REINHOLD ENVIRONMENTAL Ltd.

2019 NOx-Combustion-CCR Round Table Presentation

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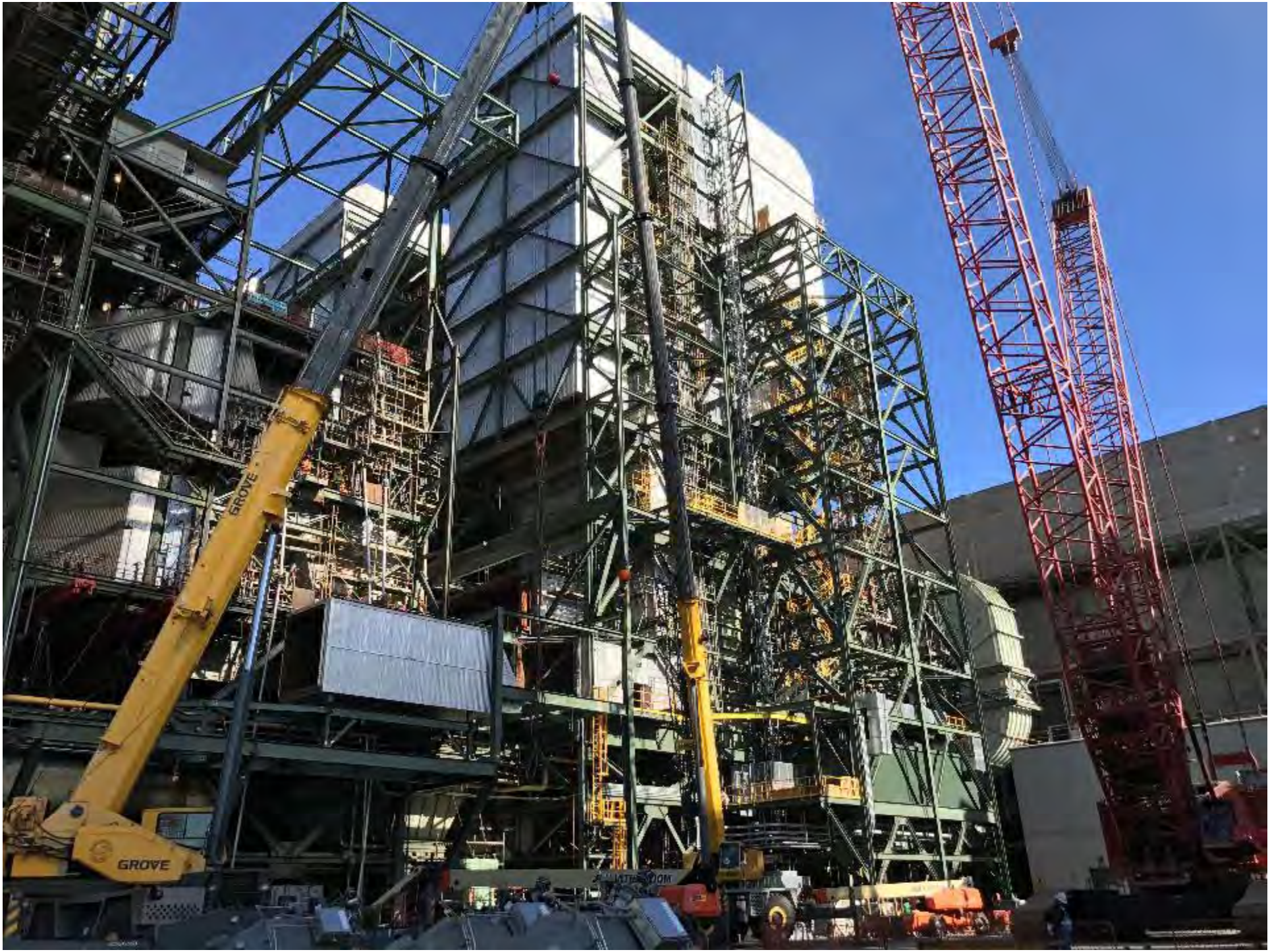
SCR Lessons learned by APS.

Bruce Salisbury

February 10th, 2019


GROVE
GROVE

Particulars

- Two, 800MW Supercritical units, burning a southwestern, Bituminous coal
- The timeline for Engineering was less than a year.
- The time line for the build was less than three years.
- The end result would have the Nox emissions dropping from 0.52 lbs/mmbtu to 0.08 lbs/mmbtu
  - Due to the inability to operate these machines at low temperatures, the 30 day rolling average needed to be at 0.065 lbs/mmbtu.
- The Build was taking place in a footprint too small for the machine. A typical condition for an SCR retrofit.
- We were starting from the position of being the largest NOx emitter in the U.S.
- No pressure….

Particulars, cont'd

- We will speak to three pieces of this process;
  - The things we did right.
  - The things we did wrong.
  - The things we did not do.

Build the right team !

- At the end of this build, the success of the project was due to the hard work, and good decisions of several hundred people. So make sure they are the right people.
- It only takes one bad neighbor to make a bad neighborhood.

Build the Right Team

- Teams involved with the build have to understand that everyone is here for exactly the same reasons;
  - Keep the employees safe.
  - Leave the customer with a machine that works as advertised.
  - Help the contractors finish the job, having made money.
- So they should have the same priorities.

Demonstrate the right priorities!

- The People driving results were expected to execute the following tasks, in this particular order .
  - Assure that people are working safely.
    - Working with a sense of urgency, but not getting in a hurry.
  - Assure that scope is not creeping.
  - Remove obstacles on a daily basis that prevent real work from happening.
  - Always be looking for opportunities to help contractors and subcontractors to save time and money.

Milestones

- The Milestones of this project were separated into the following, divisible pieces;
  - The Contract
  - Engineering
  - Mobilization
  - Below ground construction
  - Above Ground Construction
  - Startup.
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The Contract

- The contract was established as an EPC contract
- This was a senior management decision

Engineering

- There were two “show stoppers” along the way with this project. Technical issues with high price tags.
  - High Speed Operation of Booster fans, versus new Fans.
  - The Economizer, Waterside Bypass.
- Both of these issues would have stopped the project, effectively leaving the plant to close in mid-2016.
- Because of the specter of plant closure, Engineering proceeded on the front end under a limited notice to proceed. Not the optimum environment for design.

It was all about timing.

- Simultaneously, there were several end of coal lease issues the plant had to deal with.
  - Renewal of the lease, and the related coal contract.
  - Since this takes place on the Navajo Nation, the NEPA Process for lease renewal needed to take place.
- The original mining company for the Navajo Mine quit North American Operations.

Booster fans

- There will always be pressure drop introduced in the addition od new elements like an SCR. This pressure drop would ultimately require more fan to move gas through the system. There were three possible solutions:
  - New Fans.
  - Run the existing fans at higher speed.
  - Find opportunities to reduce pressure drop in the system.

Booster fans

- The existing fans were a two-speed, Westinghouse fan that the plant had never successfully run at high speed.
- New fans were not an option, adding enough to project cost to effectively kill the project at an add-on of 147,000,000$.
- The existing fans exhibited a critical frequency issue when run at high speed.

Booster fans

- Several months of study indicated that the vibration issue was due to an initial assembly that was too loose to run effectively at high speed.
- Fans were disassembled, and reassembled to the proper, high speed tolerances, and will now run at high speed, at an acceptably low vibration
- . Successful high speed operation was demonstrated on November 30th, 2014. Senior management had a must have date for successful high speed operation of December 2nd.

Other Pressure Drop Opportunities

- Early, 1980's ductwork was not optimized for pressure drop .
- The units had reverse gas baghouses with a high pressure drop fabric in it.
- The High pressure drop fabric was kept in place for its ability to provide mercury oxidation, for mercury control.

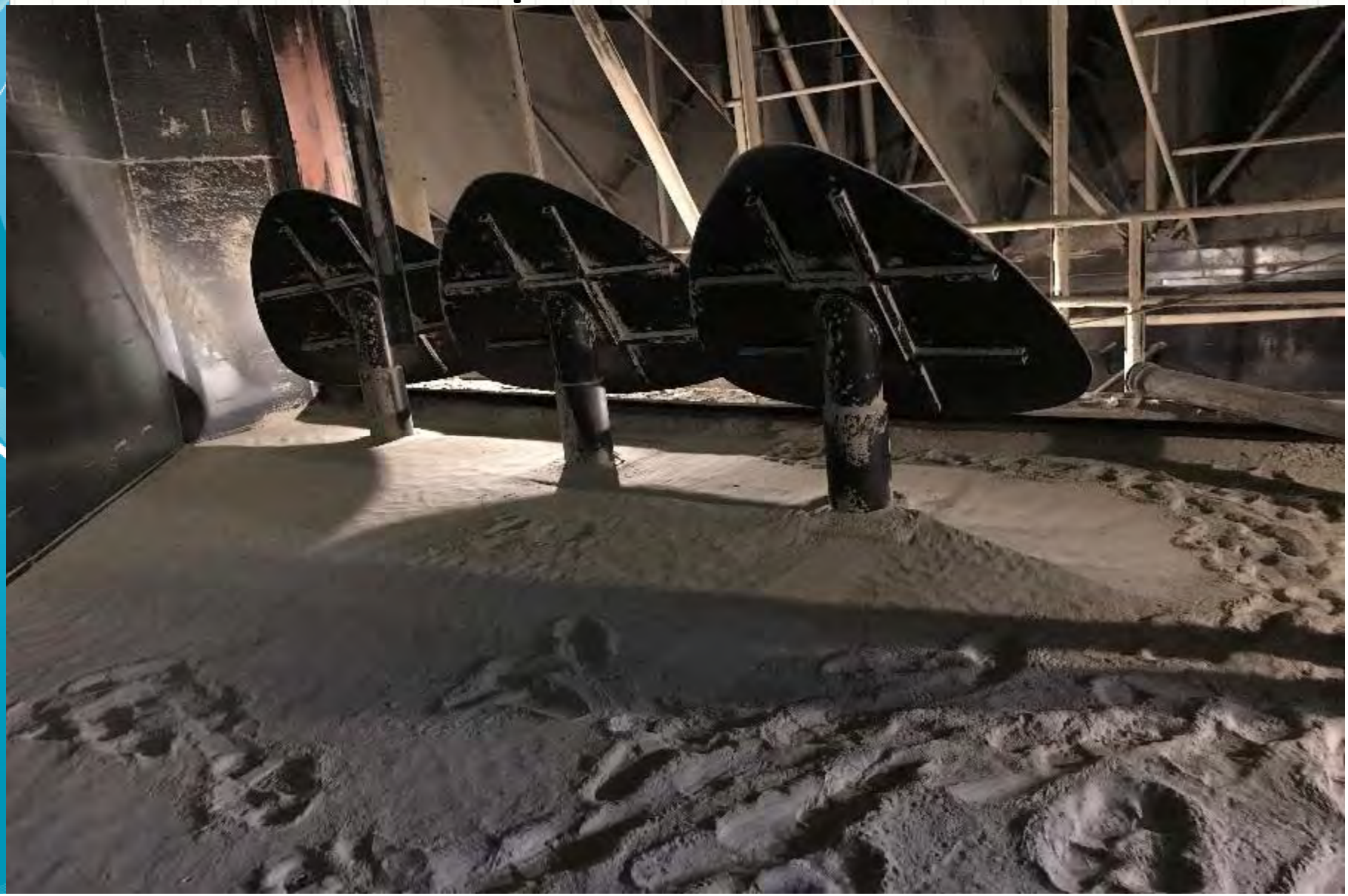
Pressure Drop Solutions

- With the commissioning of the SCR's, the SCR would provide the oxidation potential necessary to oxidize mercury for capture in the baghouse, so changes in filter media were possible.
- The facility started a change out to a PTFE membrane approximately 1-1/2 years ahead of commissioning.
- As new membrane sections were installed, pressure drop decreased, allowing the plant at present to run only half of the Booster fans at high speed.
- When the Membrane change out is complete, the facility will go back to all fans running at low speed.

Pressure Drop Solutions

- During the design process, internal ductwork was designed to have minimal drag.
- Existing inlet ductwork was redesigned to remove internal trussing for pressure drop relief.
- All of this was modeled mechanically. As an unintended consequence, it was discovered that roped flow conditions existed in the original inlet ductwork, explaining a long-term issue the plant had with erosion in the inlet ductwork.
- Delta wings were added in the existing ductwork outside of the scope of the build to rectify a long-term plant issue

Pressure Drop Solutions



Economizer Waterside Bypass

- An economizer Waterside Bypass is designed to allow increases in temperatures in flue gas, to allow the SCR to come on sooner in the start-up process. It does this by bypassing feedwater around the boiler, allowing more heat to escape the boiler, bringing higher temperatures to the SCR.
- The issues with the conventional Economizer Waterside Bypass were that they are expensive (46,000,000$/unit) and they would have added an extensive amount of time to the outage portion of the build.
- Since we were dealing with a supercritical boiler, we were incapable of steaming the economizer, once the unit was above critical pressure

Economizer Waterside Bypass/ The solution:

- The Economizer Waterside Bypass concept was rethought, as a “Waterside bypass lite”. This was a simpler design that could be installed in less time than the scheduled SCR cutover outage.
- Historically low flue gas temperatures (the problem) contributed to the solution.
- The Waterside Bypass Lite, was less than 1/10th of the unit cost of a conventional Waterside bypass, allowing the funding of the SCR build to proceed.

Supercritical Thermodynamics

- The key to the success of Waterside Bypass lite, were the facts that:
  - Economizers above supercritical pressure cannot steam.
  - At the temperatures and pressures seen, the low viscosity and high Nusselt and Prandtl numbers attenuate any issues with high temperatures.

Foundations and Caissons:

- Soils Engineers want the builders to excavate all of the subgrade for the entire site, mix it thoroughly, and compact it back into place before construction starts.
- That was a modest exaggeration, but extensive soil testing was performed on the build site providing the geotechnical engineers as much data as practical.
- Turns out it was not enough data.

Foundations, various and sundry:

- Recognize opportunities to save money.
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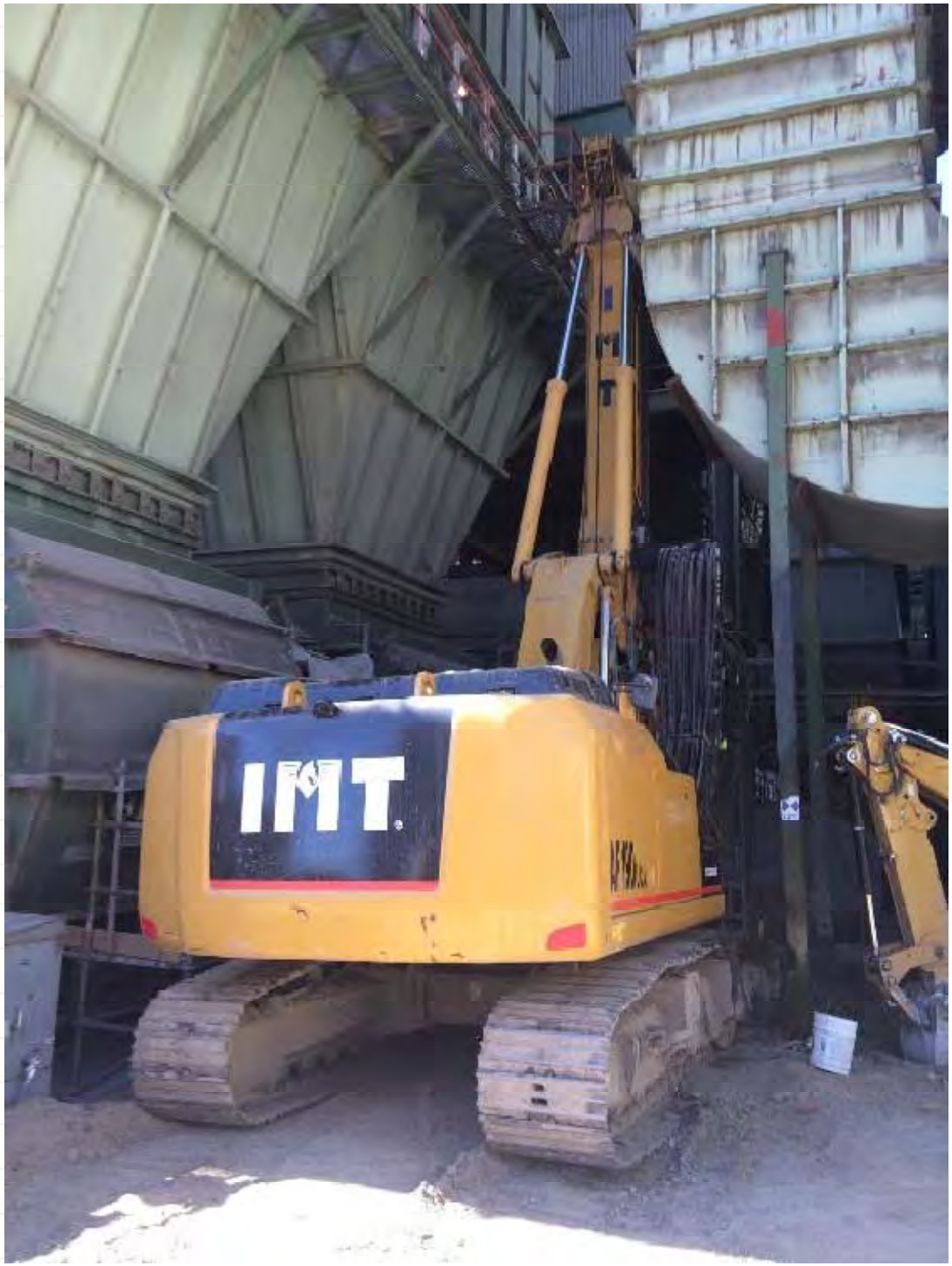
- When the conditions of the previous slide are not met, there is a propensity to over-engineer the foundations. This provides the project with an opportunity to save money on the project by;
  - Doing a test Caisson, to allow designing to a lower factor of safety.
  - Determine the exact conditions required for a foundation, allowing for a redesign, with a smaller foundation.
- A Test Caisson was cast and broken. It indicated that the finished caissons could be substantially shallower and smaller than originally thought. This led to a redesign of a smaller, less expensive foundation.
- This specific opportunity was recognized, and placed into the EPC contract prior to commencing work, to allow the customer to recover savings, if the foundations could be re-engineered.
- The reengineered foundation ended up saving the customer a large amount of cost on the build.

Like almost all SCR builds, sometimes you are working in a phone booth. Low clearance drilling rig drilling caissons between existing unit fans,



The Structural Steel build :

- The Presenter was not a fan of bolted, structural steel.
  - The contractor who supplied the structural steel did an unparalleled job of assuring that the dimensions on bolted connections were precise.
  - When the initial dimensional checks were performed at the 170-foot elevation, the largest dimensional variation was ¼" along one axis.
  - On the finished dimensional checks at the top of steel (255 feet) the largest final dimensional variation was ¼"
- The presenter is now a fan of bolted, structural steel fan.

Reducing outage schedule:

- Re-tasking of old air heaters as ducts
  - Since new air heaters were being built in a new location, the old air heaters were going to demolished.
  - Rather than remove them outright, the outside shell was reconfigured as ductwork, to shorten schedule in the cutover outage, and reduce cost.
- jhakjdshf

Reducing outage schedule:

- Bifurcating ductwork
  - Originally the units had two secondary air heaters, and a tube and shell air heater for the Primary air heater.
  - The original design had a bifurcated duct running through the primary air heater air heater area back to the secondary air heater ductwork for pressure drop reasons.
  - When it was discovered that this would only provide 0.2” w.g. pressure relief, the ductwork was abandoned, both for cost, and outage schedule.

Reducing outage schedule:

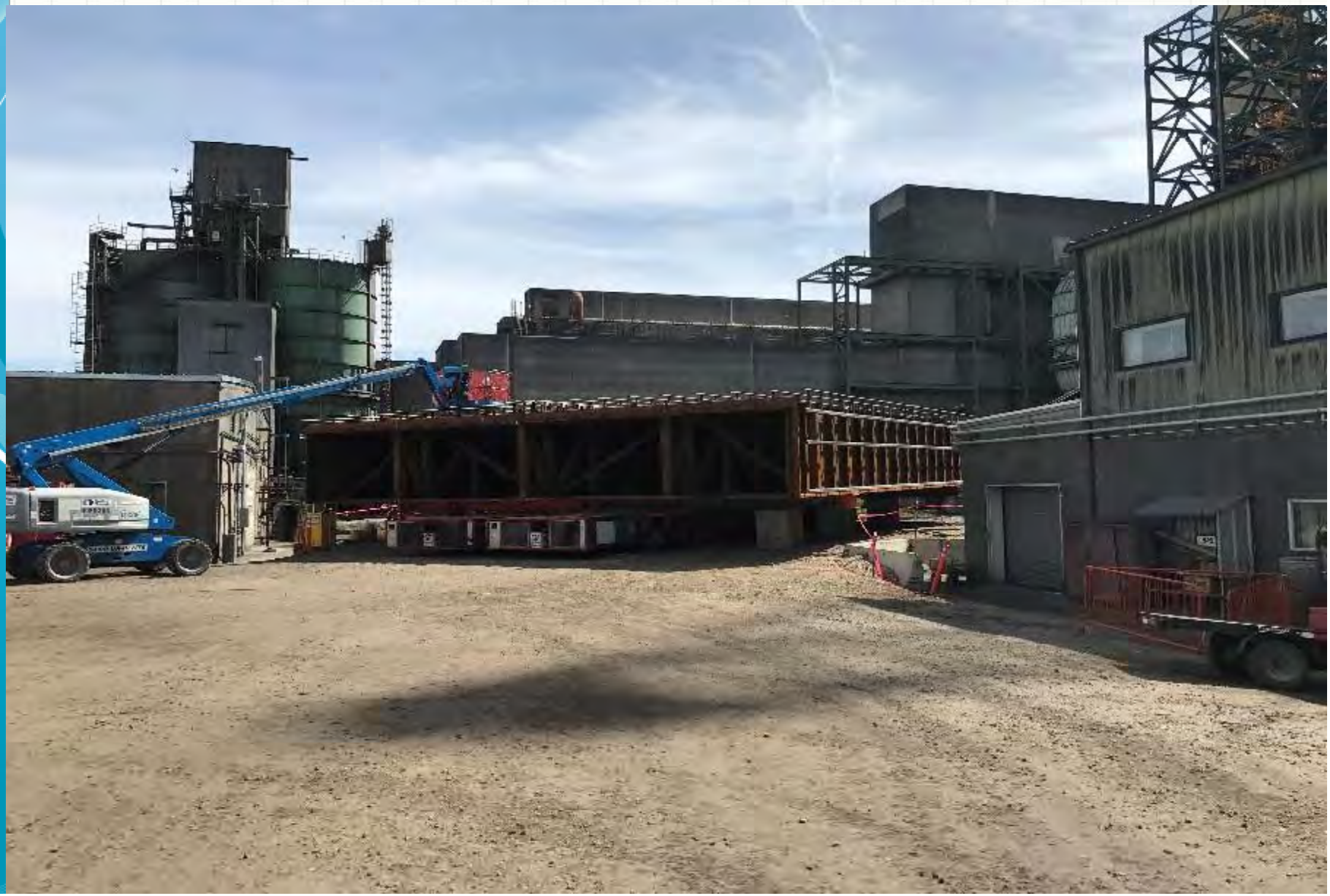
- 3-D modeling of the work site
  - While a huge model, it was detailed enough to show tack welds on structural bolts. Allowing a high degree of precision on manufacture of ductwork.

- During the cutover outage, the largest dimensional bust was less than ¼”

Optimizing Construction: Laying out the worksite

- Taking a page from the assembly line, ductwork pieces were laid out in the fabrication area, in the order that they were going to be installed.

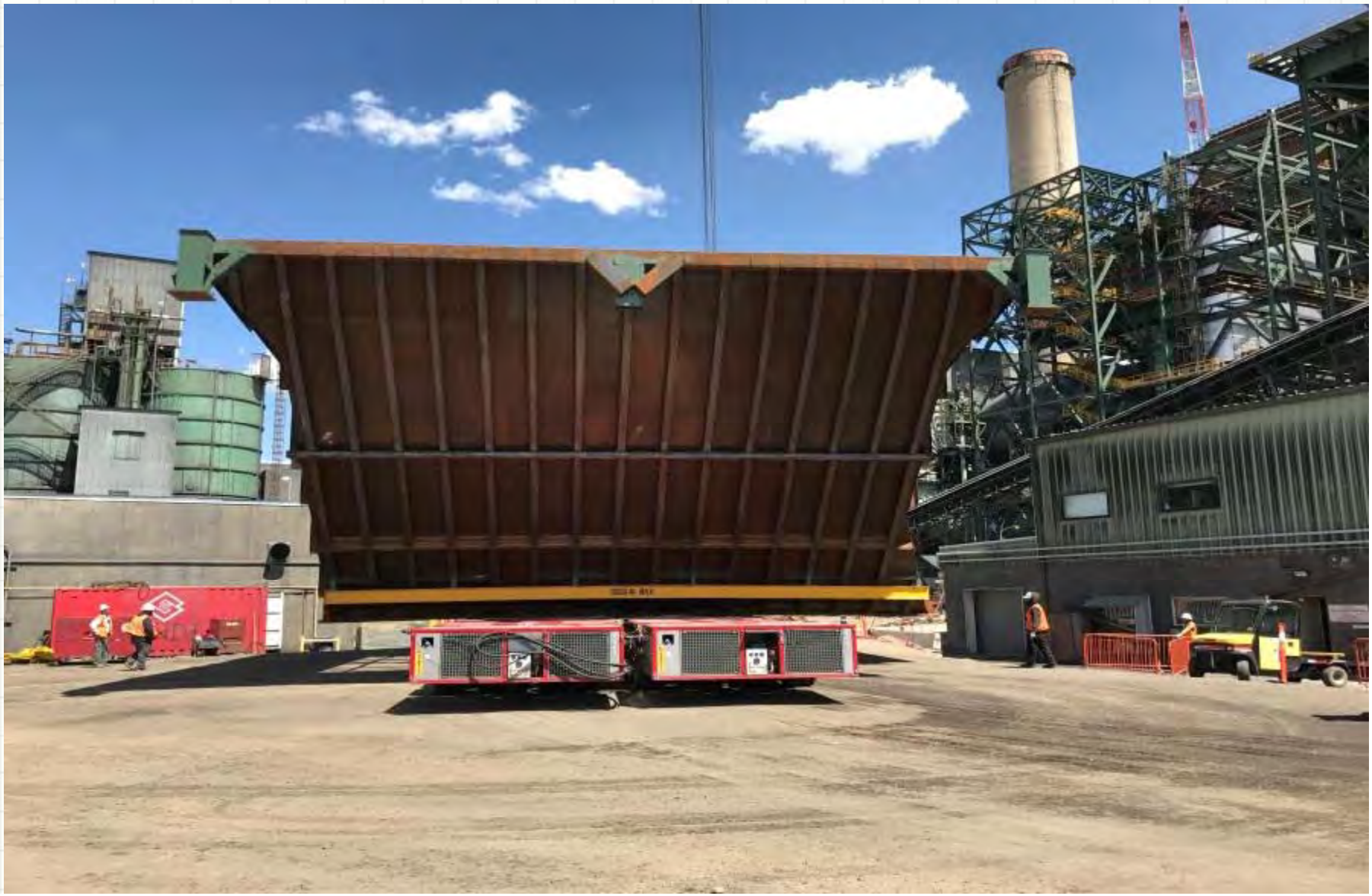
Optimizing Construction: the end of the assembly line



Optimizing Construction:

- Building as big as possible, on the ground
  - Productivity drops as you elevate works off the ground, and reduce their footprint of movement.
- This requires a lot of thought on crane size and placement.

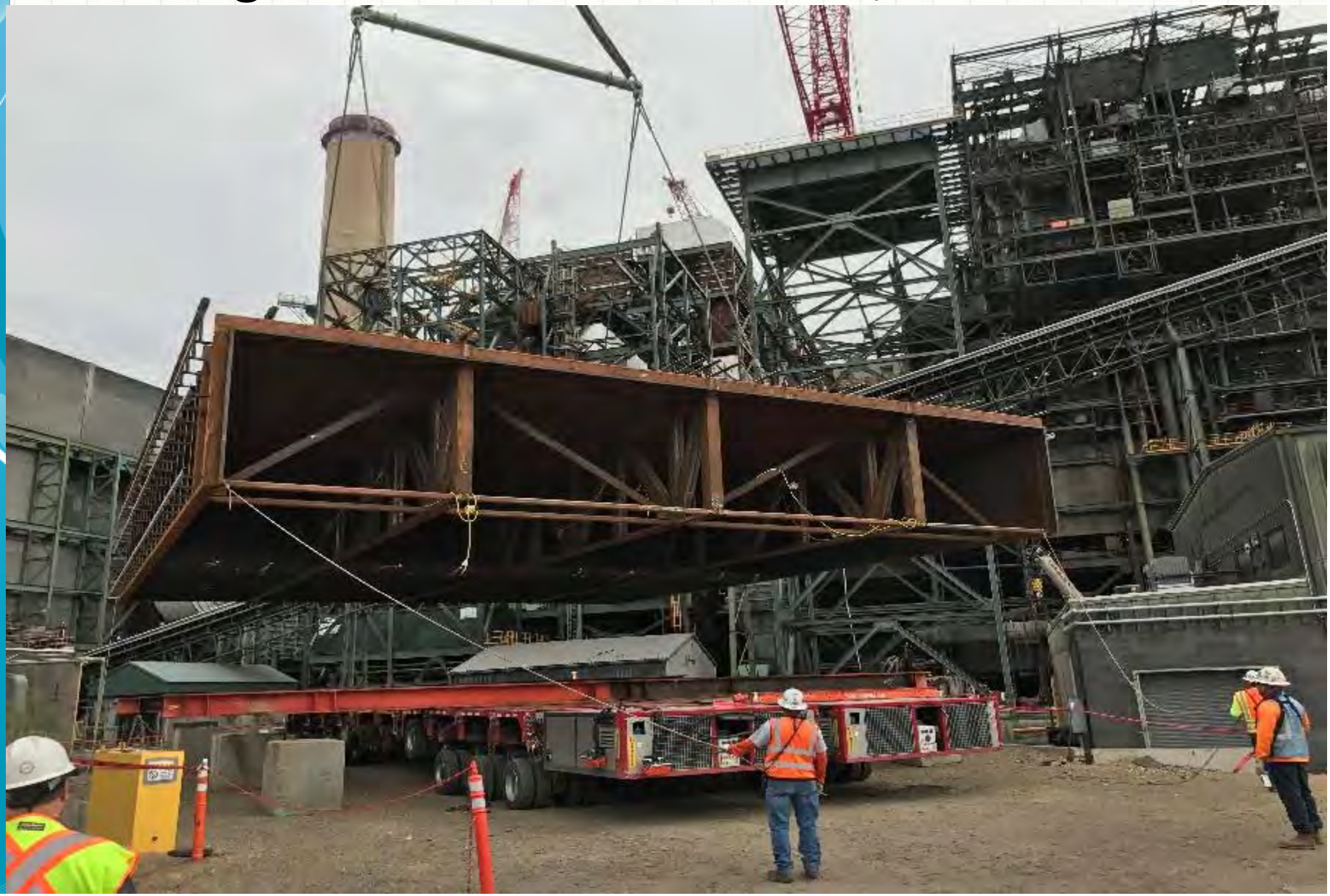
Build as big as possible on the ground.



If you build it, can you move it?

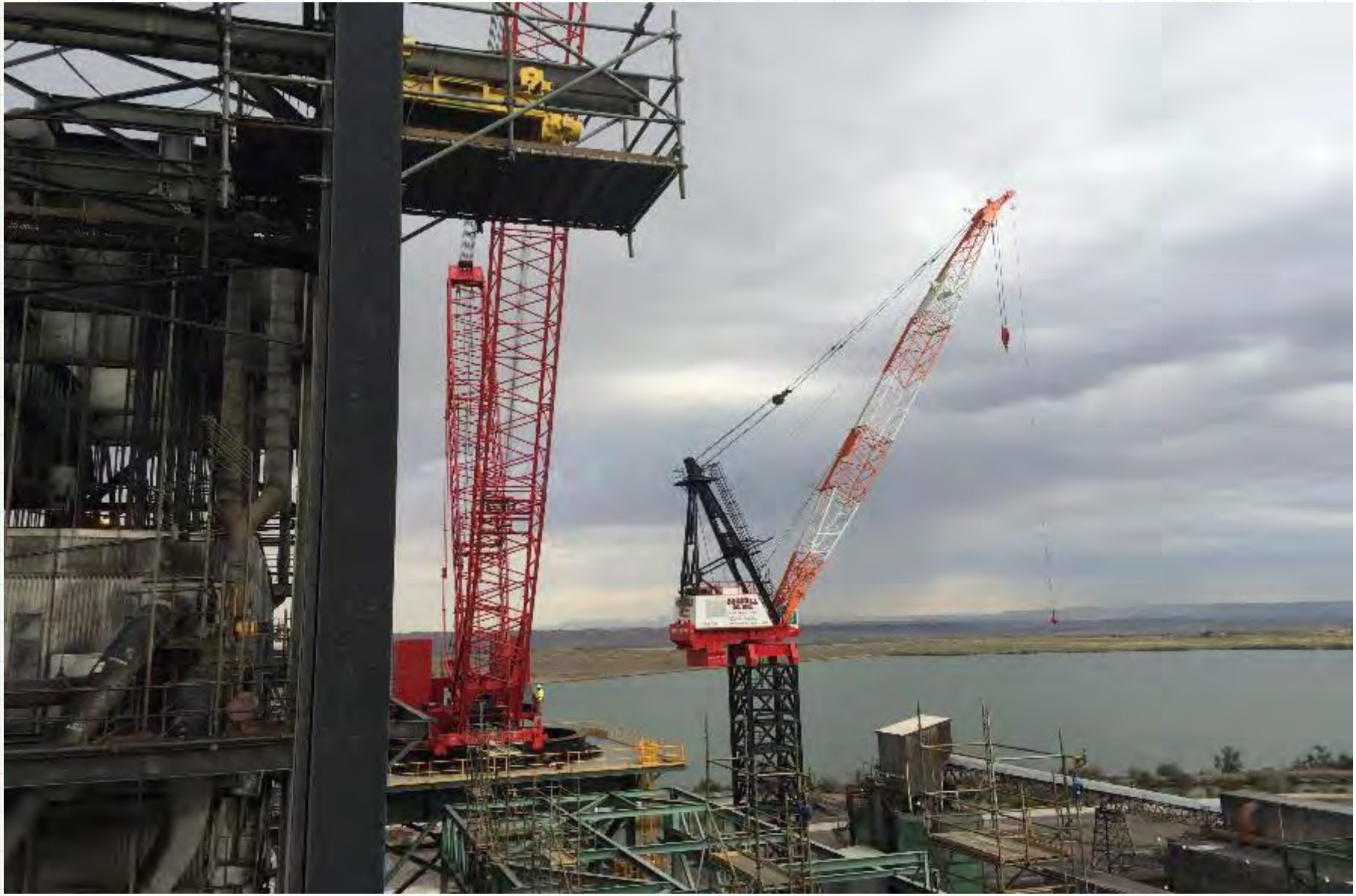
- Once the size of components was determined, the site was examined in detail to assure that all of the parts could be moved from the fabrication area to the pick point.
- A 12 KV and 69 KV line wrapping around the plant limited how much fabrication could happen “outside the fence”
- Large enough footprints were found adjacent to the units to allow the fabrication of large enough and heavy enough parts to maximize the efficiency of the cranes.

888 ringer on 170 foot tall tower, for Unit 4



Manitowok 18000 for the Unit 5 side of the build.

Elevation view of the Unit4 tower crane and the small tower crane between unit 4&5



So how many hours do you work??

- The Maximum amount of productivity you can expect out of a person is 55 hours per week.
  - Working more than 60 hours a week actually results in a drop of productivity below 55 hours.
  - Extreme schedules of 80 to 90 hours per week usually result in productivities at or below 40 hours a week.
- The Prime contractor settled in on a 60 hour work week This allowed 5 hours a week for meetings, and 55 hours a week for working.
- This maximized the contractors productivity, allowing them to increase the profitability of the build for them.

Capitalize on opportunities to save the contractor time and money:

- There was a prescriptive requirement to pour concrete within 12 hours of drilling caissons.
  - This required the contractor to work very long days during this activity with large amounts of overtime.
  - The Engineers merely wanted the concrete poured as soon as practical to reduce the risk involved with open holes, and issues with material sloughing back into the excavation.
  - Resolution of this technical issue resulted in the contractor going back to normal work hours, saving the contractor hours, without impacting the quality of the finished product.
  - This was one, of multiple opportunities that presented itself during the build to save schedule, and money.

Prevent scope creep:

- Scope was rigidly held into place during the entire build.
  - All scope changes had to go through an approval structure to get on the table.
  - Due to the nature of the contract the owners had the ability to send scope changes to the primary contractor.
- There were a total of 107 scope changes for the entirety of the build, with a net total cost of less than 2,000,000$
- 90% of what made this possible was a complete scope at the end of the initial engineering.

Safety; The elephant in the room

- There were safety issues in the front end of this project.
- No project will be successful, if the project is not completed safely.
- Additional safety personnel were brought in with the understanding that they were observers, not “The Safety Police”
- Observations led to the following:
  - Good contractors work with a sense of urgency. When urgent slips over into “being in a hurry”, people get hurt.
  - Several tasks, such as rebar placement, required a minimum number of personnel to execute safely. When the number dipped below that threshold, people got hurt.
- The project completed with an AIIR of 0.62

Contingency versus Risk

- The utility side of the contract was done without contingency. It was however, done with a risk register.
- The original risk register was populated, and the project started, at a risk of 3-1/2% of the project value.
- Specific groups spent the entire project mitigating risks.
- As Risks were mitigated, the money in the risk register was swept back to the corporation for use in other capital work.
- The project only ended up using an amount of money equal to 1% of the project cost by projects end.

So what would we do differently?

- Make the contingency side of the Prime Contractor a risk register, and require the Prime Contractor to get permission to spend “contingency”.
- Put more time and thought into how you keep subcontractors from holding the schedule hostage.

Cutting to the chase…..

The Project finished two weeks ahead of schedule.

- The Project finished under budget.
- The machine has performed as advertised
- We started life as as the Highest Nox emitter in the US, and the third highest emitter in North America.
- We finished, on paper at 304th place with a 400 MW station in Oklahoma.

Unintended consequences, sometimes it's good stuff

- During the same cutover outage, we were removing the bypass ducts on the scrubber, with SO2 removal rates going to 95% removal.
- Removal of the bypass left the outlet ductwork and stack in a saturated condition, allowing them to work as additional particulate control devices.
- While not efficient, 60 to 70% removal is very noticeable when the first 99.9% has already been done.

bruce.salisbury@aps.com

QUESTIONS?