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LCLS-II helium cryoplant and cryo distribution system installation

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Abstract. The helium cryoplant and cryo distribution system (CDS) are key elements of the new superconducting Linac Coherent Light Source (LCLS-II) and will provide superfluid helium to the accelerator. The cryoplant consists of two helium refrigerators with an equivalent 4.5 K refrigeration capacity of 18 kW each. The 37 cryomodules of the LINAC will be operated at a temperature of 2.0 K to accelerate a 4 GeV electron beam that will generate extremely bright X-ray laser light. Two five-stage cold compressor cold boxes will be utilized to provide superfluid helium II for the superconducting cavity structures with a total cooling capacity of 8 kW at 2.0 K. This paper describes the installation of the LCLS-II cryoplant and CDS. The LCLS-II cryoplant was designed and contributed by Jefferson Lab. To expedite the project completion the reuse of proven design and technology from the Jefferson Lab CHL-2 cryoplant was the preferred strategy. The CDS consists of ~260 m thermally shielded and vacuum super insulated transfer lines, two distribution boxes and eight feed and end caps, and was designed and contributed by Fermilab. SLAC installed the cryoplant components into a newly erected building and the CDS components into the existing accelerator tunnel and klystron gallery with strong engineering support from both partner labs.

1. Introduction
The Linac Coherent Light Source (LCLS-II) is a X-ray free-electron laser (FEL) based on a 4 GeV superconducting RF linear accelerator. The LCLS-II is designed to produce hundreds of watts of X-ray from 200 eV up to 5 keV [1].

The cryogenic system is one of the key components of this project. Figure 1 shows a simplified schematic of the cryogenic system. It consists of the cryoplant complex in orange color and the cryo distribution system (CDS) and cryomodules (CM) depicted in blue.

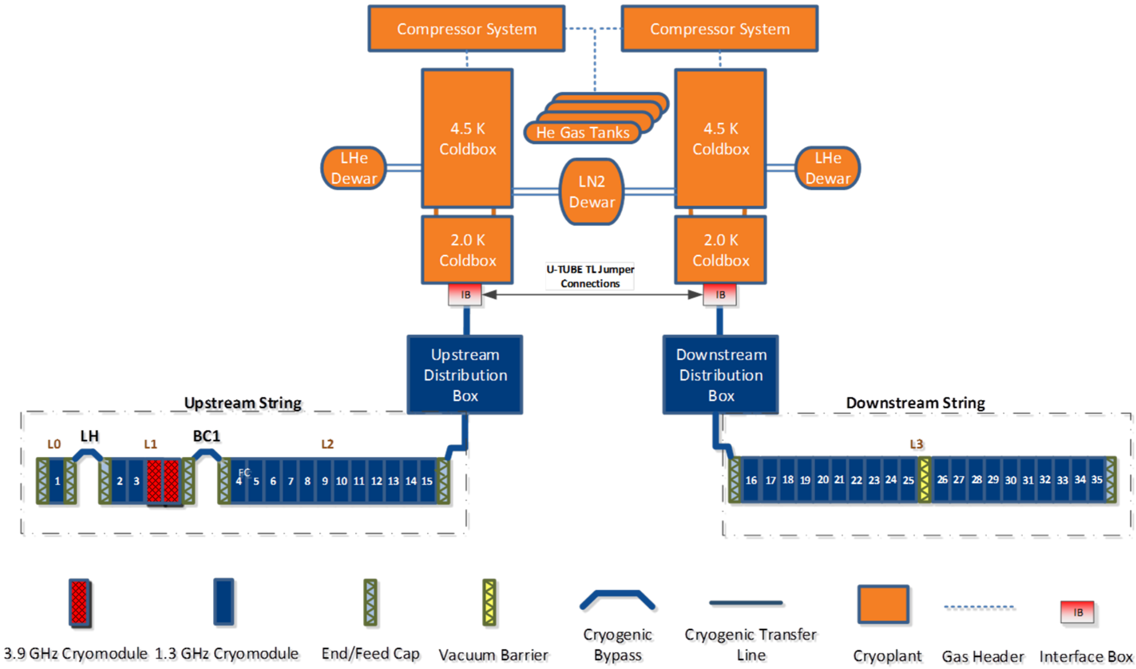

Figure 1. LCLS-II cryogenic system overview.

The cryoplant system was designed and engineered by Jefferson Lab following the example of the central helium liquefier (CHL-2). Fermi National Lab (FNAL) was responsible for the specification and procurement of the cryo distribution system.
Each system contains equipment and sub-components that were fabricated by different subcontracted industrial vendors and delivered directly to the SLAC National Accelerator Laboratory construction site.

SLAC managed the installation and integration of the provided equipment. The collaborating laboratories provided technical support for this effort.

2. Cryoplant

2.1. Layout

A new cryoplant building (75 m x 25 m x10 m) was erected on the green field at sector 4 of the existing LINAC building (Fig. 2). It comprises the two identical cryoplants on each side of the building (Fig. 3).

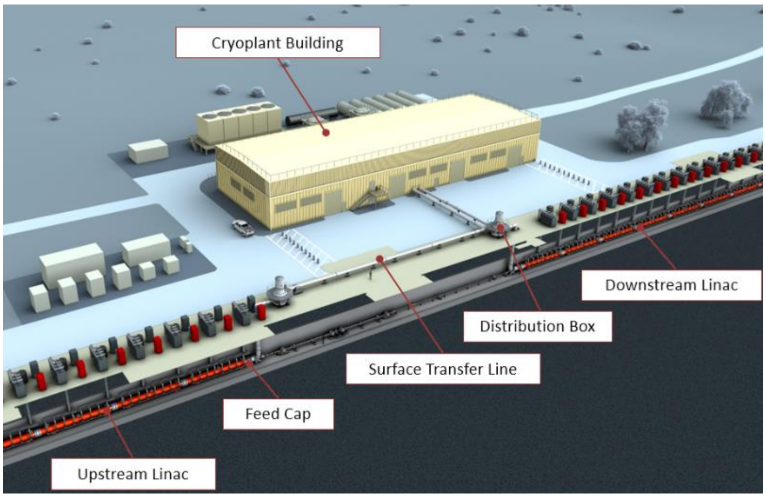

Figure 2. LCLS-II Cryogenic building at sector 4 of the LINAC building.

The warm helium compressor station (WHC) with six Howden WLVi 321/193 compressors and the motor control center are located at the east and west rooms of the building. In addition, the compressor room 1 on the west side accommodates all auxiliary systems like the recovery compressor system, the guard vacuum system, the gas analyser cabinet and the oil processor.

The oil removal system consists of one coalescer for each compressor followed by a final oil removal system including three coalescers, one charcoal adsorber and a final filter. These components are located outside of the building on the north slab together with the helium purifier, the ambient heat exchangers and upper cold boxes. The vertical upper cold box cools the helium from 300 K down to 80 K with a LN2 precooling system while the horizontal lower cold box cools further down to 4.5 K utilizing four Air Liquide turbines. The entire 4.5 K cold box system was fabricated and assembled by ALATUS / PHPK.

The lower cold boxes, the adjacent two 10,000 l liquid helium dewars (Wessington Cryogenics), the 2 K cold boxes (1x PHPK, 1x Linde) and the interface box (Demaco) are located in the central cold box room. Two LN2 storage dewars (AES) with a capacity 75 m^2 each and six helium storage tanks (Modern Custom Fabrication) with a volume of 114 m^3 each are placed at the tank farm.

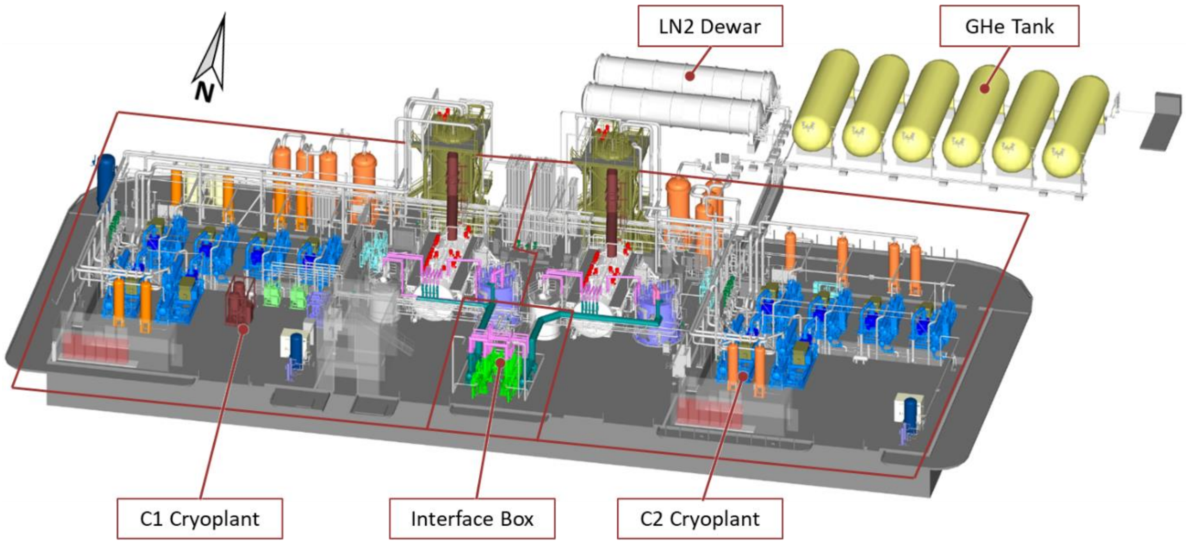

Figure 3. LCLS-II cryoplant layout.

Table 1. Main parameters of the cryoplant.

Component	Parameter
2x 4.5 K cold box	18 kW @ 4.5 K (equiv.)
2x 2 K cold box	4 kW @ 2 K
2x compressor station	
3x LP-compressor	600 kW, 243 g/s, 1 to 6 bara
1x MP-compressor	750 kW, 580 g/s, 2.5 to 6 bara
1x HP-compressor	1870 kW, 1310 g/s, 6 to 19 bara
1x swing compressor	1870 kW, variable

2.2. Installation

The installation process was strongly interconnected and dependent on the fabrication lead time of the individual components. Some components arrived several months before the building was completed while others were procured and scheduled later or were delayed in production. The warm helium compressors arrived early therefore SLAC had to identify sufficient storage area to temporarily stage the units before installation could start.

An indefinite delivery/indefinite quantity (IDIQ) contract with a local rigging company (Peninsula Crane & Rigging) allowed to handle and set the heavy equipment in position on site. SLAC worked in close collaboration with the subcontractor and the partner labs for the planning and execution of the installation work on site. The development of detailed installation procedures was important in order to ensure that the high technical and safety requirements are met. The seismic anchoring of the equipment presented a particular challenge since SLAC is located in a seismic area close to the San Andreas Fault.

A documentation package consisting of a technical specification, a comprehensive drawing package and detailed installation guide was developed by JLAB and SLAC. An architectural and engineering company (SmithGroup) was contracted to create and compile a technical specification in the MasterFormat® developed by the Construction Specification Institute (CSI). This specification format organizes the content of the specification in predefined and standardized divisions, order and numbering system and is common in the US construction industry. JLAB prepared a 3D CAD model and derived a comprehensive and detailed installation drawing package from this model.

The interconnection and integration of the individual components of the plant was performed by a general contractor (GC). An early vendor evaluation and qualification was conducted by SLAC. Subject matter experts visited several potential vendors in order to evaluate the qualification and technical standards. The focus of these audits was on the detail design capabilities, prefabrication, handling and installation of pipe spools for high purity helium service.

Kinetics Systems, Inc. was awarded as a general contractor to execute the cryoplant installation in a design-bid-build fixed price subcontract. Multiple subcontractors were engaged to perform various trades within the installation project (Fig. 4).

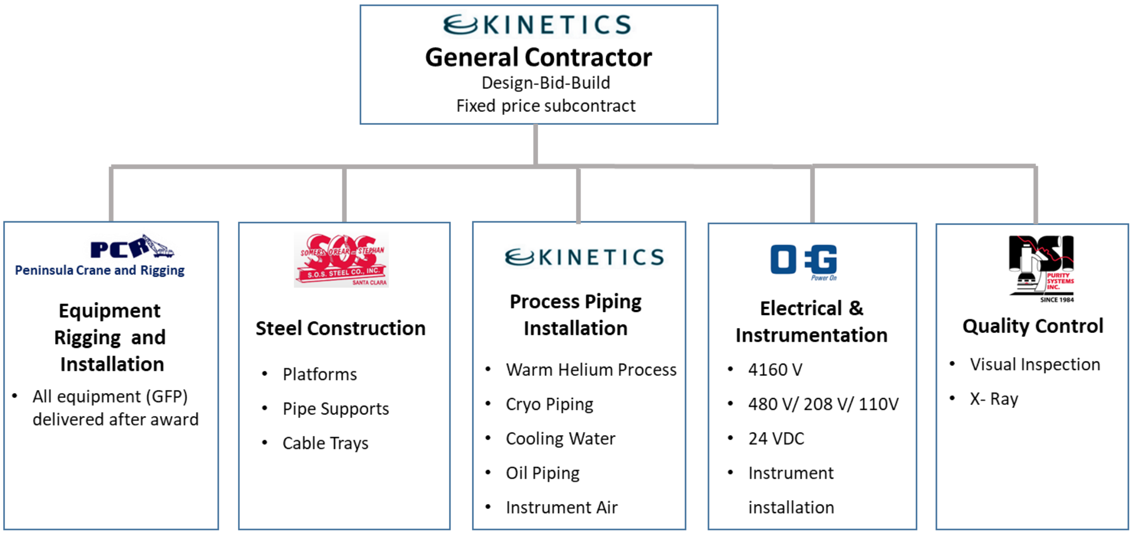

Figure 4. General contractor and subcontractors by trades.

Long lead items such as valves, check valves, pressure transducers, flow meters and filters were procured by SLAC ahead of time to meet the project schedule. All preinstalled equipment and long lead items were provided and formally transferred to the GC as government furnished property.

The installation project was subdivided into performance periods A, B, C, and D in order to allow the early commissioning of the C1-WHC system and later the 4.5 K cold box in parallel to the ongoing installation.

Performance period A was the prerequisite for the C1-WHC commissioning. In the course of the project the performance period A was even further subdivided into priority phases 1 to 3 to perform a pre-commissioning of subsystems. One example is the dry out of the charcoal adsorber as priority 1 which also required the tank farm with LN2 and GHe supply to be completed. The recovery compressors and helium purifier became priority 2 as a prerequisite for the entire WHC commissioning (priority 3). Figure 5 shows a colour coded representation of the defined performance periods and priorities by location.

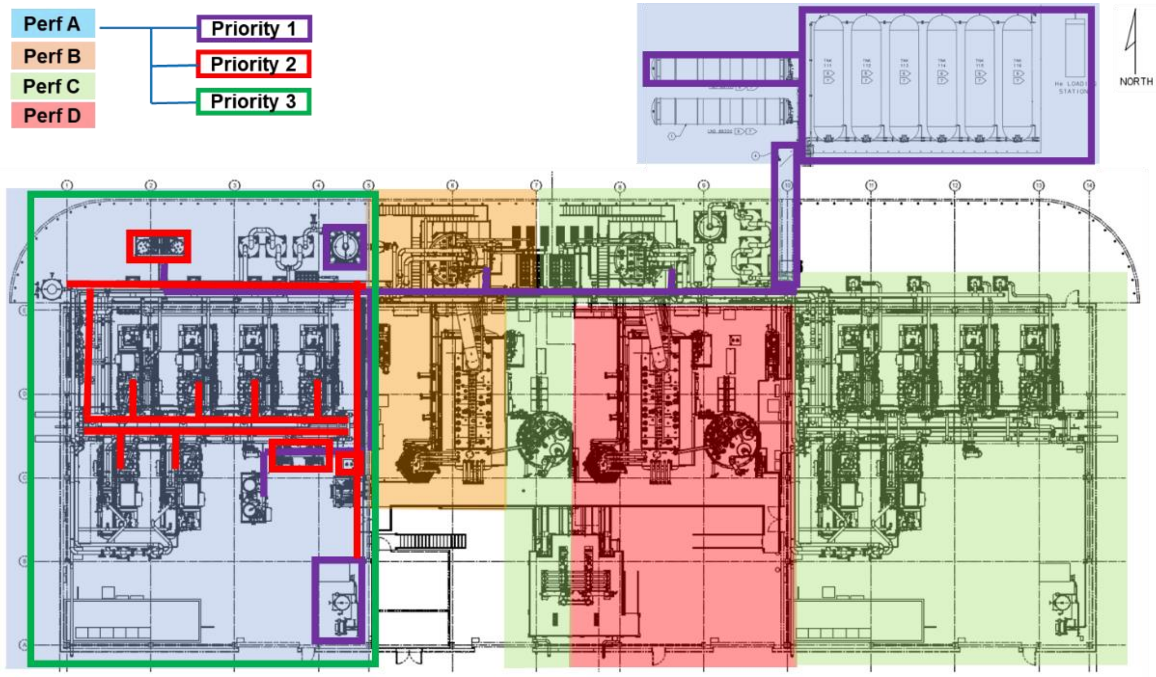

Figure 5. Performance periods by site location.

A timeline of the installation with the technical completion of the performance periods (PP) is shown in Fig. 6. The smaller technical scope of PP D compared to PP C which included the entire C2-WHC system eventually led to a completion date of PP D ahead of PP C.

The formal transfer of the PP A areas back to SLAC allowed the pre-commissioning and commissioning activities for the start-up of the WHC system. The pre-commissioning and commissioning of the warm helium compressor system is described in detail in [3].

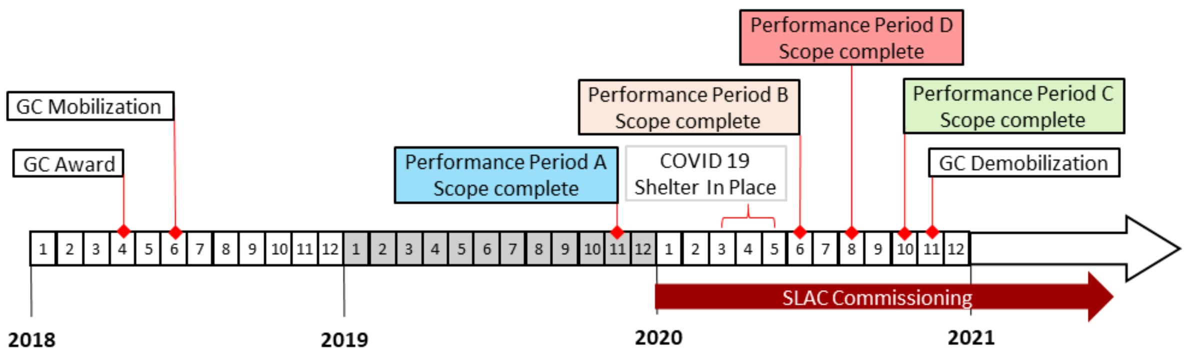

Figure 6. Installation timeline with performance period technical completion.

On March 17, 2020, the construction work had to stop due to the COVID-19 shelter in place order. The work on site restarted with limited forces on May 15, 2020, under strict COVID-19 safety protocols and ramped up the workforce slowly within several weeks.

Nevertheless, the installation scope was finished, and the GC demobilized in November 2020. The finalization of the turnover documentation package and resolution of punch list items was completed with a small crew remaining on site. The cryoplant installation is shown in pictures in Figure 7.

Figure 7. Upper left: Compressor room 1,
Upper right: Tank farm with LN2 and GHe storage tanks,
Lower left: North slab installations with oil removal system, upper C1 and C2-CBX
Lower right: Cold box room with lower C2-CBX, C2-10,000 l- LHD, C1-2 K CBX, C1-lower CBX

3. Cryo distribution system

3.1. Layout

Vacuum super insulated and thermal shielded cryogenic multi transfer lines connect the cryoplant and the LINAC (Fig. 2). The above ground sections of the cryo distribution system (CDS) are defined as the surface transfer lines. These lines connect the interface box inside the cryoplant building with the distribution box (DB) in the klystron gallery. Downstream of the DB the vertical transfer lines supply the helium 10 m down to the feed caps that are located inside of the LINAC tunnel. The feed caps (Demaco) and end caps (Cryotherm) are considered as the interfaces to the cryomodule sections. At the laser heater (LH) and bunch compressor (BC1) sections where the electron beam is not accelerated by superconducting cavities a cryogenic bypass is used to supply cryogens to the next cryomodule section of the string (Fig 1.).

The transfer lines in a cross-sectional view (Fig. 8) consists of six individual process lines surrounded by a copper thermal shield and a vacuum shell. The individual lines as well as the copper thermal shield are wrapped in multi-layer super insulation to minimize the radiation heat in leak. All cryogenic multi transfer lines were designed and fabricated by Demaco.

Each distribution box for the LINAC upstream and downstream string comprise the 2 K heat exchanger and the process safety relief valves for the cryomodule strings and the transfer line system. The DBs were designed and fabricated by Linde Cryogenics based on the FNAL specification.

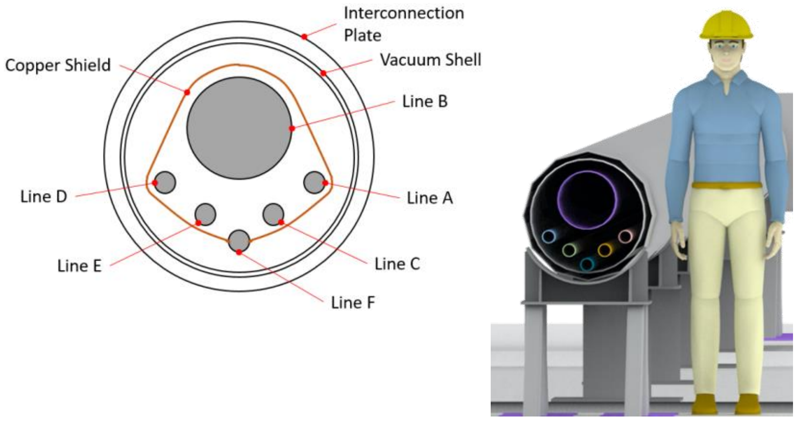

Figure 8. Transfer line cross-section.

Table 2. CDS process line operating parameters [2].

	Line A	Line B	Line C	Line D	Line E	Line F
Purpose	CM cooling Supply	CM subatm. gas return	Low temp. intercept supply	Low temp. intercept return	High temp. shield supply	High temp. shield return
Nom. temp [K]	4.5 to 2.5	2.0 to 3.5	5	8	35	55
Nom. pressure [bara]	3.2	0.031 to 0.027	3.2	2.8	3.7	2.7
Nom. pipe size [DN]	50	250	50	50	50	50
Nom. mass flow [g/s]	100	100	30	30	80	80
Max. mass flow [g/s]	215	215	37	37	146	146
Press. drop budget [bar]	1	0.004	1		1.5	
Heat load budget [W]	290		280		4350	

3.2. Installation

The cryo distribution system had to be installed before all other components for the LCLS-II in the LINAC tunnel due to the space and access restrictions. The feed and end caps were delivered already in 2017 and leak tested at SLAC prior to the installation. A local rigging subcontractor (Bragg) performed the transport and anchoring of the CDS components inside the tunnel. Kinetics Systems Inc. was contracted for the interconnection of the prefabricated cryogenic pipe spools because of their long term experiences in high purity process piping.

The tunnel sections of the transfer lines were staged on mobile pipe stands to provide easy access for the welding process. The assembled tunnel bypass lines were then lifted in their entire length with manual lifting jacks into the pre-mounted hangers on the ceiling (Fig. 9). The final connection to the feed and endcap had to be performed in elevated position from a scaffolding.

The distribution boxes were delivered in horizontal position on a low deck trailer. A critical lift and tilt in vertical position utilizing two mobile cranes was required before the DBs could be installed through an opening in the klystron gallery roof (Fig. 9).

The surface transfer line sections were placed and anchored by the rigging company before the interconnection welding was performed by an installation crew of the manufacturer DEMACO.

Figure 9. Installation of the tunnel transfer lines and distribution box installation in the klystron gallery through a roof opening.

4. Conclusion and lessons learned

A complicated cryo system with very high demands on leak tightness and cleanliness was designed, fabricated and installed in a cooperation between the Department of Energy, national laboratories and many industry partners and subcontractors. The work planning, coordination of all trades, and supervised execution even under permanent changing circumstances were the key for a safe and successful installation in order to meet the schedule, cost and quality requirements.

Some major lessons learned can be summarized:

- Evaluate the capabilities and the existing engineering and fabrication processes of potential general contractors early in the project.
- Create a scope matrix for clear definition of responsibilities.
- Design an open plant layout to allow changes in the installation sequence.
- Prefabricate as much as possible, limit the number of vendors, procurements and interfaces.
- Provide a very mature 3D model and P&IDs to the GC to start the detail design process.

5. References

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