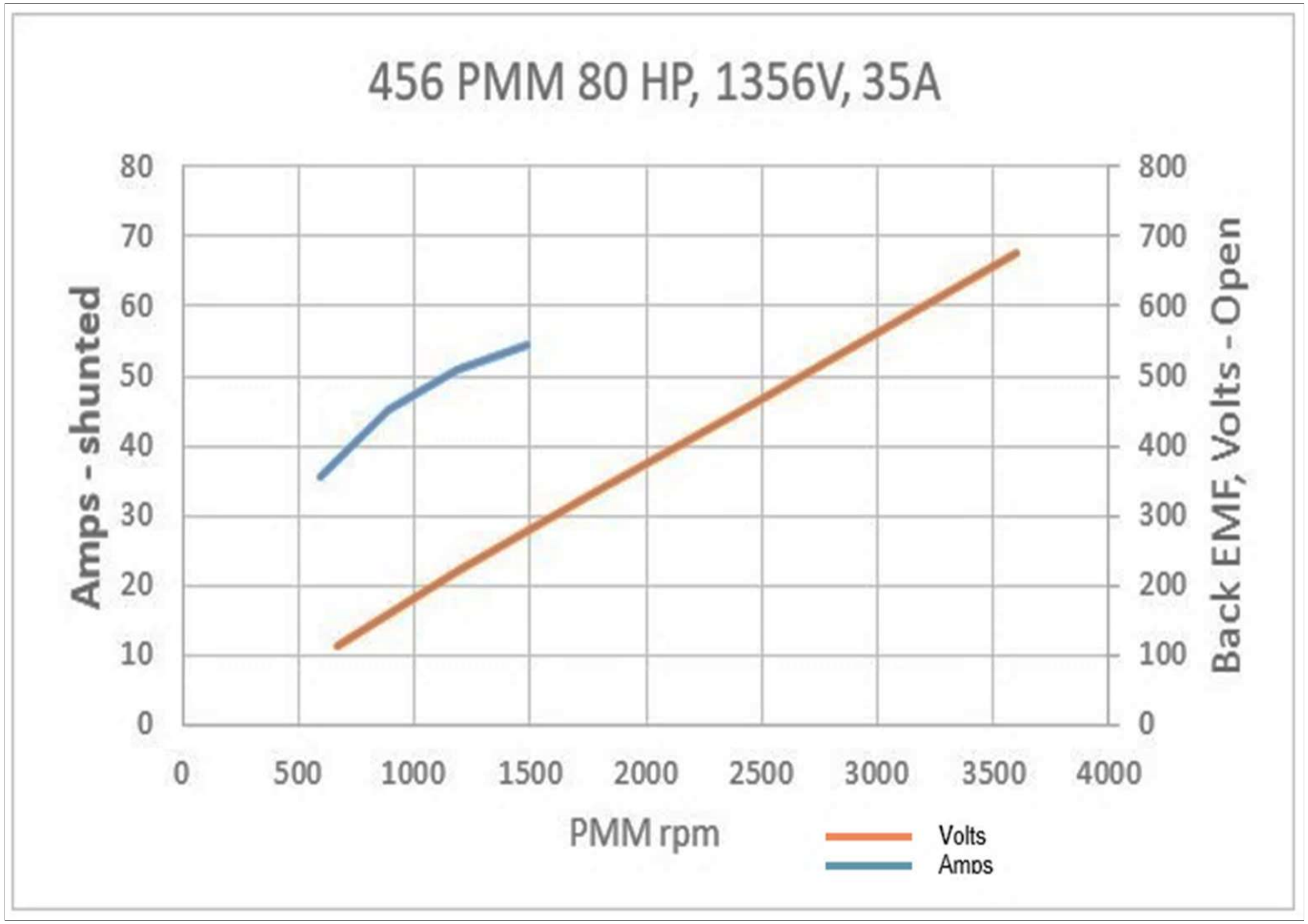
The short circuit acts as a dynamic **BRAKE** and the variable to monitor is **CURRENT** having **Zero Voltage at Surface.**

It i … est a

OPEN Leads	Shorted Leads
Surface P-P Volts = Max Volts	**Surface P-P Volts = Min. Volts(0)**
Phase current = Min. Amps(0)	**Phase current = Max. Amps**
Backspin Time = Min. time	**Backspin Time = Max. time**

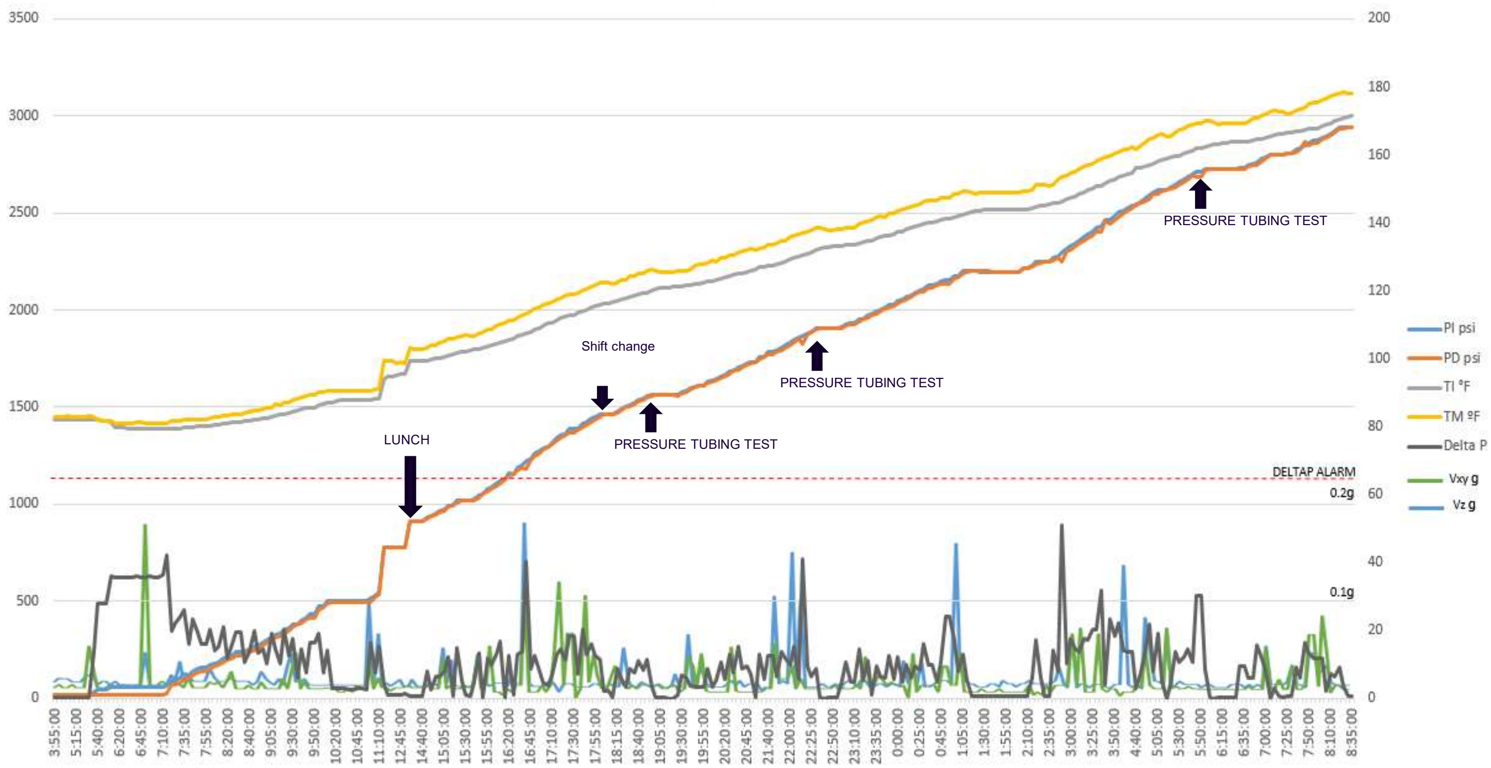


PMM – Shunted and Open Performance



Actual Well Log RIH

Time vs Delta Pressure & Cable Current



Other carbon usage calcs

Flight Long Beach, CA (LGB) to Salt Lake City, UT (SLC)

- Duration: 1:49 – 1:58
- Distance: 588 miles
- Aircraft: E7W – Airbus A320
- Emissions: 512.9 lbs CO 2 e - 512.9

Flight Salt Lake City, UT (SLC) to Tulsa, OK (TUL)

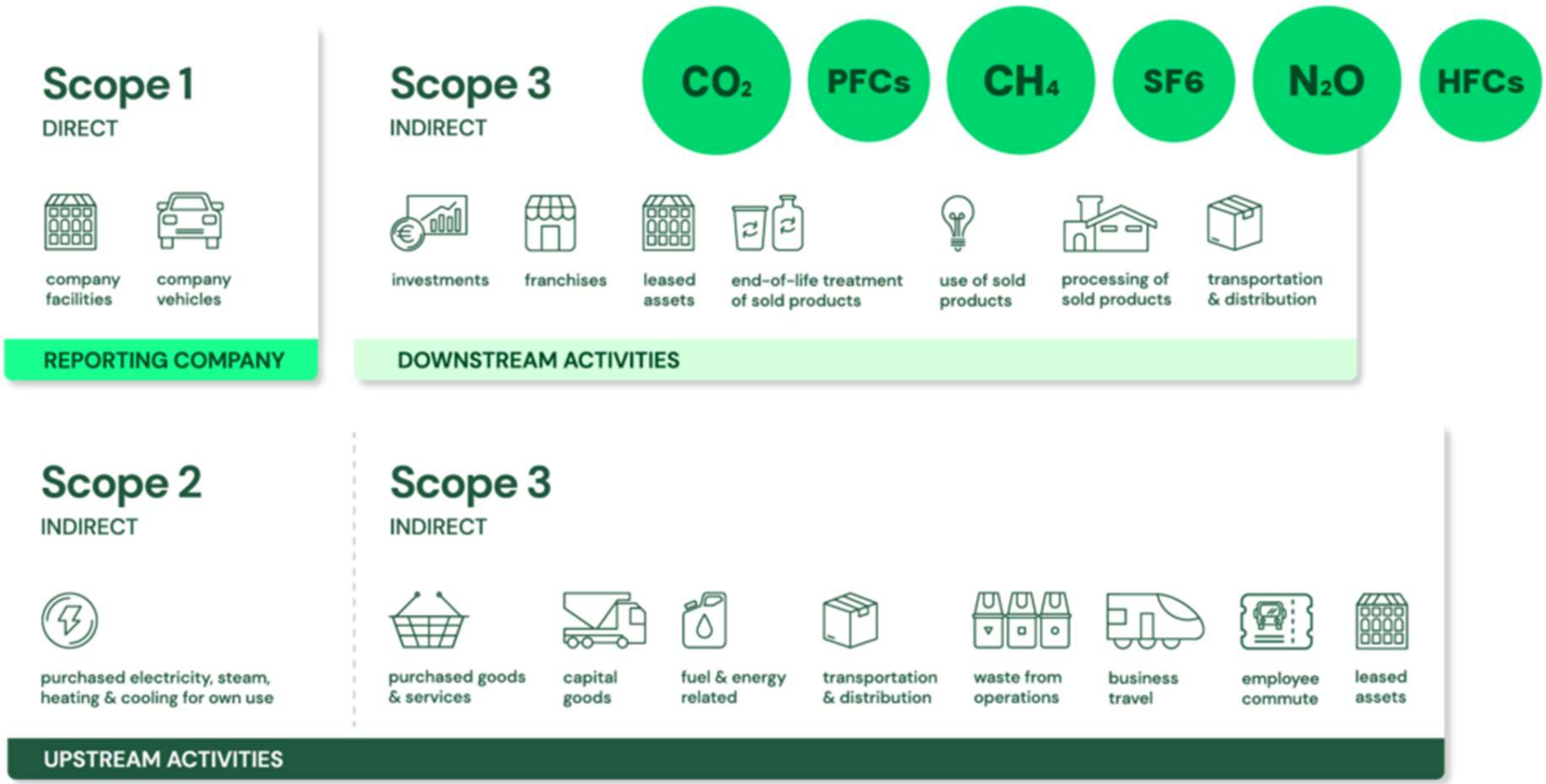
- Duration: 2:30 – 2:50
- Distance: 924 miles
- Aircraft: E7W – E7W
- Emissions: 503.3 lbs CO 2 e - 503.3

Outbound

PMM Installed Base

- 7000+ active PMM wells
- Ave 21 kWh (PMM vs IM)
- 0.0092 tons CO_2 / 21 kWh
- 80.9 tons CO_2 / yr / well
- Total 565,000 tons yearly reduction

Carbon Counting



PMM RE Magnet Life Cycle

- HT SmCo used in ESP's
- Nd-Fe-B used in wind / EV
- PMM vs IM better reuse

PMM Key Takeaways

Decrease electrical spending by **$ MM**

Emphasis on risk mitigation and safety protocol

Reduce carbon footprint by **XX** metric tons