



# ***Compression Modernization Options – Which is Best***

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Williams Companies, AER Equipment Reliability

4-18-2023

A large white flag with the Williams logo (the word "Williams" in black with a blue swoosh) waving against a blue sky with clouds. The flag is attached to a metal pole on the left.

**Williams**

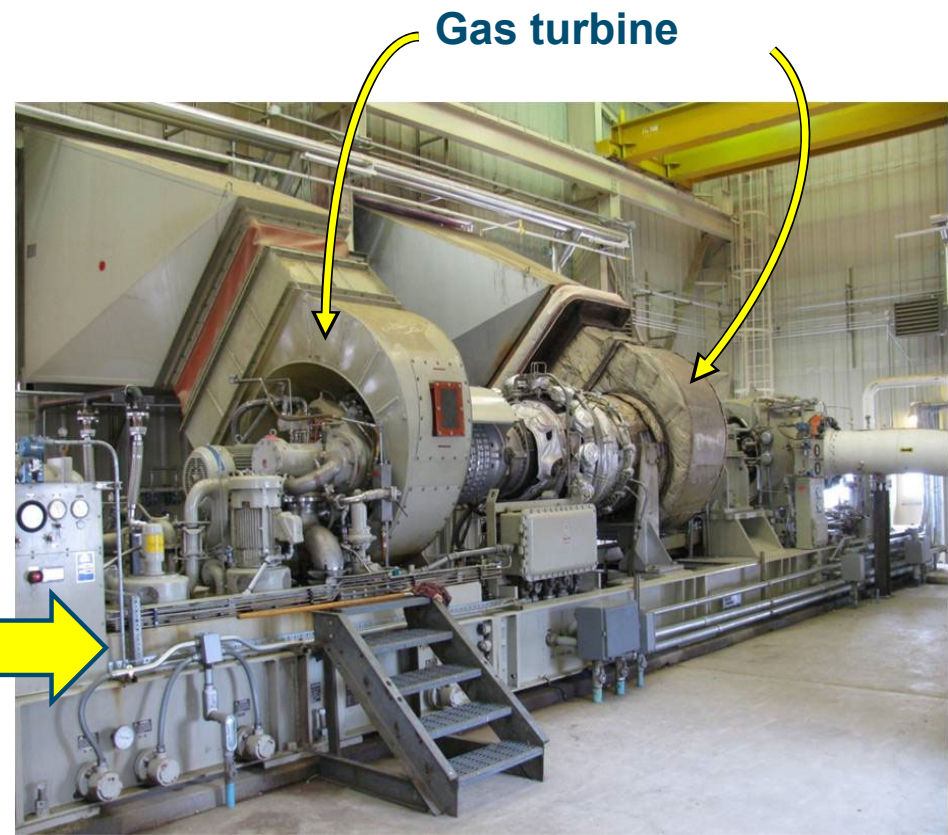
## Agenda

- > What does “Modernization” mean?
- > Why Modernize?
- > What are the options?
- > What is important to consider when looking at “modernization”?
- > Pros and Cons of Options

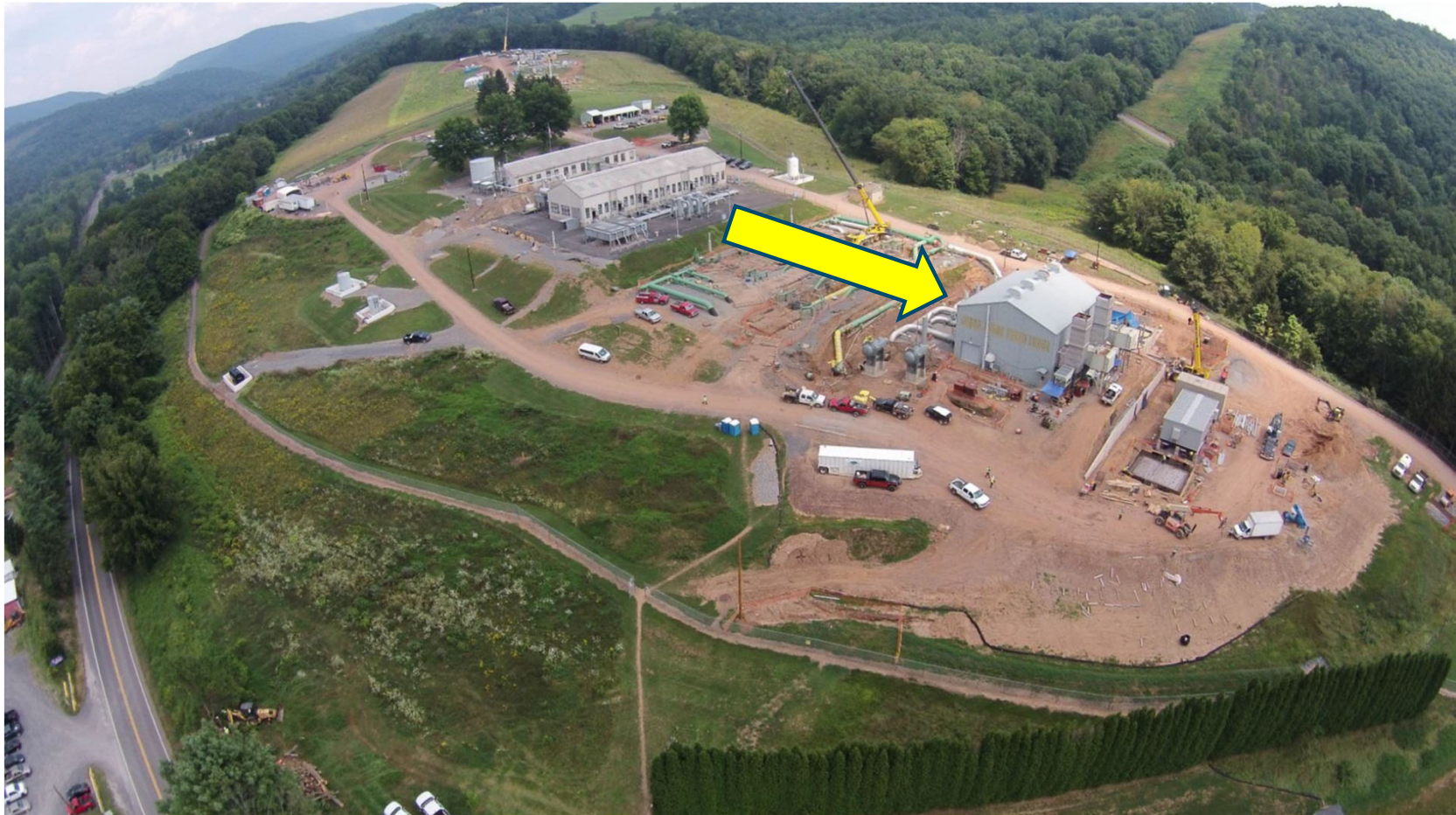
## Modernization – what is it?

- > In general, it's the retirement of “legacy” slow speed integral recips and replace them with new equipment.
  - Ancillary equipment are all at end of life
    - Intakes, exhaust, coolers, valves, tanks, buildings / windows, conduit, wires, control systems, etc...
- > Legacy slow speed recips make up 29% (by horsepower) of our interstate gas transmission systems.
- > The average age of those 316 machines is 64 years old (1959)
- > The equipment is not getting any younger

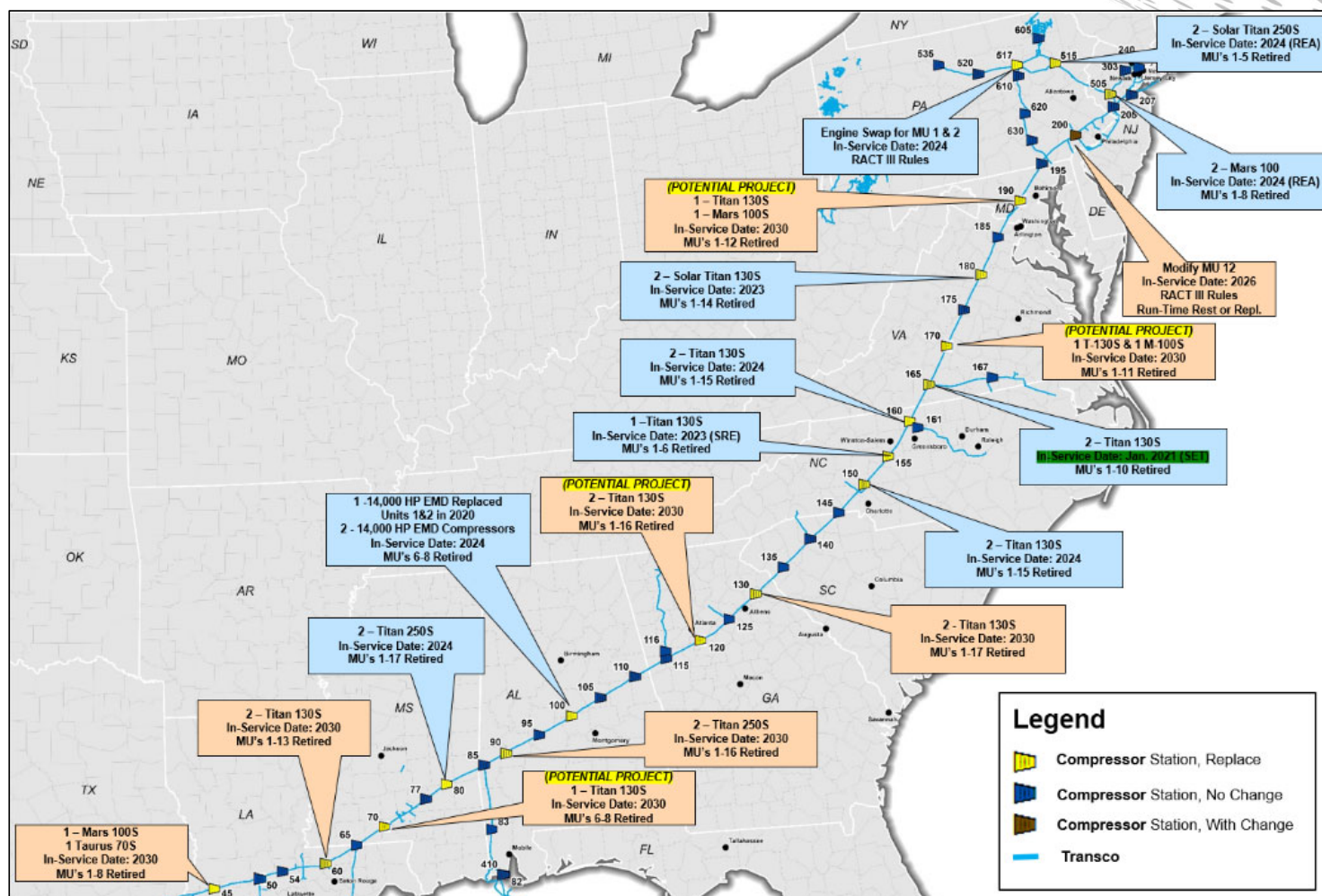
## Building of recip to centrifugal equipment



## Old vs new



# Transco Plan





## Why Modernize?

- > Reduce O&M expense
  - Lube oil / coolant
  - Maintenance
  - Other
- > Experience / knowledge is retiring – or has retired
- > Increase Capex
  - Exchange turbine using capex vs overhaul / maintain reciprocating engines using expense
- > Investor relations / Optics
- > Can reduce NOx emissions
  - Also helps with investor / public relations

## Modernization Options

1. Replace legacy recips with large turbine driven centrifugal compressor package(s)
2. Replace legacy recips with large EMD driven centrifugal compressor package(s)
3. Hybrid approach
  - Replace older (and smaller) “A” building of legacy recips with an option above but keep and upgrade the newer – larger legacy recips in “B” building.
4. Update / modernize legacy recips with new technology

## How do we decide what facilities to prioritize?

- > Tons NOx reduced
- > Tons CO<sub>2</sub>e reduced (combustion, methane slip, and vented)
- > Utilization Criticality (# days running more than 90% of available power)
- > Station reliability and health (ranked by Tech managers and Ops directors)
- > Station reliability and health (ranked by pipeline control)
- > Projected Utilization
- > Growth Opportunities

## 11

Presentation name (edit footer in slide master pages) | 1/1/16

## Once facilities are chosen, how do we decide compression?

- > What will our customers pay for
  - Total Capex, and available funding
  - Rate case timing
- > Operability (turndown, Operational flexibility)
- > Annual O&M cost
- > Annual Fuel / electricity cost
- > Availability of electricity to site
- > Maintenance (aftermarket support, Ops experience with unit, inventory)
- > Schedule risk

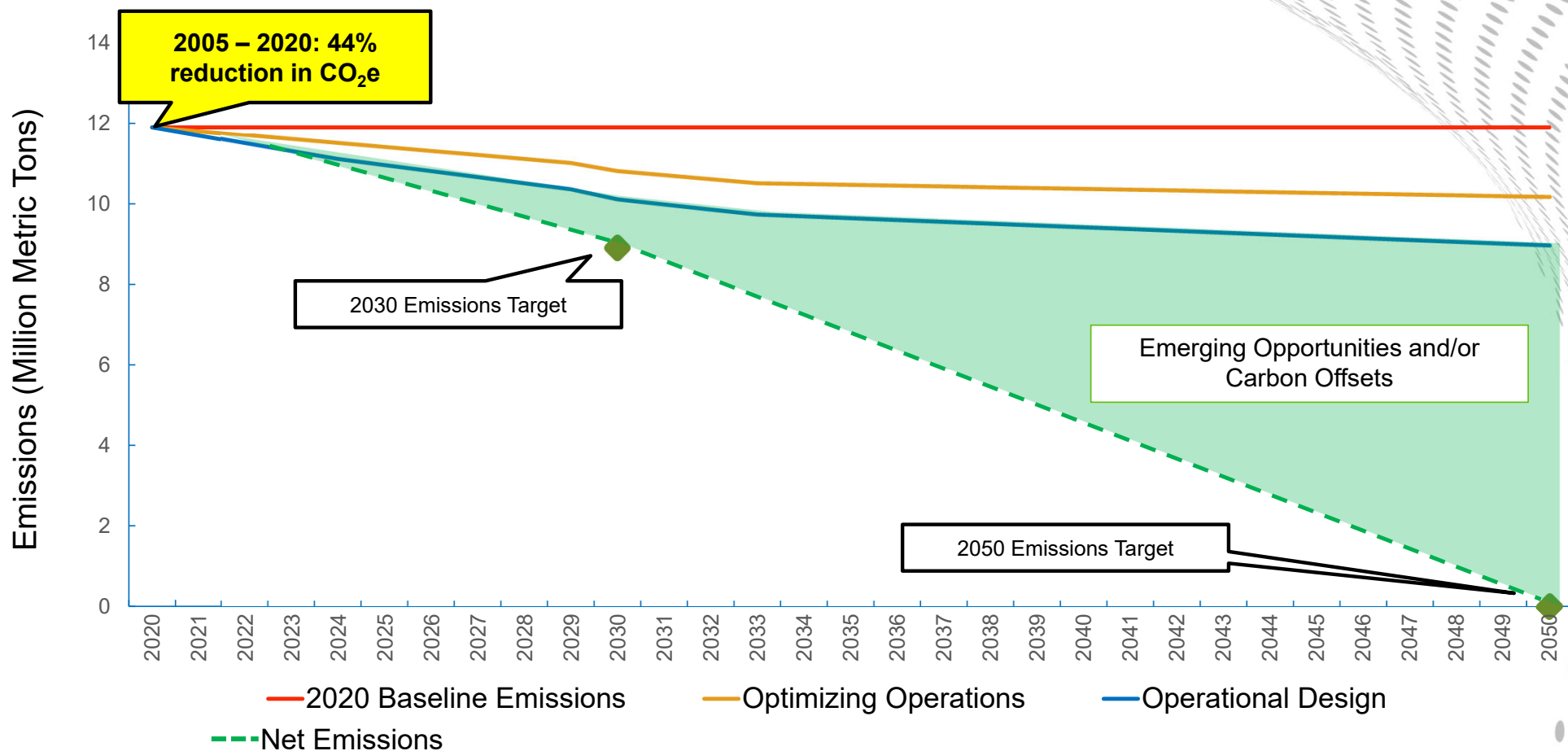
## Technical Alternative Heat Map example

| Station 80 RFP - TECHNICAL ALTERNATIVES HEAT MAP |                                                                                                                                                                              |        |                                                                                                                                              |                                                                                                                                                                     |                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                                                 |                                                                                                                                         |                 |
|--------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------|----------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------|-----------------|
| Criteria                                         | Criteria Description                                                                                                                                                         | Weight | OPTION 1                                                                                                                                     | OPTION 2                                                                                                                                                            | OPTION 3                                                                                                                                                                                                                                                          | OPTION 3a                                                                                                                                                                                                                                                                                                                       | OPTION 4                                                                                                                                | Total Raw Score |
|                                                  |                                                                                                                                                                              |        | 2 Turbines<br><br>94% Reduction, 2117 tons (Actuals) down to projected 123 tons.                                                             | Single Turbine Case:<br>Install 1 x 100% Unit<br><br>94% Reduction, 2117 tons (Actuals) down to projected 123 tons.                                                 | 2 EMDs<br>100% reduction due to Electric Units; 123 tons become Scope 2.                                                                                                                                                                                          | Replace 1-11 (29,550 hp) with 1 EMD. HPFI V250 Units 12-16 (21,200hp)                                                                                                                                                                                                                                                           | Single EMD Case:<br>Install 1 x 100% Unit<br><br>100% reduction due to Electric Units; 123 tons become Scope 2.                         |                 |
| Scenario Notes                                   |                                                                                                                                                                              |        | 2 x Titan 250S- 30,000 HP                                                                                                                    | 1 x Siemens SGT- 750 (55K HP)                                                                                                                                       | 2 x 30,000 HP EMD w/ C- 75 Compressors.                                                                                                                                                                                                                           | 1 x 30,000 HP EMD w/ C- 75 compressor plus HPFI recip retrofits and pinch valve                                                                                                                                                                                                                                                 | 1 x 56,000 HP EMD                                                                                                                       |                 |
| Capital                                          | Fully loaded with contingency and indirect costs<br>Highest Cost = 1<br>Lowest Cost = 4                                                                                      | 25%    | 108.44 MM                                                                                                                                    | 91.35 MM                                                                                                                                                            | 100.54 MM                                                                                                                                                                                                                                                         | \$75.00                                                                                                                                                                                                                                                                                                                         | 88.60 MM                                                                                                                                | 14              |
|                                                  |                                                                                                                                                                              |        | 1                                                                                                                                            | 3                                                                                                                                                                   | 2                                                                                                                                                                                                                                                                 | 4                                                                                                                                                                                                                                                                                                                               | 4                                                                                                                                       |                 |
|                                                  |                                                                                                                                                                              |        | 0.25                                                                                                                                         | 0.75                                                                                                                                                                | 0.50                                                                                                                                                                                                                                                              | 1.00                                                                                                                                                                                                                                                                                                                            | 1.00                                                                                                                                    |                 |
| Operability                                      | Turndown, Operability Flexibility<br>Lowest Turndown = 1<br>Highest Turndown = 4                                                                                             | 15%    | Turndown capability is achievable for the turbine units, just slightly lower than the EMD w/ VFD option.                                     | Reliance on a single unit. Also from an efficiency standpoint, it is also not preferable.                                                                           | A lot of flexibility with ability to turn down the EMD units. Upwards to 50% capability.                                                                                                                                                                          | Complete flexibility to meet demand of station operating on different lines. (from one recip unit part load to full station load = 3% to 100%)                                                                                                                                                                                  | VFD available, however, too much reliance on a single unit. Also from an efficiency standpoint, it is also not preferable.              | 13              |
|                                                  |                                                                                                                                                                              |        | 3                                                                                                                                            | 1                                                                                                                                                                   | 4                                                                                                                                                                                                                                                                 | 4                                                                                                                                                                                                                                                                                                                               | 1                                                                                                                                       |                 |
|                                                  |                                                                                                                                                                              |        | 0.45                                                                                                                                         | 0.15                                                                                                                                                                | 0.60                                                                                                                                                                                                                                                              | 0.60                                                                                                                                                                                                                                                                                                                            | 0.15                                                                                                                                    |                 |
| Annual O&M Cost                                  | \$18P-yr O&M based on Transco 2017-2018 Report<br>Highest \$18P-yr = 1<br>Lowest \$18P-yr = 4<br><br>\$3818p-yr for Turbines<br>\$2518p-yr for EMDs<br>\$6518p-yr for Recips | 10%    | 2.28MM                                                                                                                                       | 2.13MM                                                                                                                                                              | 1.5MM                                                                                                                                                                                                                                                             | 2.128MM                                                                                                                                                                                                                                                                                                                         | 1.5MM                                                                                                                                   | 12              |
|                                                  |                                                                                                                                                                              |        | 1                                                                                                                                            | 1                                                                                                                                                                   | 4                                                                                                                                                                                                                                                                 | 2                                                                                                                                                                                                                                                                                                                               | 4                                                                                                                                       |                 |
|                                                  |                                                                                                                                                                              |        | 0.10                                                                                                                                         | 0.10                                                                                                                                                                | 0.40                                                                                                                                                                                                                                                              | 0.20                                                                                                                                                                                                                                                                                                                            | 0.40                                                                                                                                    |                 |
| Annual Fuel/Electricity Costs                    | Electricity Cost of \$.05K/Wh (MS Power)<br>Natural Gas Cost of \$2.50/MMBtu (Updated Avg. Cost for Program thru 2024)<br>Assume ST 80 Avg. Utilization Annually 2020-2025   | 10%    | At 41% utilization fuel costs = 232K/Monthly or 2.79MM yearly.                                                                               | At 41% utilization fuel costs = 232K/Monthly or 2.79MM yearly.                                                                                                      | At 41% utilization elec. costs = 839K/monthly or 10.07MM yearly.<br>4.2MM in minimum billing charges.                                                                                                                                                             | At 41% utilization, elec costs are 449K/mo + recip costs at 80k/mo = 529K/mo or 6.45MM yearly.<br>Option to run gas fired at lower demand and save partner customer \$.                                                                                                                                                         | Sample bills show monthly utility bill to range from 712K-1MM USD.<br>Yearly costs would be 8.5 to 12 MM for the first 10 years.        | 12              |
|                                                  |                                                                                                                                                                              |        | 4                                                                                                                                            | 4                                                                                                                                                                   | 1                                                                                                                                                                                                                                                                 | 2                                                                                                                                                                                                                                                                                                                               | 1                                                                                                                                       |                 |
|                                                  |                                                                                                                                                                              |        | 0.40                                                                                                                                         | 0.10                                                                                                                                                                | 0.10                                                                                                                                                                                                                                                              | 0.10                                                                                                                                                                                                                                                                                                                            | 0.10                                                                                                                                    |                 |
| Maintenance                                      | Maintenance - Aftermarket Support, Operations Experience with Unit, Inventory capability.<br><br>Lowest Level = 1<br>Highest Level = 4                                       | 15%    | Relationship & Agreement in place. Known commodity when FSRs are needed. Titan 250s can be inventoried more readily based on current system. | Ops not experienced with Operating this type of unit. Unproven relationships for repair. Inventory becomes an issue.<br><br>Would be outside of the Solar Alliance. | Relationship and availability for FSR reps. with other Companies is questionable. GE (now ABB) not in PEC and is problematic trying to get reps. in the field.<br>Solar compressor with Siemens drive have been proven execution. Ranking based on this approach. | Half of power is proven reliable recips with plenty of technical support, parts, etc., available. Relationship and availability for electric unit FSR reps. with other Companies is questionable. GE (now ABB) not in PEC and is problematic trying to get reps. in the field.<br>Solar compressor with Siemens drive have been | Ops not experienced with Operating this type of unit. Unproven relationships for repair. Inventory becomes an issue.                    | 14              |
|                                                  |                                                                                                                                                                              |        | 4                                                                                                                                            | 2                                                                                                                                                                   | 3                                                                                                                                                                                                                                                                 | 4                                                                                                                                                                                                                                                                                                                               | 1                                                                                                                                       |                 |
|                                                  |                                                                                                                                                                              |        | 0.60                                                                                                                                         | 0.30                                                                                                                                                                | 0.45                                                                                                                                                                                                                                                              | 0.60                                                                                                                                                                                                                                                                                                                            | 0.15                                                                                                                                    |                 |
| Schedule Risk                                    | Schedule Driven Project - Nov 30, 2023 ISD<br>Lowest likelihood to meet target ISD = 1<br>Highest likelihood to meet target ISD = 4                                          | 25%    | Company would own and control schedule.                                                                                                      | Company would own and control schedule. Other project have been impacted by Siemens delays.                                                                         | 30 months from contract execution; January 2022 to July 2024 is 30 months. Contract execution needed by Nov. 1, 2021; otherwise schedule risk for EMDs is present. ISD cannot be shifted out further.                                                             | EMD: 31 months from contract execution; January 2022 to July 2024 is 30 months. Contract execution needed by Nov. 1, 2021; otherwise schedule risk for EMDs is present. ISD cannot be shifted out further. Recps: Great relationship with Crooner and execution can be completed.                                               | Company is not in control of MS Power substation construction. 30 months from contract execution. Delays in single large block HP Unit. | 17              |
|                                                  |                                                                                                                                                                              |        | 4                                                                                                                                            | 3                                                                                                                                                                   | 4                                                                                                                                                                                                                                                                 | 4                                                                                                                                                                                                                                                                                                                               | 2                                                                                                                                       |                 |
|                                                  |                                                                                                                                                                              |        | 1.00                                                                                                                                         | 0.75                                                                                                                                                                | 1.00                                                                                                                                                                                                                                                              | 1.00                                                                                                                                                                                                                                                                                                                            | 0.50                                                                                                                                    |                 |
|                                                  |                                                                                                                                                                              | 100%   | 2.80                                                                                                                                         | 2.45                                                                                                                                                                | 3.05                                                                                                                                                                                                                                                              | 3.50                                                                                                                                                                                                                                                                                                                            | 2.30                                                                                                                                    | 82              |
|                                                  | FINAL RANKING                                                                                                                                                                |        | 3                                                                                                                                            | 4                                                                                                                                                                   | 2                                                                                                                                                                                                                                                                 | 1                                                                                                                                                                                                                                                                                                                               | 5                                                                                                                                       |                 |

## Williams Goals

- > 2023 Environmental goal
  - Methane Emissions Reduction of 5% from a 3-year average baseline
  
- > 2030 Climate Commitment Goal of a 56% absolute emissions reduction of total CO<sub>2</sub>e (Scope 1 + Scope 2) from our 2005 level.
  - Scope 1 = direct emissions from operations at Williams facilities (i.e., blowdowns, fugitive emissions, venting)
  - Scope 2 = indirect emissions from purchased electricity used at Williams facilities
  
- > 2050 Net Zero CO<sub>2</sub>e

# Emission Targets



## Compression Efficiency

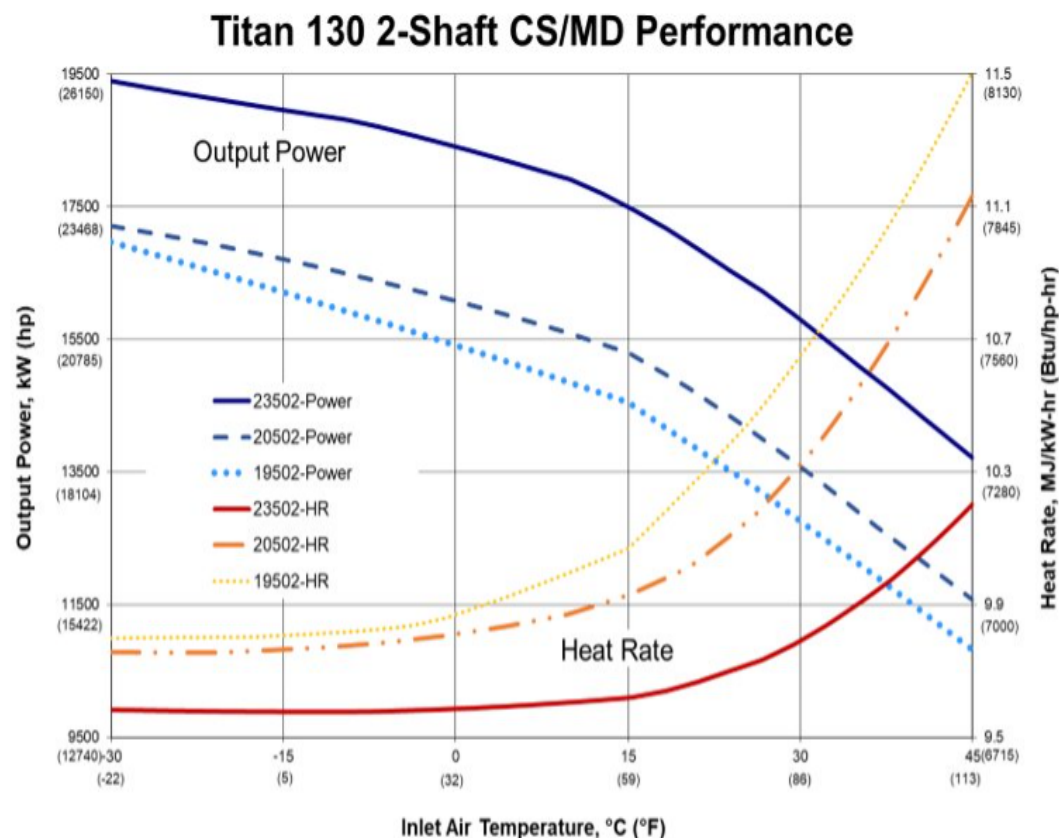
Compression as the main source of CO<sub>2</sub>e – What goes into that number?

Unit compression efficiency = Driver efficiency x Driven efficiency

- > Driver efficiency: How efficient is the machine as converting energy (electric or fuel) to shaft power?
  - Includes recip engines, turbines, electric motors, etc...
  - Driver “Heat Rate” in BTU/hp-hr is the metric that shows combustion efficiency
- > Driven efficiency: how efficient is the compressor at developing work
  - Includes recip compressors, pulsation bottles, etc...
  - Includes centrifugal compressors, gearboxes, transmissions,

## Driver: Turbine fuel efficiency vs load (New Titan 130)

- > At 100% load and 60degF, fuel efficiency is ~6,800 Btu/Bhp-Hr
- > At 83% load and 60degF, fuel efficiency is ~7,120 Btu/Bhp-hr (4.7% decrease in efficiency)
- > Large derates in fuel efficiency and power from ambient when more than 60 deg F outside



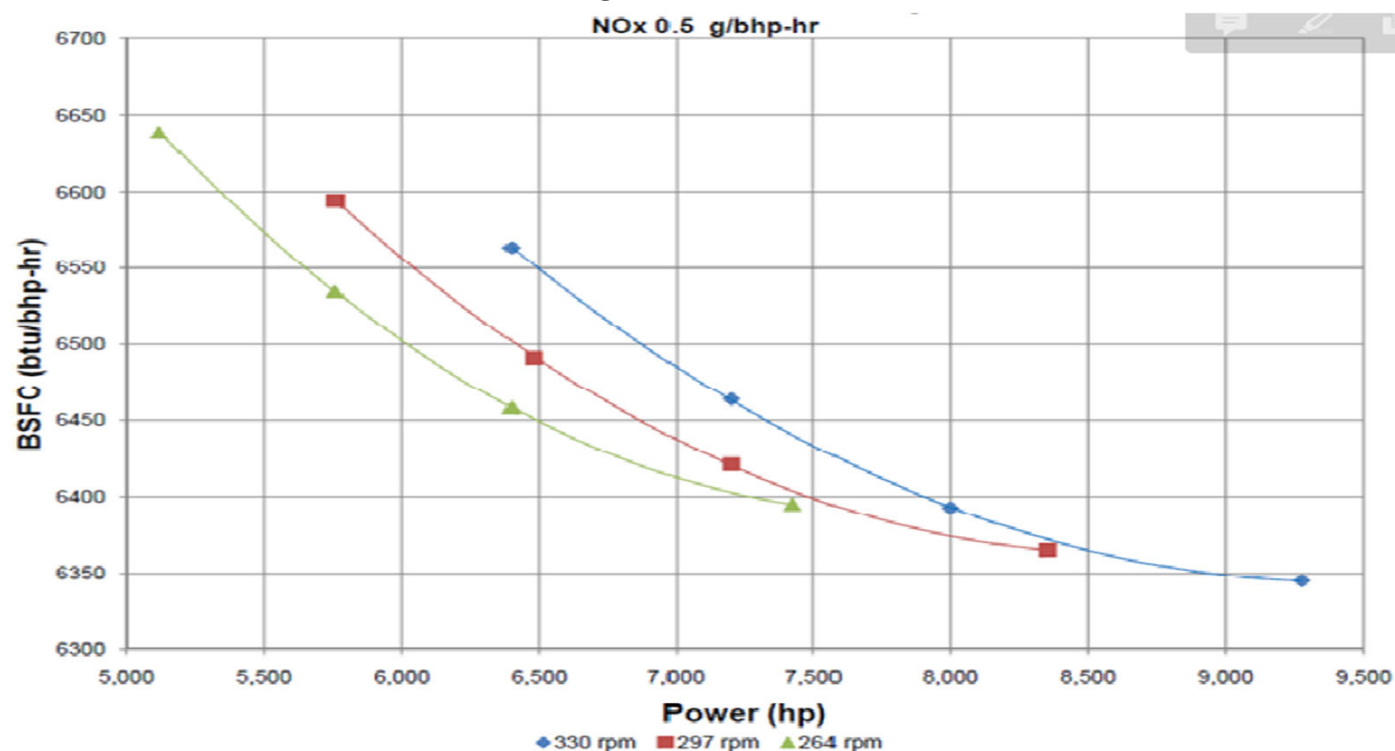
\* Excludes Accessory Gear Box Load for Lube Oil Pump, Gas Fuel, ISO Conditions

**Solar Turbines**  
A Caterpillar Company

**Powering the Future**

## Driver: Recip fuel efficiency vs load

- > When recips are slowed down and off load they maintain 100% torque and thus the fuel efficiency decrease is not nearly as drastic. Note; the recip compressor efficiency increases due to lower valve losses from slower gas velocities at the lower rpm.
- > At 100% load, fuel efficiency is ~6,350 Btu/Bhp-Hr
- > At 80% load fuel efficiency is ~6,400 Btu/Bhp-hr (only a 0.8% decrease)
- > No ambient temperature de-rate

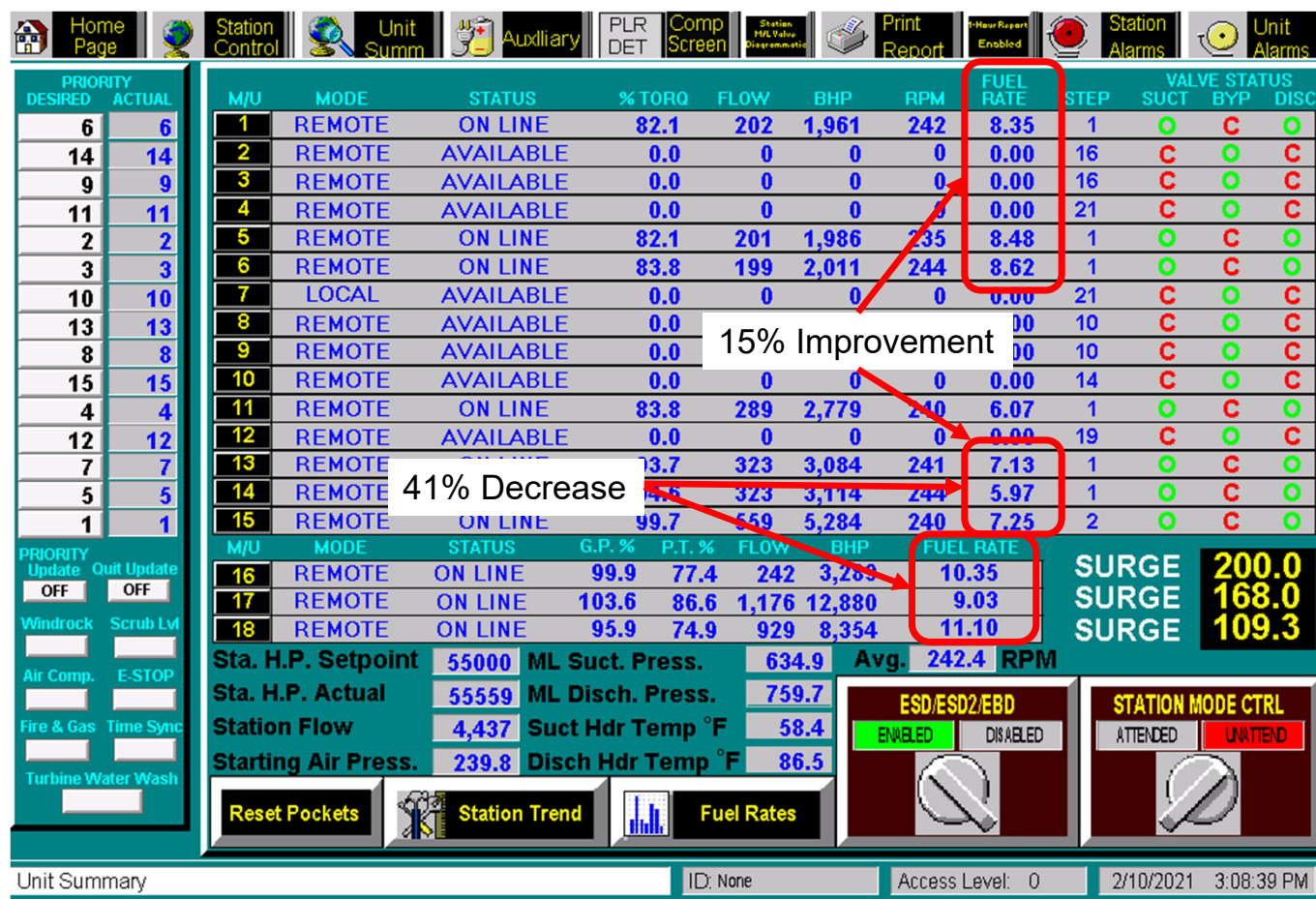


## Summary of driver examples – recip vs turbine fuel efficiency

- > Using a Solar Titan 130 in new condition
  - At 100% load, the recip is ~7% more fuel efficient.
    - 6,800 vs 6,350 heat rate
  - At 83% load, the recip is ~11.6% more fuel efficient.
    - 7,120 vs 6,380 heat rate
- > These fuel efficiencies go directly to CO2 emissions

## Station 90 fuel efficiency example

- > Note the fuel rates for the ~newer recip installed in the late 60's vs early 1950's
- > Turbines installed in 2000, 2010, and 2003, all have worse fuel performance than the recip.



## Station 140 fuel efficiency example

- > Unit 14 at 140 is very efficient with a fuel rate of 6.46 CF/hp-hr
- > That's 33% better than the turbine next to it.

**Home Page** **Station Control** **Unit Summary** **Air Comp Summary** **Composite Screen** **1** **2** **Tryon Lateral** **Auxiliary** **Print Report** **Station Alarms**

**Main Unit ESTOP Screen** **U14 SPD/TRQ OVERRIDE**

| M/U | MODE   | STATUS      | % TORQ | BHP   | RPM | STEP | FUEL RATE | SUCT | BYP | DISC |
|-----|--------|-------------|--------|-------|-----|------|-----------|------|-----|------|
| 1   | REMOTE | ON LINE     | 94.4   | 2,359 | 250 | 1    | 7.53      | 0    | C   | 0    |
| 2   | MANUAL | UNAVAILABLE | 0.0    | 0     | 0   | 23   | 0.00      | C    | 0   | C    |
| 3   | REMOTE | ON LINE     | 93.4   | 2,327 | 250 | 1    | 7.48      | 0    | C   | 0    |
| 4   | MANUAL | UNAVAILABLE | 0.0    | 0     | 0   | 23   | 0.00      | C    | 0   | C    |
| 5   | REMOTE | AVAILABLE   | 0.0    | 0     | 0   | 23   | 0.00      | C    | 0   | 0    |
| 6   | REMOTE | AVAILABLE   | 0.0    | 0     | 0   | 23   | 0.00      | C    | 0   | C    |
| 7   | REMOTE | ON LINE     | 96.9   | 2,545 | 249 | 1    | 7.45      | 0    | C   | 0    |
| 8   | REMOTE | AVAILABLE   | 0.0    | 0     | 0   | 10   | 0.00      | C    | 0   | C    |
| 9   | REMOTE | ON LINE     | 97.3   | 2,543 | 249 | 1    | 7.38      | 0    | C   | 0    |
| 10  | REMOTE | AVAILABLE   | 0.0    | 0     | 0   | 14   | 0.00      | C    | 0   | C    |
| 11  | REMOTE | ON LINE     | 99.9   | 3,424 | 250 | 2    | 7.11      | 0    | C   | 0    |
| 12  | MANUAL | UNAVAILABLE | 0.0    | 0     | 0   | 13   | 0.00      | C    | 0   | C    |
| 13  | REMOTE | ON LINE     | 99.1   | 3,369 | 249 | 4    | 7.84      | 0    | C   | 0    |
| 14  | REMOTE | ON LINE     | 93.7   | 7,327 | 281 | 1    | 6.46      | 0    | C   | 0    |

For more details click a Unit Number

| M/U | MODE   | STATUS  | G.P. RPM | BHP      | P.T. RPM | FUEL RATE | SURGE MARGIN |
|-----|--------|---------|----------|----------|----------|-----------|--------------|
| 15  | REMOTE | ON LINE | 103.6    | 12,689.0 | 90.4     | 8.61      | 38.9         |

STATION TOTAL HP 38,892 HP JACKET WATER 150.5 °F LUBE OIL 111.4 °F  
 LOWEST SUCTION PRESS 557.7 PSIG  
 HIGHEST DISCHARGE PRESS 720.0 PSIG  
 STATION FLOW 2,582 MMSCFD  
 STARTING AIR PRS. 237.9 PSIG  
 INSTRUMENT AIR PRS 87.3 PSIG

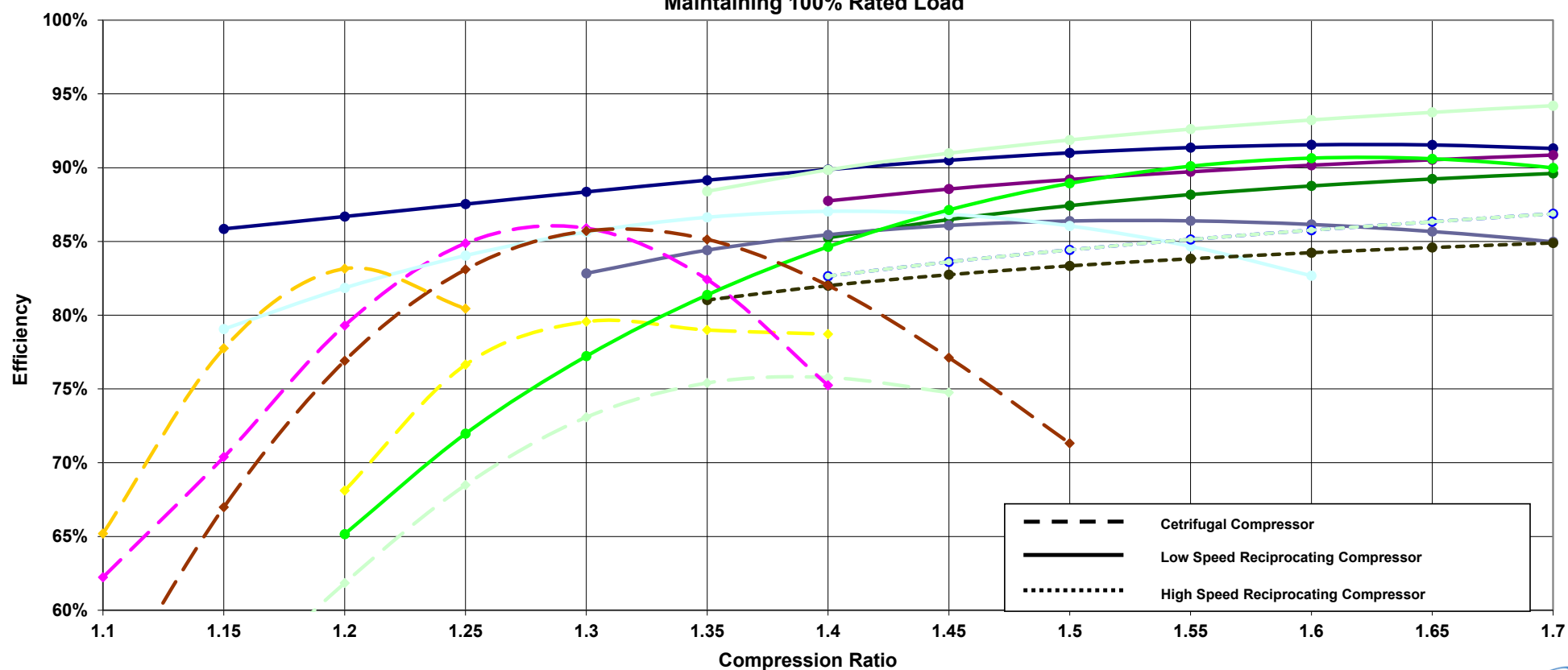
**STATION CONTROL** LOCAL REMOTE  
**ESD/ESD2/EBD** ENABLED DISABLED

**Vibration** **Fuel Rates** **Reset Pockets**

Unit Summary >> Operator Notes << ID: NONE Access Level: 0 2/10/2021 3:26:27 PM

# Driven: Compressor Efficiency – recip vs centrifugal

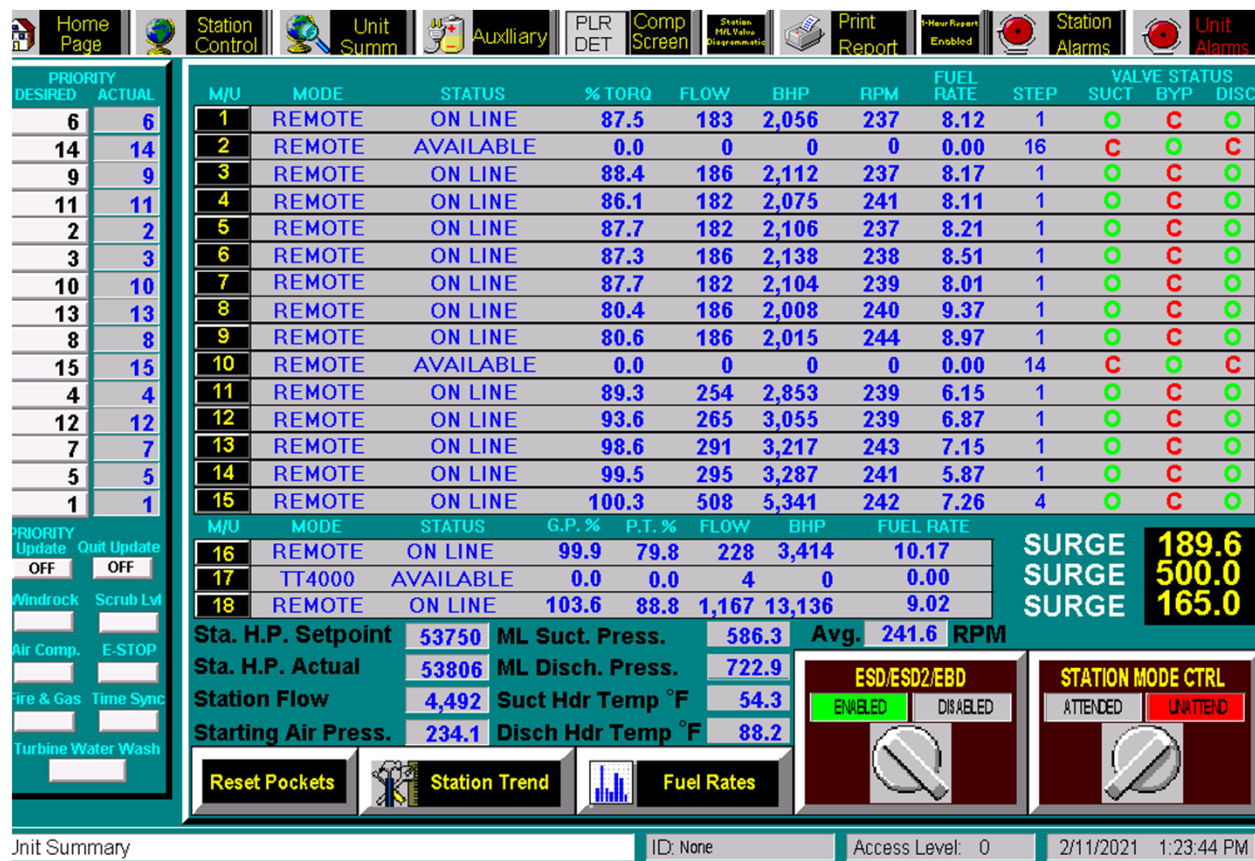
Examples of Compressor Efficiency vs. Ratio  
Maintaining 100% Rated Load



## Driven Compressor Efficiency example using HP/MM

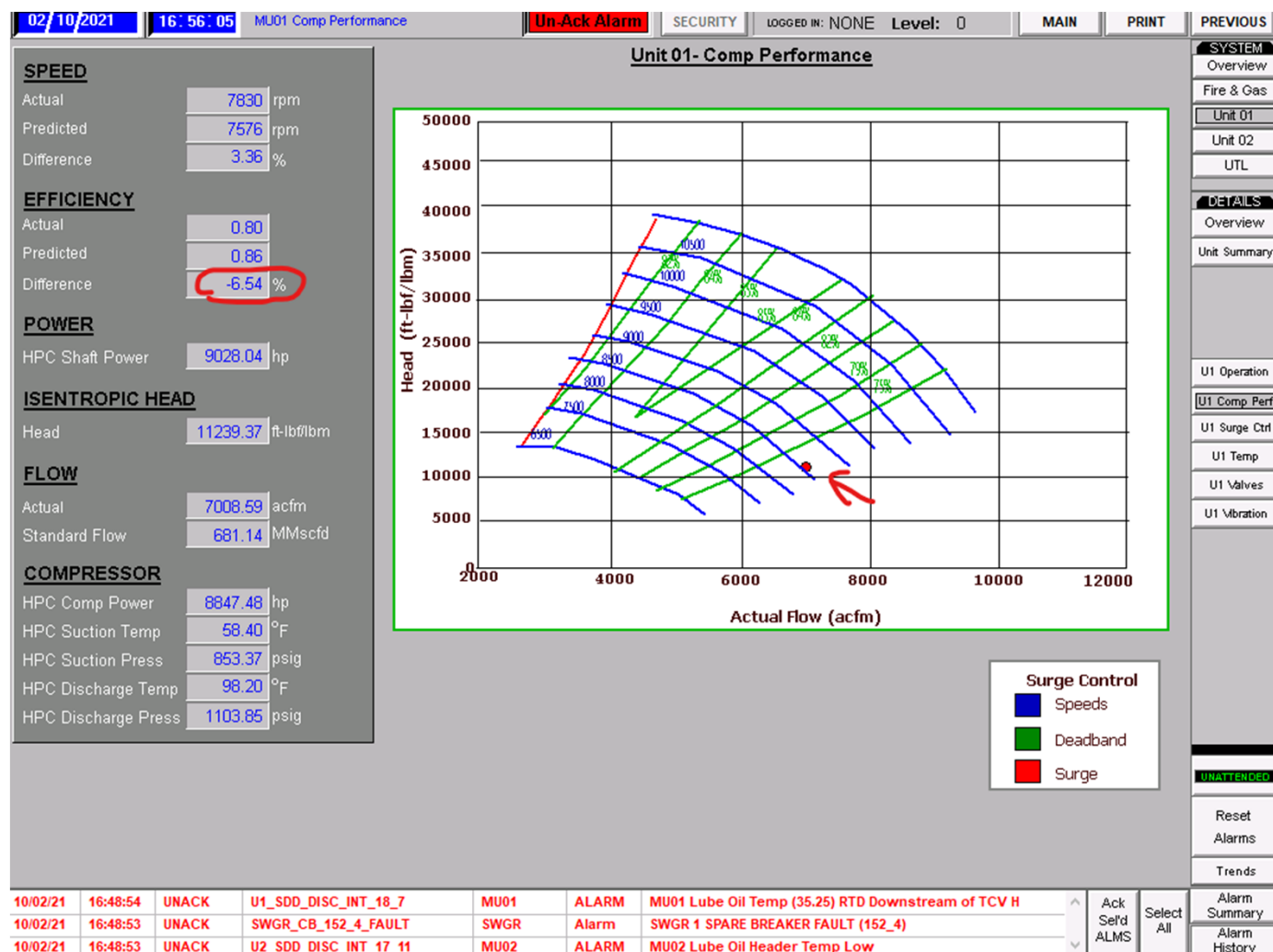
- > Here are the numbers normalized. Unit #18 is 7% less efficient than the “new” #15 recip. **7% is big.**

| Unit | Flow -MM | BHP   | BHP/MM |
|------|----------|-------|--------|
| 1    | 183      | 2056  | 11.2   |
| 3    | 186      | 2112  | 11.4   |
| 4    | 182      | 2075  | 11.4   |
| 5    | 182      | 2106  | 11.6   |
| 6    | 186      | 2138  | 11.5   |
| 7    | 182      | 2104  | 11.6   |
| 8    | 186      | 2008  | 10.8   |
| 9    | 186      | 2015  | 10.8   |
| 11   | 254      | 2853  | 11.2   |
| 12   | 265      | 3055  | 11.5   |
| 13   | 291      | 3217  | 11.1   |
| 14   | 295      | 3287  | 11.1   |
| 15   | 508      | 5341  | 10.5   |
| 16   | 228      | 3414  | 15.0   |
| 18   | 1167     | 13136 | 11.3   |



# 610-01 and 02

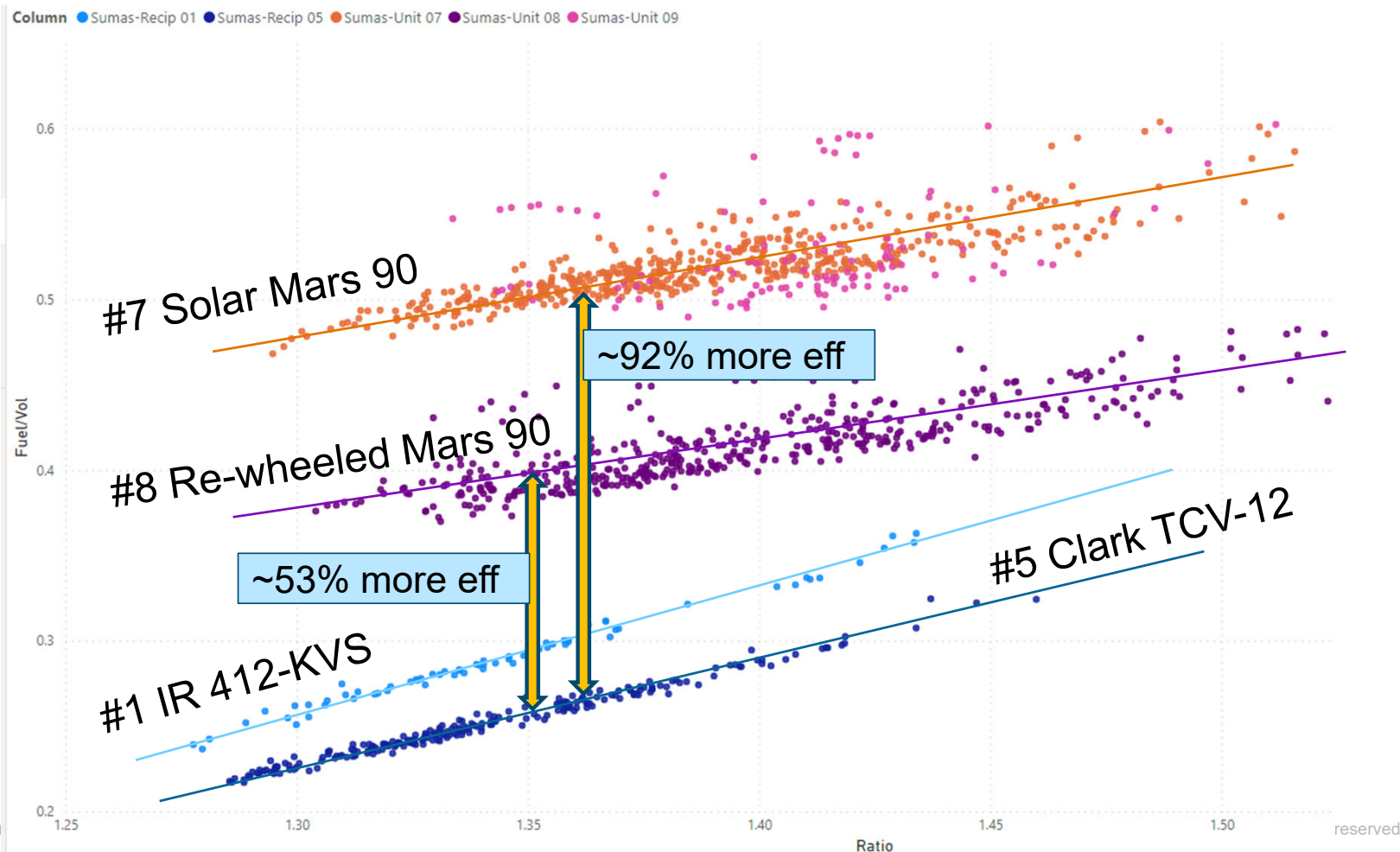
- > Some of our newest machines operating on the outskirts and off efficiency.



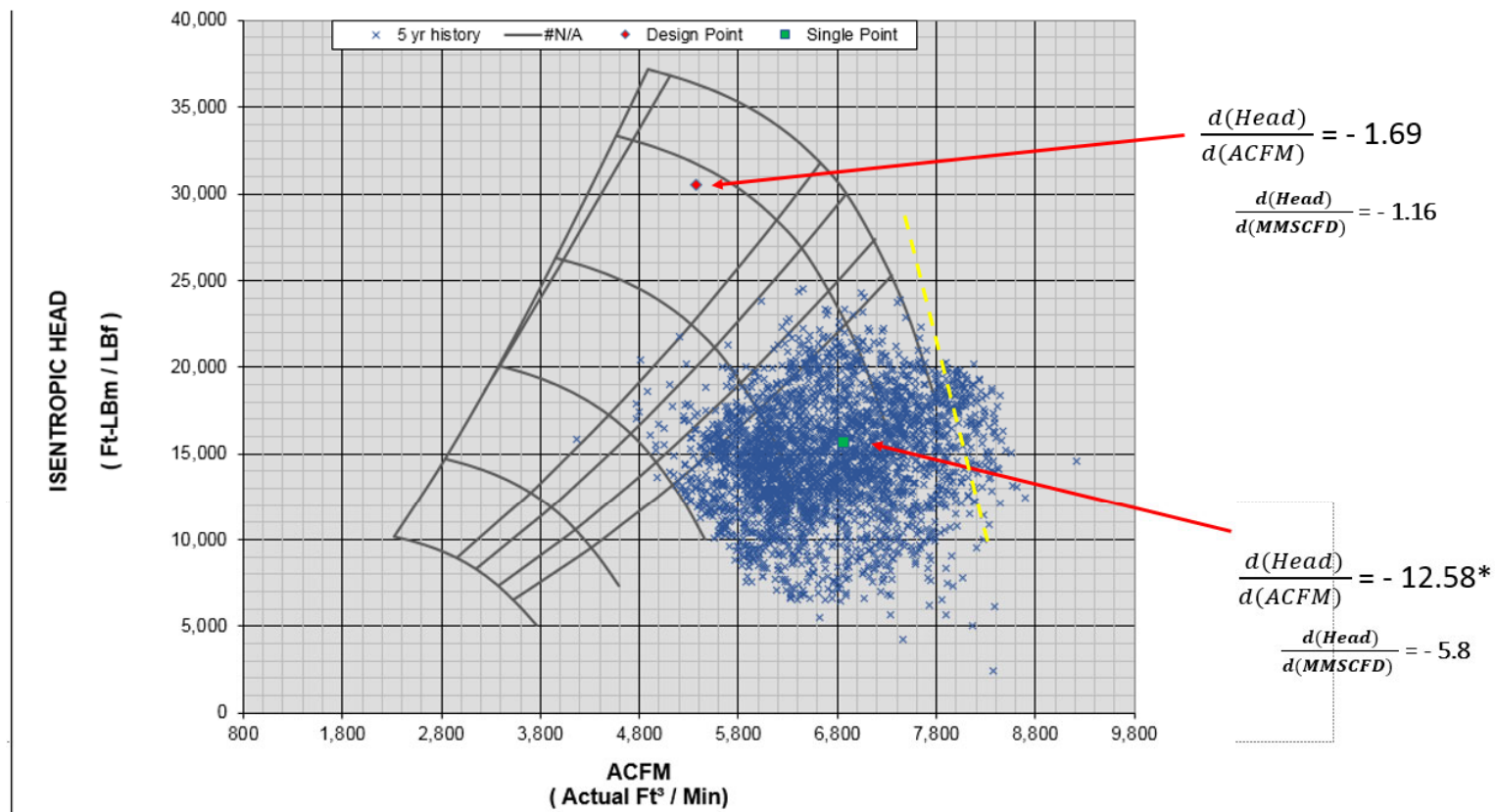
**The Future:  
Move from driver (fuel) and driven (compressor)  
efficiency to “Compression Efficiency” that combines  
driver and driven to choose what is best...**



# Compression Efficiency: Sumas Unit Efficiency differences



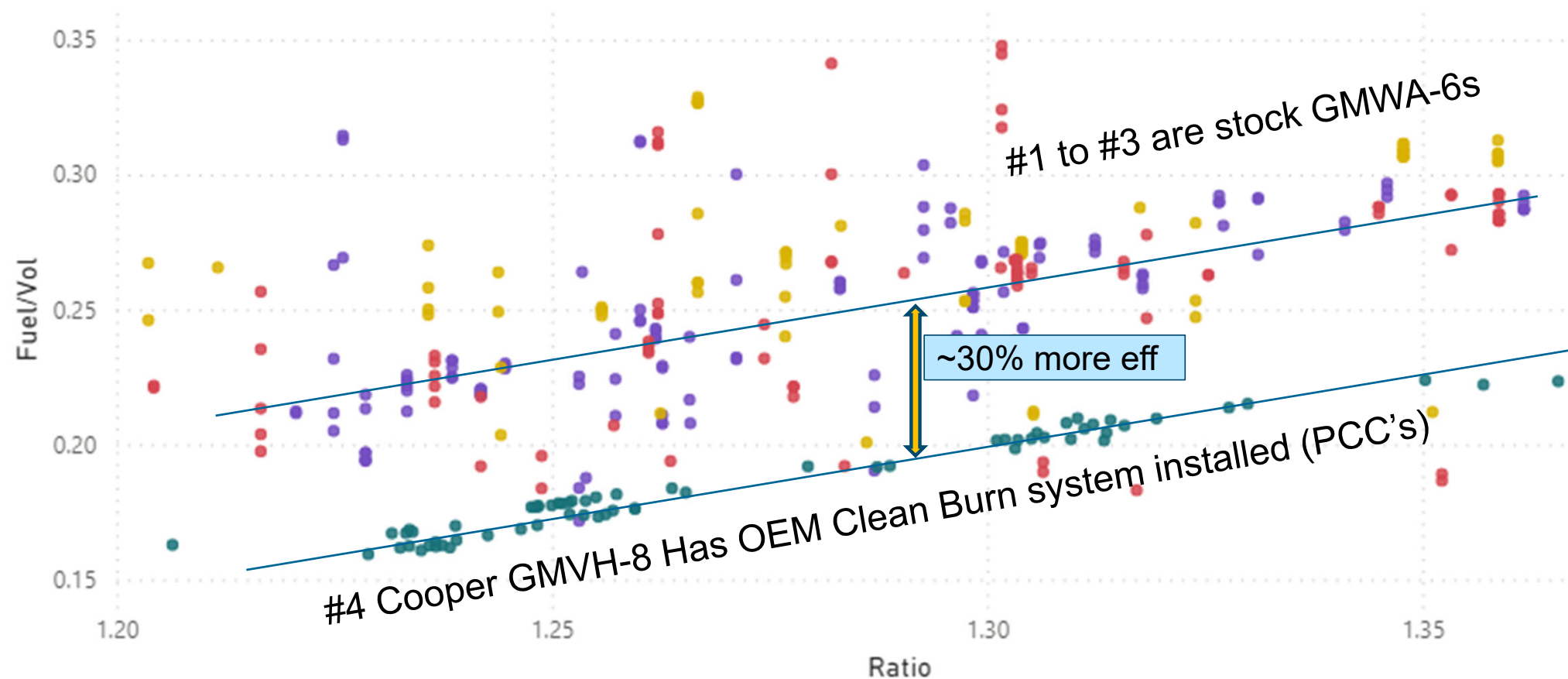
## NWP Sumas #8



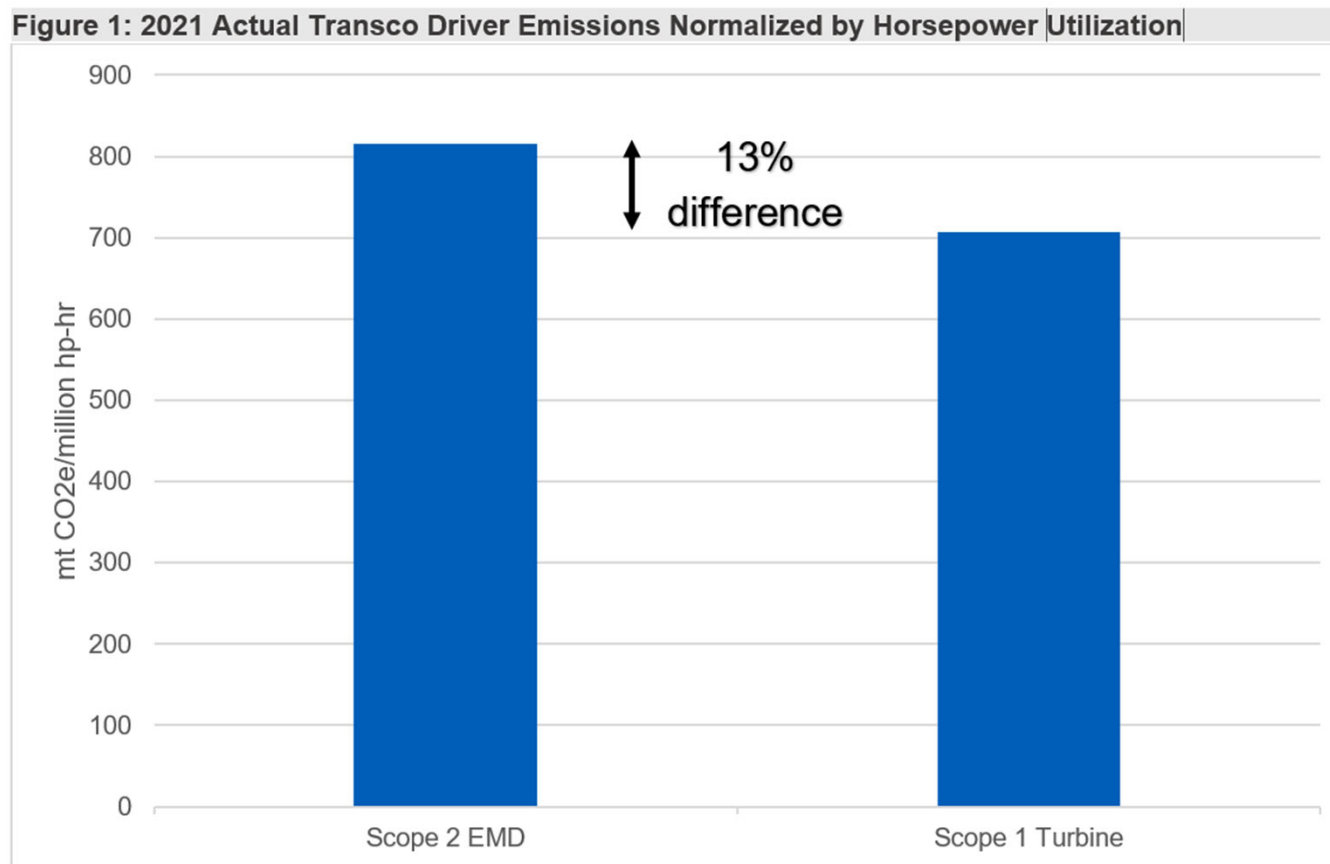
- At 8,000 rpm (worse at higher rpm), constant speed line
- MMSCFD numbers are holding suction pressure and power (and Nox production) constant, and change in pressure/flow is measured as a %

## NWP Baker

Column ● Baker-Recip 01 ● Baker-Recip 02 ● Baker-Recip 03 ● Baker-Recip 04

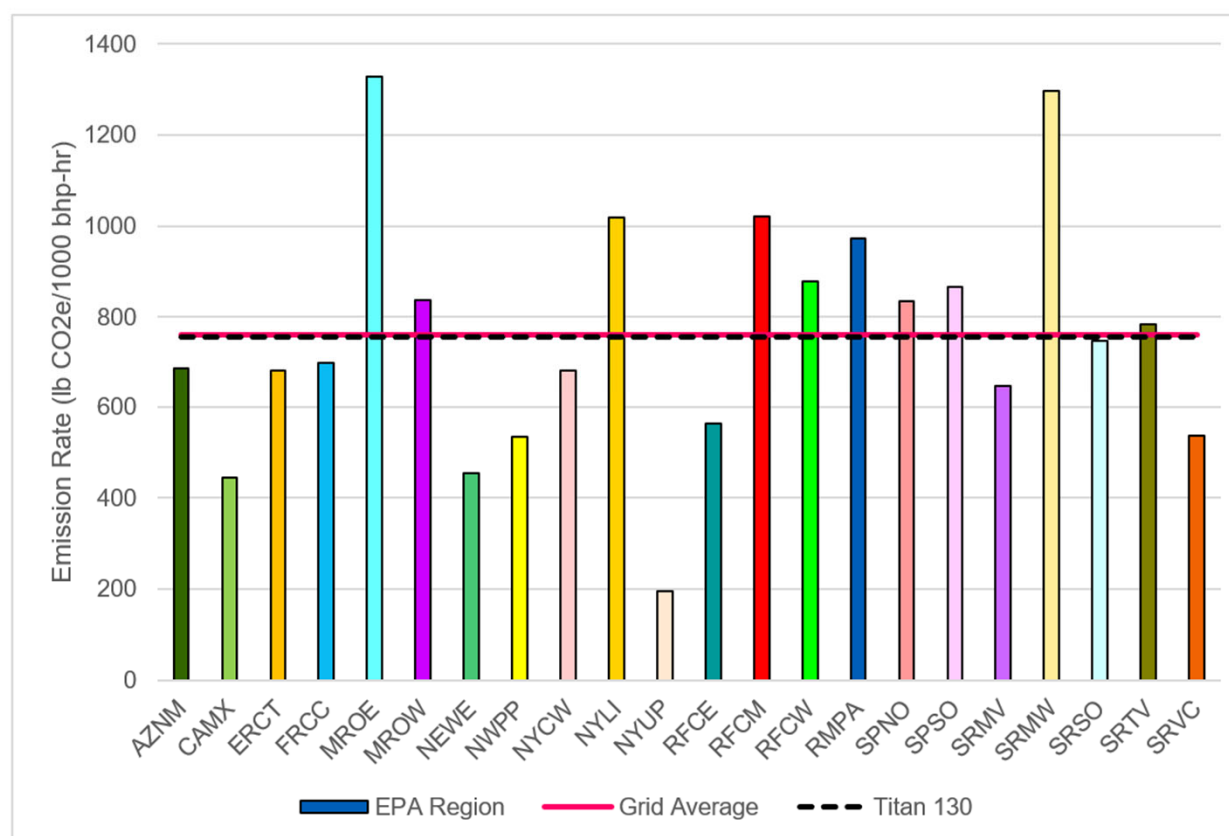


## Electric emissions (Scope 2) intensity



# Grid emissions

Figure 3: Scope 2 Emissions of EPA Subregions in 2021 vs. Scope 1 Emissions of Titan 130



## Summary – What is the best choice for modernization?

- > It depends...
- > Recip compression wins out in just about every category but has downsides
  - Higher Nox emissions
  - Higher maintenance expense \$ (can't "exchange" unit every 30,000hrs using capital \$)
  - Etc...
- > If we just focused on efficiency and GHG emissions, especially when factoring in efficiency off-load, recip compression is the right choice but there are many other variables.
- > My recommendation – Hybrid approach. Replace the small, older, less efficient blocks of recip compression with a centrifugal unit and update the larger / newer – more efficient recip at the facilities to get the best of both worlds. Baseline operation with the more efficient recip.

## Questions?

