FINAL REPORT

C-5 Fuel Cell Facility

167th Airlift Wing

Martinsburg, WV

Kyle Goodyear

Construction Management

April 7, 2010

Dr. Magent

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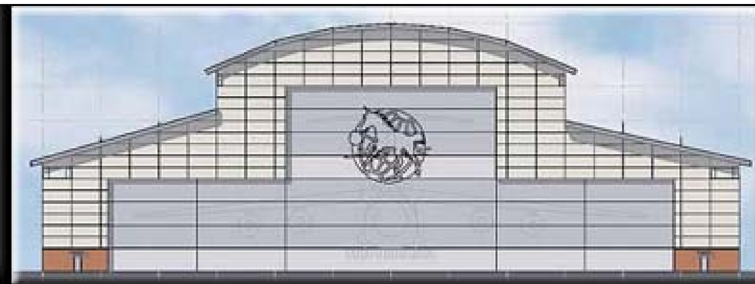
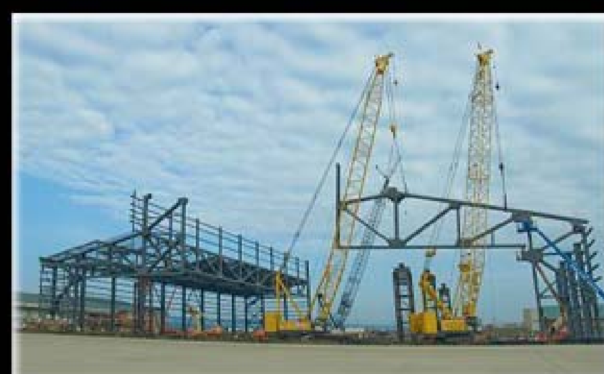


Project Team:
- Owner: 167th Airlift Wing, WV ANG
- General Contractor: Kinsley Construction, Inc.
- Architect: LSC Design
- Civil Engineer: Greenway Engineering
- Structural, MEP Engineer: TranSystems

Project Information:
- Location: Martinsburg, WV
- Function: Hangar and Maintenance Building for C-5 Aircraft
- Building Size: 78,825 SF
- Project Cost: $27 million
- Construction Dates: Oct. 2008 - May 2010
- Delivery Method: Design-Build

Structural System:
- Drilled caisson foundations around perimeter of building
- Braced frame lateral force resisting system
- Structural steel framing with combination of wide flange and hollow structrual steel columns and beams
- K-series and Longspan joists supporting roof
- Steel trusses spanning nearly 220 feet



Architecture:
- Split-face CMU covers first 10' of exterior wall space above finished floor level, with accent course
- Insulated metal panels cover all other exterior wall area
- Insulated translucent sandwich panels allow natural light into building
- MEGADOOR assembly on Southeast face- 14,600 SF
- Standing seam metal

Mechanical System:
- Vented infrared radiant heaters in hangar
- (2) 15,000 CFM make-up air units
- Inline centrifugal exhaust fans
- (2) 300 GPM boilers
- 4,000 CFM air handling unit
- VAV boxes
- (3) 1400 CFM energy recovery units

Electrical/Lighting System:
- Service transformer to convert 12.47kV utility distribution to 480Y/277V utilization
- 200A load break junction boxes distribute power to building
- Connections for 400Hz generators
- 277V fluorescent fixtures in support areas
- 277V metal halides in hangar area
- 277V HPS wall mounted on exterior
- 120V LED roof mounted as obstruction lights
- 277V LED emergency lighting inside

KYLE GOODYEAR CONSTRUCTION MANAGEMENT

http://www.engr.psu.edu/ae/thesis/portfolios/2010/keg5031/index.html

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ACKNOWLEDGEMENTS

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Dallas DiFiore	Project Executive
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Zak Wolpert	Estimator

WV Air National Guard, 167th Airlift Wing

LTC Bill Burkhart	Contracting Officer
Capt. Jeff Musser	Project Engineer

Industry Members

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Anthony Anello, Solyndra, Inc.	Rick Barry, Lorne G. Seifert, Inc.
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Penn State AE Faculty

Professor Kevin Parfitt

Professor Robert Holland

Dr. Chris Magent

EXECUTIVE SUMMARY

This document is a comprehensive collection of the technical analyses which have been performed on the C-5 Fuel Cell Facility project in Martinsburg, WV as part of the Penn State AE Senior Thesis assignment. Its contents include background information to the project such as: client information, local conditions, an explanation of the project delivery method that was used, project costs, and the project schedule among other items. Also included are the four topics of analysis which have been researched and developed over the past semester, as well as two topics of breadth study outside of the construction management option. Each of these analyses is directed at studying productivity on a construction project with respect to alternative methods and design options.

The first analysis that is discussed is the installation of a solar collection system to the roof of the C-5 Fuel Cell Facility. Specifically, the system produced by Solyndra, Inc. has been analyzed in order to determine the electrical output that could be expected from such an addition and then compared to the expected total power usage of the building. The second analysis involves changing all CMU walls on the project to precast concrete or prefabricated walls. The exterior façade is examined primarily on the basis of a quality finished product and the interior load-bearing walls are analyzed based on structural design. In both instances, cost and schedule impacts are discussed, as well as site congestion. The third area of analysis focuses on finding the most efficient sequence for constructing the slab on grade in the hangar area. The expectation of producing a quality product while maintaining high productivity is the key measurement, along with cost and schedule impact. The fourth analysis explores the affect that using the design-build delivery method has on project productivity, specifically on the management and design side of the project.

The breadth topics that will be discussed in this document focus on the electrical and structural options of Architectural Engineering. The breadth in electrical will come from the analysis of the solar collection system by calculating the approximate quantity of energy that could be produced and then determining the building's overall power usage. The structural breadth analysis will be part of the study on changing the interior load-bearing CMU walls to a precast concrete system. Design of a concrete wall structure based on the current loads will be completed.

PROJECT BACKGROUND

CLIENT INFORMATION

The Owner and future occupant of the C-5 Fuel Cell Facility is the 167th Airlift Wing of the West Virginia Air National Guard. This unit is responsible for the flight and maintenance of the C-5 Galaxy aircraft. The Fuel Cell Facility is part of the overall C-5 Conversion project at the Martinsburg base which consists of major renovations to the West Virginia Eastern Regional Airport. Some of the other individual projects that have been completed as part of the Conversion project include complete reconstruction and expansion of the runways at the airport, construction of the Maintenance Hangar which is located to the immediate east of the Fuel Cell Facility, and a new control tower.

Cost expectations for this project are slightly different than private construction projects. As with all parts of the public sector, federal funding is set by a budget and the money must be spent or the budget will most likely be decreased in the future. Of course, this does not mean that there is unlimited funding and the project is still expected to be completed for budgeted cost. Completion of the project by the scheduled date is of importance to the owner mainly because of a desire to occupy the building as soon as possible. While the owner is not looking to make a profit from the final product as in commercial projects, the completion of this building means that the overall Conversion project is one step closer to being complete. Also, there are no plans for any phased occupancy of the building, so the Airlift Wing cannot move in to the building until completion.

Safety is of utmost importance to the Owner but has not been an issue on the Fuel Cell Facility project. This is due in large part to the safety program in place by Kinsley Construction which includes training of all individuals who are to work on the site, as well as safety inspections by company safety officials. The Contracting Officer, a Lt. Col. in the Airlift Wing, has discussed some of the discrepancies he has had in the past with contractors concerning safety issues, and expressed that he has no problems with kicking somebody off the site for violations.

With regards to the quality of the project, the Lt. Col. has also repeatedly explained, through examples of the two similar hangars on the base, what he expects as a result for the Fuel Cell Facility. While there are no high-end finishes in the hangar, the details that are present are expected to be just right. One item that has been specifically addressed is the jointing in the slab for the hangar area. The Lt. Col. has shown the two existing hangars and specified the parts in each that he likes best.

SITE CONDITIONS

SITE LOCATION

- Project located at West Virginia Eastern Regional Airport in Martinsburg, WV
- Part of base for 167th Airlift Wing of West Virginia Air National Guard

NEIGHBORING STRUCTURES

- North- Access road into and out of the base
- East- Maintenance Hangar for C-5 aircraft; almost identical to the proposed Fuel Cell Facility
- South- Taxiway and runway for C-5 aircrafts
- West- Fire department for the Airlift Wing

SPECIAL CONDITIONS

- As a military base, access is restricted
- Security of the runway is of extreme importance- painted lines on concrete of taxiway denote that contractors may not cross
- After blasting procedures, a survey was required to check for any stones that may have flown on to the taxiway
- Dust from construction activities is required to be minimized for sake of operation of aircrafts at the airport- site needs to be watered down
- All structures at the airport need to be lit at night as well as flagged during the day- this includes the building itself as well as the cranes being used on site
- Construction activities can be stopped at any time by Contracting Officer when under a security warning

See Appendix A for Site Plans

LOCAL CONDITIONS

PREFERRED METHODS OF CONSTRUCTION

The Martinsburg, WV region is one in which a particular structural system is not necessarily preferred over the other. That is, there are buildings with concrete structures as well as those with steel structures. For the Fuel Cell Facility though, it is obvious that a steel structural system is required due to the incredibly long spans that are required. Such a building could not be done as a concrete structure. All other parts of the project stay fairly close to the typical construction methods of the region such as slabs on grade and CMU exterior walls. The architectural features of the building, while not typical for any buildings outside of the base, match perfectly with the existing structures on the base.

CONSTRUCTION PARKING AVAILABILITY

The site for the Fuel Cell Facility is such that construction parking is very convenient. There is a large gravel covered area between the building footprint and the access road to the north which is used for job trailers, office trailers, and material laydown, as well as parking for the project.

RECYCLING AND TIPPING FEES

Disposal of all debris and construction waste is to be done off the base and is the responsibility of the contractor. The cost of this service is approximately $650 per month.

SOIL AND GROUNDWATER CONDITIONS

According to the Geotechnical Report, the subsurface stratification is divided into two strata: (1)residual soils with sands, silts and rock fragments, and (2)rock which is primarily shale. From the borings that were completed, it was found that the condition of the shale for bearing ranged from being very poor to good. It was suggested in the report that drilled shaft foundations be used in order to have bearing on competent rock, hence the use of caissons. The report also stated that no groundwater was found during the borings, but noted that it may become present depending on the fracture structure of the shale. This information was based on the construction of the Maintenance Hangar to the east of the Fuel Cell Facility; no groundwater was found during borings for that building, but it was encountered when holes for caissons were drilled. Submersible pumps were used to dewater the drilled holes for the caissons when necessary, but subsurface water was minimal.

BUILDING DESIGN BACKGROUND

ARCHITECTURE

This project is primarily a functional building and does not display many outstanding aesthetic features. However, as mentioned in the *Client Information* section, the occupant is still interested in a quality product. The hangar features an extremely large door assembly on the Southeast façade which opens to the taxiway of the existing airport. Within the hangar there are adjoining offices and support rooms to the Northwest which will be primarily divided with CMU partition walls.

BUILDING ENCLOSURE

Building Façades: The exterior of the Fuel Cell Facility consists of courses of split-face CMU for the first 10' above finished floor level with an accent course at approximately 3' above finished floor, and insulated metal panels for the majority of the remainder of the wall areas. As mentioned previously, the Southeast face of the building is taken up mainly by the door assembly which is a polyester material. Insulated translucent sandwich panels are the means by which natural light enters the structure.

Roofing: A standing seam metal roof system is being used for this building, attached to 3.3" of rigid roof insulation which is fastened to 1.5" metal deck.

STRUCTURAL

The structural system for the Fuel Cell Facility is a structural steel system with a drilled caisson foundation. There are 3' and 6' diameter caissons that are located along the exterior edges of the building at varying spacing. These caissons are laid out symmetrically about the centerline of the building and vary in depth from 12' to 25'. Pier caps with cross sections ranging from 4' x 4'6" to 14' x 5'6" are made with 3000 psi, reinforced concrete. Wide flange and hollow structural steel shapes are used for the columns of the building, with sizes of W33x291 to W40x593 and HSS6x4x1/2 to HSS 16x8x1/2.

Above the support areas of the building, there are W24x94 beams with 27' spans supporting 18K4 joists and W36x393 girders with 30' spans supporting 24LH joists. In the hangar area of the building the

structural steel is broken into two parts, the portions that will cover the wings of the plane and the portion that covers the fuselage, or the center of the building, which is much taller. At the interface of these two portions, on both sides, there is a steel truss configuration which spans approximately 219 feet. The trusses consist of W14x500 and W14x605 beams to form the top and bottom chords with interior members varying in size between W14x99 to W14x283. On the wings of the building, a grid of W12x65 and W24x94 beams make up the typical structural system. The center of the building has a grid of W12x87 and W16x67 beams typically.

Governing Codes: Load calculations per ASCE 7-02

Concrete design and placing per ACI 318 and 301

ELECTRICAL

A new service transformer, on the North side of the building, will convert the utility distribution of 12.47 kV (delta) to the building utilization of 480Y/277V. Service for the building is provided from 200A load break junctions coming from an electrical cabinet in the electrical room. In the hangar area, 400Hz receptacles are provided as well as three 480V electrical and air compressor connection points. Connection points for 400Hz generators are located within the electrical room.

LIGHTING

In the support spaces of the building, artificial light is provided by a variety of styles of luminaires, some recessed and some pendant. All of these luminaires use 277V fluorescent T8 lamps. The hangar area is lit by 277V metal halide pendant luminaires, each providing 1000W of light. Outside of the building, 277V high pressure sodium luminaires are wall mounted, as well as 120V LED lamps which are mounted along the roof lines as obstruction lights. Emergency lighting is provided within the building by 277V LED lamps.

MECHANICAL

The Fuel Cell Facility mechanical system, like every other system, is different for the hangar than that of the support areas. The hangar area, due to the sheer volume and enormous doors, has a heating system and a ventilation system, but no cooling system. The heating is provided by 13 vented infrared radiant heaters which provide 300MBH each and are suspended from the structural steel. Ventilation comes from two 15,000 CFM make-up air units which are located, one each, in the two mechanical rooms. Inline centrifugal exhaust fans also support the ventilation system. For the support areas, the HVAC system consists of two 300GPM boilers, a 4,000 CFM air handling unit which connects to 4 VAV boxes, and 3 energy recovery units which average 1400 CFM each.

Governing Code: Per ASHRAE 90.1

FIRE PROTECTION

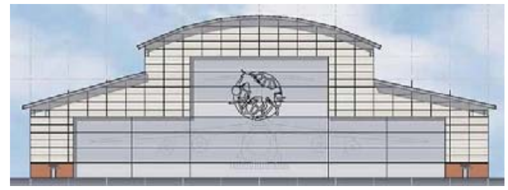
A wet pipe automatic fire sprinkler system provides fire protection for the entire building. The water for this system is supplied from an existing fire pump house near the site. In the hangar area of the Fuel Cell Facility, a low-level high expansion foam system is also provided in addition to the wet pipe system.

Governing Codes: Design of wet pipe for support areas per NFPA 13

Design of wet pipe for hangar area per NFPA 13 with stringent modifications

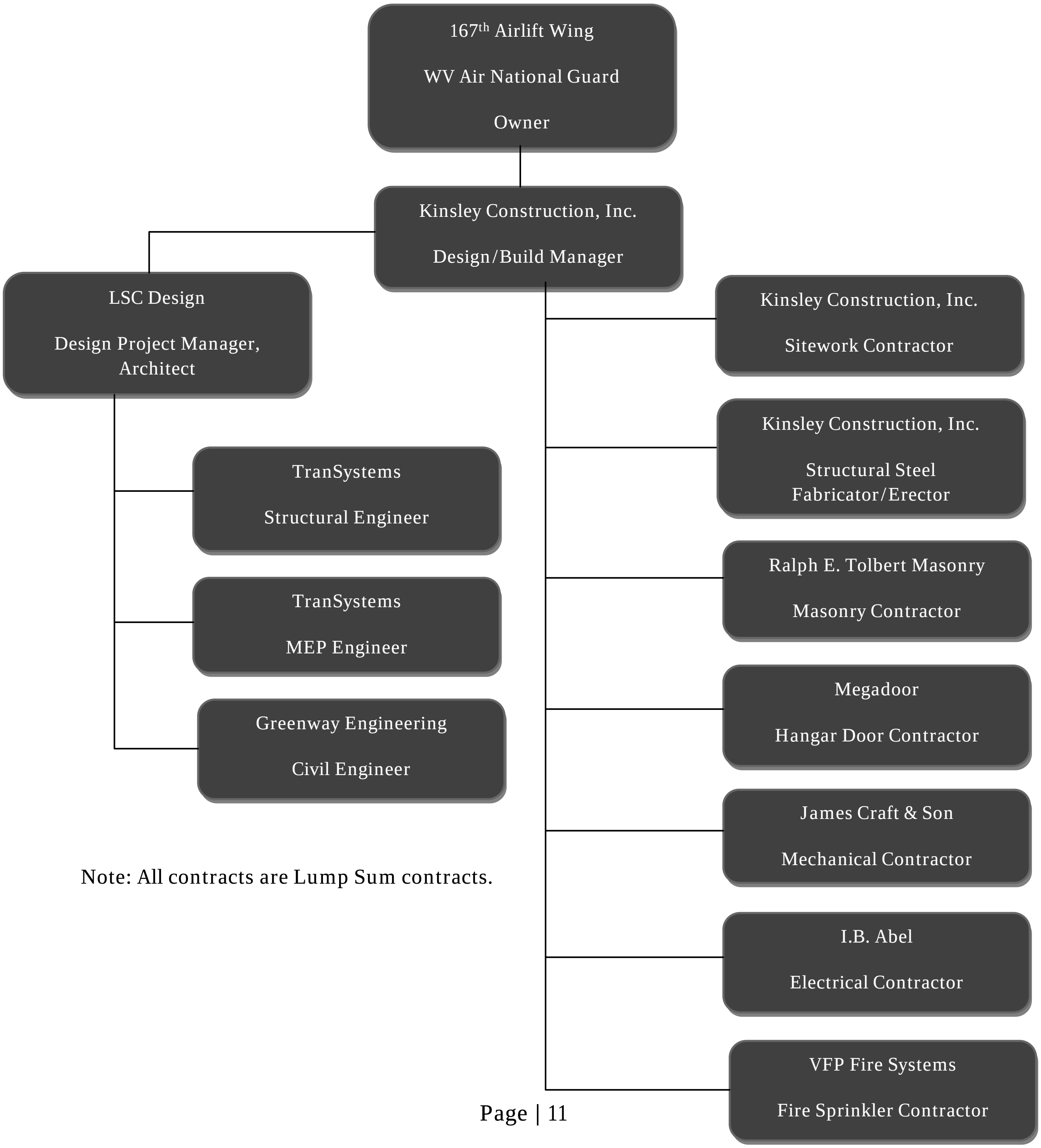
Design of HEF per ANG-ETL 02-15 Fire Protection Engineering Criteria

Installation per NFPA 72 and NFPA 70



PROJECT ORANIZATION

PROJECT DELIVERY SYSTEM



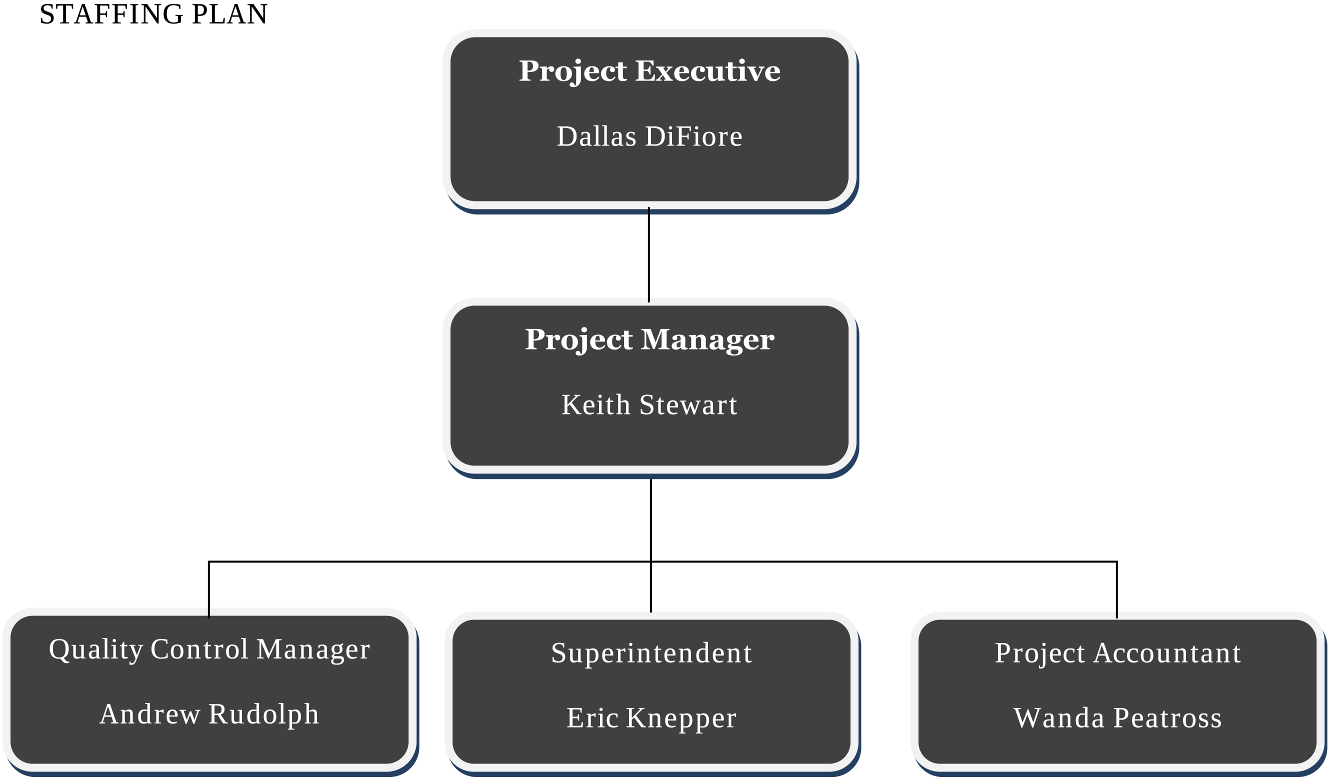
Note: All contracts are Lump Sum contracts.

The C-5 Fuel Cell Facility project has a unique organizational structure, as seen in the chart above. This abnormal structure has been used because a design-build delivery system was chosen for this project. The decision to use this project delivery method was determined based on the requirements of the funding for the project. As a federally funded project, the government was able to be selective in how this project was delivered. In some cases, this would cause projects to be bid as small business set-asides, but due to the size of this project that was not an option and so the design-build was the second option.

Kinsley Construction was selected to be the Design-Build Contractor and Project Manager based on a Lump Sum bid which was created from the preliminary project documents provided in the Request for Proposal. Acting as the Design-Build Manager and a general contractor, Kinsley was required to provide payment and performance bonds for the total value of the project. Kinsley Construction was also required to purchase Builder's Risk Insurance.

LSC Design was selected as the Design Project Manager for the project as it is an entity in the Kinsley family of companies. The contract between Kinsley and LSC is set up as a subcontract though, as are all of the contracts between LSC and the engineering firms that were selected. All of these contracts are based on a lump sum as noted above in the organizational chart. Subcontractors were selected based on lump sum bids to Kinsley Construction for the project and therefore the contracts are based on those lump sums. It can be seen in the organizational chart that Kinsley Construction opted to self-perform the sitework as well as the steel fabrication and erection.

STAFFING PLAN



The Project Executive's role in the project is to oversee the project as a whole and was primarily involved during the design phase of the project by coordinating with the Design Project Manager. He spends most of his time away from the site as he is also involved with other projects currently being worked on by the company. The Project Manager spends much more time on site and his duties include: cost control; working with the safety director; coordination with the Superintendent about manpower and materials; managing contractual arrangements with subcontractors; maintaining good working relations between Owner, Contractor, and Designer. The Project Manager also oversees all tasks completed by the QCM, Superintendent, and the Accountant relevant to the project.

The Quality Control Manager is on the site at all times and is responsible for the following: inspection of work put in place for compliance with design documents; reporting any deficiencies; field correspondence; review of plans and specifications for accuracy. Management of on-site activities is the responsibility of the Superintendent. He is in charge of: ordering and scheduling material deliveries; assigning crews; monitoring the deficiencies list created by the QCM; enforcing security on the site. The Project Accountant is responsible for tracking all costs and expenditures for the project.

SITE LAYOUT PLANNING

The site for the C-5 Fuel Cell Facility is fairly accommodating as far as space on the North side, but is fairly restricted on the other three sides. Unfortunately, Kinsley Construction, Inc. was unable to provide any site layout plans for me to analyze. Based on my visits to the site though, it seems that they were successful in locating items on the site effectively. Located in Appendix B, are site layout plans for three major phases of the Fuel Cell Facility project, excavation and foundations, steel erection, and building enclosure.

EXCAVATION/FOUNDATIONS

The excavation phase of this project consisted of blasting a large portion of the site in order to aid in lowering the grade to the design elevation. As can be seen on the Excavation and Foundation Site Layout Plan in Appendix B, the excess spoils of excavation were stockpiled near the center of the site, in an area which has no caissons. In doing this, the entire site did not need to be cleared of the excess spoils prior to foundation work, but instead they could be done simultaneously. The caissons were drilled with a drilling rig, the steel reinforcing cages were set, and then the concrete was placed. In some cases, dewatering pumps were needed to remove water from the bottom of the holes, but this issue was minimal. After the caissons were completed, the pier caps and grade beams were constructed, following the same direction of progression.

As mentioned previously, space on the project was not a major issue, with the entire North side of the project site being available for placement of office and storage trailers, as well as parking for all employees working on site. This area also allowed space for easy loading and unloading of excavation equipment at the times when it was required. It should be noted that this Northern portion of the site is at a higher grade than the portion in which the Fuel Cell Facility is located; this portion did not require mass excavation like the Southern part did. Due to this, a ramp was created during the excavation phase for easy access between the upper staging and office area, and the lower area in which the construction is taking place. The ramp is to be removed at a later date when construction of the new service road begins.

STEEL ERECTION

Steel erection for the Fuel Cell Facility is one of the most important phases of the project. For that reason, as will be discussed in the *Detailed Project Schedule* section, there were eight phases created in which the steel would be set; these phases can be seen on the sketches in Appendix D. Erection began with a single, 250 ton crawler crane setting columns in the Southwest corner and moving North along the West side of the proposed building. Meanwhile, two more crawler cranes were being constructed in the upper parking area. Two of the cranes worked simultaneously to set the transverse trusses which run approximately North to South, and the third was then used to hold the truss in place with the aid of temporary shoring towers. This set up was maintained until the apex trusses from the exterior wall to the truss were set.

Once the West side steel was erected, the process repeated itself on the East side. After all of the East side steel was erected, the high roof area steel in the center of the building was set. The most important part of this activity was the setting of the B-line truss which extends from the transverse truss on one side to the other transverse truss, creating the frame for the main hangar door. The setting of this truss required the use of all three crawler cranes, a feat that requires a great deal of communication and teamwork as well as planning. Temporary shoring was used to hold this truss in place until all other steel was set for the building.

BUILDING ENCLOSURE

The enclosure of the Fuel Cell Facility building consists of four major parts: CMU around the bottom of the building, insulated metal wall panels, standing seam metal roofing, and the main hangar door. The first three of these activities take place around the building in the same sequence as the steel erection. Roof deck was first set in the Southwest corner once the steel was erected and followed the erection process. The CMU walls were then constructed and the insulated wall panels followed behind. The main hangar door was installed at a later date. The installation of the roof panels, wall panels, and hangar door was completed with the use of platform and articulated boom lifts. On the upper level, the panels were set simply with manpower and scaffolding which was erected on the lower roof.

PROJECT SCHEDULE AND COSTS

DETAILED PROJECT SCHEDULE

As a design-build project, the early portion of the schedule for the C-5 Fuel Cell Facility is slightly different than a project built using a traditional design-bid-build system. As can be seen on the *Detailed Project Schedule* in Appendix C, the project begins with the bidding and selection period, with the design phase beginning after the awarding of the project and the Notice to Proceed. When the design is nearing completion, work on the structural steel shop drawings commences as the design, fabrication, and erection of the steel are the major driving activities to keep the project on schedule.

It may be noted when comparing the *Project Summary Schedule* from Technical Assignment #1, also in Appendix C, to the *Detailed Project Schedule* that the duration for the structural shop drawings was increased, thus pushing back the fabrication of the steel. These issues in the steel design forced the entire construction schedule to be modified in order to maintain the original completion date. The schedules have been included in their differing states to illustrate the necessity of compression of activities later in the overall project schedule.

The construction of most exterior portions of the building revolves around the major steel erection sequences that were employed for the project. These sequences, as can be seen in Appendix D, break the building into eight sections with 1A through 2C covering all of the low-roof areas of the building and 3A through 3C covering the high-roof areas. Once the building is completely enclosed, the interior finishing process begins. All interior work, as can be seen on the schedule, has been broken into two separate portions, the hangar area and the administrative area, with many of the activities in the two areas being completed simultaneously. As the installation of the MEP systems is completed, testing and balancing of the systems begins, taking up the majority of the last month of the project schedule. Final inspection takes place immediately following the conclusion of all testing and building occupancy begins the following day.

PROJECT COST EVALUATION

COST SUMMARY FOR C-5 FUEL CELL FACILITY

Construction Cost: $23,551,204 — $298.78 per SF

Note: Construction Cost includes all costs except sitework, permits, and design fees

Total Project Cost: $26,757,781 — $339.46 per SF

BUILDING SYSTEMS COSTS

Mechanical System: $3,419,475 — $43.38 per SF

Note: includes HVAC and fire sprinkler

Electrical System: $1,706,783 — $21.65 per SF

Steel: $7,768,880 $98.56 per SF

Note: includes structural steel and misc. metals

Structural Concrete: $1,598,316 $20.28 per SF

Note: includes foundations and slab on grade

Sitework: $1,650,799 $20.94 per SF

Note: does not include building earthwork, that is included in Construction Cost

GENERAL CONDITIONS ESTIMATE

The general conditions estimate for the C-5 Fuel Cell Facility was developed using a combination of RS Means Building Construction Cost Data 2009 and historical estimating data provided by Kinsley Construction, Inc. RS Means contained information concerning a majority of the reimbursable general conditions for the project, but for some items it was much more accurate to use the historical data from Kinsley due to deviations from the typical cost information. For example, it was necessary to use the historical data for estimating the cost of temporary storage trailers since many of these trailers are owned by Kinsley Construction. The costs in RS Means are based on rental of the trailers, but the cost to Kinsley for the trailers is much less since they have already been used on multiple past projects and paid for themselves.

General Conditions Estimate Summary

Description	Total Cost
Project Supervision	$746,700
Field Office and Equipment	$63,163
Mobilization	$78,500
Temporary Utilities	$1,430
Winter Protection	$81,500
Bonding	$240,821
Testing	$106,000
Safety Supervisor and Training	$159,500
Cleanup	$56,000
GRAND TOTAL	**$1,746,717**

Note: Grand Total includes extra costs beyond those listed.

The summary estimate shown above for the general conditions provides some of the major reimbursable costs for the project as well as the Grand Total. As noted, the grand total includes other costs that are not included in the table; it is included for comparison between individual components and the total. For example, it can be calculated from the listed values that *Project Supervision* makes up

approximately 43% of the total general conditions cost. Other important costs included above that should be noted are *Bonding*, *Testing*, and *Safety*. Specifically, the cost of safety on this project may seem high but it should be noted that this cost includes a safety supervisor, an expense that could also be included in the project supervision category. However, upon inspection of the *Staffing Plan*, one would notice that a safety supervisor is not included. This is because Kinsley Construction handles all safety personnel through a separate division of the company.

See Appendix E for detailed General Conditions Estimate

DETAILED STRUCTURAL SYSTEM ESTIMATE

The structural systems estimate for the C-5 Fuel Cell Facility was developed through a hand takeoff of all structural concrete, steel, and load-bearing masonry. The quantities that were found were then entered into the online CostWorks program offered by RS Means, which provides cost estimates for 2009 and also allows a location factor to be entered. The unfortunate part of the RS Means software, as with the books from the same company, is that there is a limited amount of information available. For example, when looking at structural steel members for pricing, the maximum size for a wide flange member is a W18x106. This is most likely not an issue for most common buildings, however the structural steel for the Fuel Cell Facility is anything but common with columns as large as W40x593 and truss members as large as W14x605.

To combat this lack of information, the majority of the steel was estimated based on tonnage. All open-web joists were found within the RS Means charts and were priced accordingly, as well as the metal roof deck, but all hollow structural steel and wide flange members were totaled by tonnage. This limits the ability to break down the different parts of the structure, but as can be seen in Appendix D, there has been some differentiation made between portions of the system. Below is a summary of the structural estimate.

Structural Systems Estimate Summary

CONCRETE	
Foundations	$236,441.80
Slab on Grade	$591,272.22
MASONRY	
CMU Walls	$55,046.70
STEEL	
Metal Deck	$243,222.40
Open-Web Joists	$218,099.68
Wide Flange and Hollow Members	$8,110,373.44
TOTAL	**$9,454,456.23**

ASSUMPTIONS/METHODS

- Open shop labor used for all parts
- “Concrete in place” category was used to include all formwork, reinforcement, placement, and finishing as one cost
- No overhead or profit is included in this estimate
- CostWorks from RS Means 2009 employed to create the estimate

See Appendix F for detailed Structural Systems Estimate

ANALYSIS 1: SOLAR ENERGY COLLECTION

BACKGROUND INFORMATION

In the Request for Proposal documents for this project, there was a bid option to design the building such that it would be capable of obtaining LEED-NC Silver certification. The bid option was dropped because the bids came in over the budgeted amount for the project. It is my personal feeling that if the U.S. government wishes to promote sustainability to its citizens, it should lead by example, even if it means spending a little extra money. As a government-owned project, dropping the LEED Silver bid option due to monetary reasons is not exactly setting a good example. Even if the option is not selected, sustainable features could still be added to this structure.

Unfortunately, due to its shape and usage type, improvements upon the C-5 Fuel Cell Facility's energy efficiency with respect to mechanical systems would be extremely difficult. There is a gigantic space that is closed on one end primarily by a fabric door; this is obviously not going to prevent airflow between the interior and exterior of the building. However, there is also a very large amount of roof area on this building that is open to absorbing a great deal of solar energy. This is ideal for solar collection, a process that would reduce the amount of power that the Fuel Cell Facility would be taking from the grid.

Specifically, a potential product to be used on this project is one developed by Solyndra, Inc., which was discussed in one of the breakout sessions at the PACE Roundtable discussion. This product differentiates itself from the typical solar panels that many owners are trying to incorporate into their buildings through sheer production. The photovoltaic system created by Solyndra is able to convert a much higher percentage of the sunlight which hits the building's roof into electricity because of the cylindrical shape of its modules.

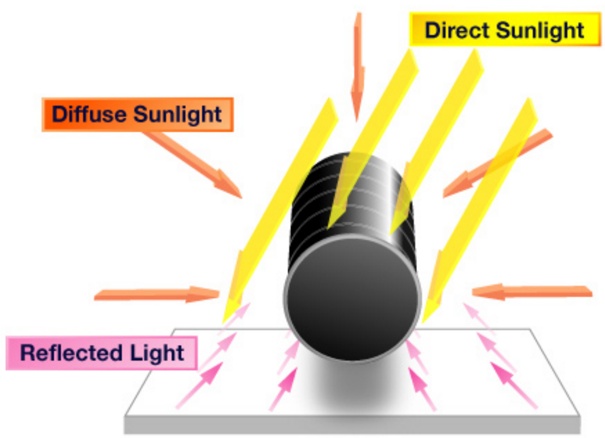
http://www.solyndra.com

GOAL OF ANALYSIS

The primary goal of this particular analysis is to determine, through a constructability review, whether or not the installation of the Solyndra panels is a positive addition. The review is based on: estimated energy production, estimated building power usage, costs of acquiring and installing the system, and an estimated payback period. Schedule impact and productivity impact are also components of the constructability review.

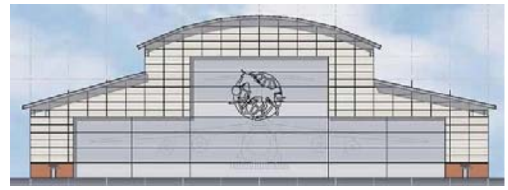
SOLYNDRA PANELS

As mentioned above, the photovoltaic system which has been created by Solyndra, Inc. sets itself apart from the competition through its increased energy production capabilities. This is primarily due to the unique construction of the system. Unlike typical photovoltaic systems which are comprised of a flat panel, the Solyndra system is an array of cylinders. Solar collection is highly dependent on the angle at which the sunlight hits the collector; the closer the panel and sunlight are to being perpendicular, the better. This is why some flat plate systems incorporate sun-tracking mechanisms which allow the panel to rotate to follow the sun's position throughout the day. With the Solyndra system, sunlight is always hitting the cylinders at a perpendicular angle, meaning that there is greater collection potential.



One of the other benefits of the Solyndra system is the ability to collect reflected and diffuse light as seen in the diagram to the left. By leaving small spaces between the individual cylinders some light will pass through, but a portion of that light will also be reflected off the roof material and can then be collected on the underside of the cylinders. The amount of solar gain due to this reflected light is largely dependent upon the type of roof material that is installed beneath the Solyndra panels. For example, Solyndra recommends the use of a white TPO roof material as this will have the best possible reflective capabilities.

The space that is left between the individual cylinders serves other purposes as well. With these spaces, air flow is allowed to occur between the cylinders, and this has a dual purpose. First, the airflow through the panel reduces the need for significant mounting procedures. One of the major issues with typical photovoltaic systems is the uplift load from wind. Solyndra, Inc. states that the product has been tested and certified to be used in winds of up to 130 mph without any significant mounting. Second, this airflow allows the cylinders to be cooled off which allows for higher energy production. When photovoltaic systems are at high operating temperatures the production rate decreases, but with the Solyndra system the operating temperature is lowered, therefore increasing the production rate.

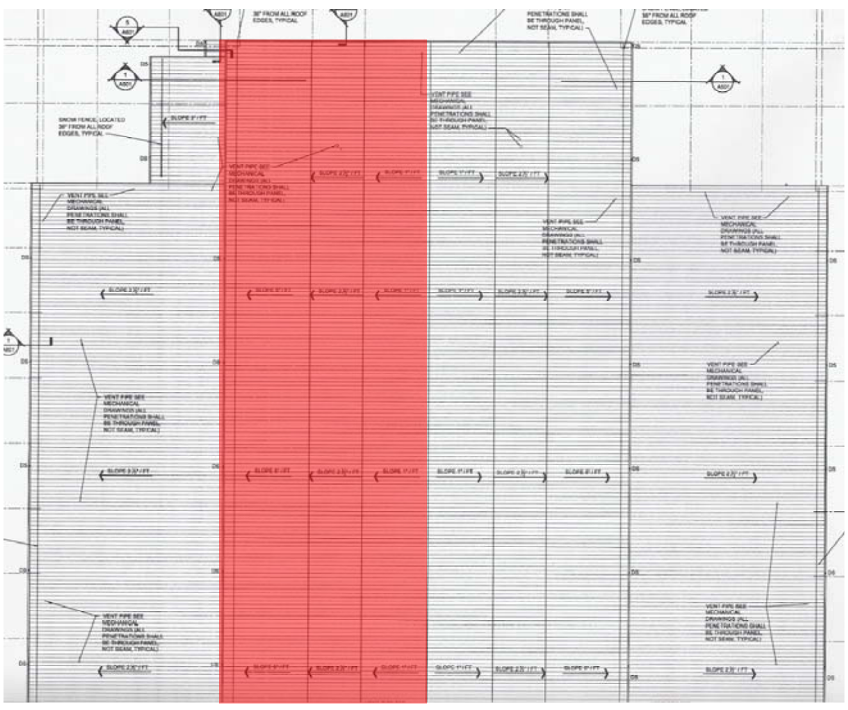


ELECTRICAL BREADTH STUDY

The addition of a solar collection system to the Fuel Cell Facility would greatly impact the amount of electricity that would need to be purchased to run the building. To discover this impact, there are several steps that must be completed: calculating the number of panels that could be installed; calculating the potential amount of energy that could be produced; and calculating the approximate cost of electricity for the building. Other key factors when considering whether or not this would be a positive addition include: analyzing the cost impact of the project; calculating a payback period; and analyzing the schedule impact with respect to productivity in the field.

PANEL QUANTITY

The first step in determining the number of panels that could be installed on the Fuel Cell Facility's roof, is analyzing the orientation of the building. There is plenty of roof space on this structure to "slap on" on a lot of panels, but if those panels are only going to be producing a minimal amount of electricity, there is no sense in installing them. By examining the orientation of the building and considering the neighboring structures it was determined that panels should only be installed on the high roof area on the Southwest side of the building. The space that was selected can be seen highlighted in the diagram below. It includes three different sections with varying slope.



The next step in determining the number of panels was comparing the dimensions of the panels, which were found in the Product Specifications attached in Appendix G, to the dimensions of the roof sections. It was also important to account for walking space around sections of panels for maintenance purposes. As can be seen in the full calculations in Appendix H, it was determined that the panels would be oriented lengthwise down the slope of the roof. As a total for the three sections of roof being used, 13 panels can be installed in the lengthwise direction of the panel. After factoring in the walking spaces, it was determined that 78 panels could installed in the widthwise direction of the panel. This totals to 1014 panels being installed on the roof of the Fuel Cell Facility.

PANEL PRODUCTION POTENTIAL

Determination of the potential energy production for the Solyndra panels began with research on how to convert a given Power Rating found in the Product Specifications into kilowatt-hours. After learning that this was based on insolation, a measure of solar radiation energy on a given surface, it was necessary to determine what the insolation value is for the location of the Fuel Cell Facility. This information was found at www.gaisma.com which contains weather-related information from the NASA Langley Research Center, Atmospheric Science Data Center. The insolation values were reported as monthly averages for the location of Martinsburg, WV as can be seen in the table below. It was then necessary to multiply this value by the maximum power rating as provided in the Product Specifications as well as the number of days in the respective month. These quantities which can be seen in the far right column of the table are the maximum kilowatt-hours produced by a single panel in each given month and total to 274 kWh/panel for the year. The value seen in the *Max Power Rating of Panel* column is based on using the SL-0010200 model by Solyndra, Inc.

GAISMA Insolation Values for Martinsburg, WV

Month	Insolation (kWh/m^2/day)	Sun Hours per Day	Max Power Rating of Panel (W_P)	Days per Month	Max Output for 1 Panel (kWh/panel)
Jan.	1.85	1.85	200	31	11.47
Feb.	2.59	2.59	200	28	14.50
Mar.	3.56	3.56	200	31	22.07
Apr.	4.59	4.59	200	30	27.54
May	5.21	5.21	200	31	32.30
Jun.	5.70	5.70	200	30	34.20
Jul.	5.60	5.60	200	31	34.72
Aug.	5.03	5.03	200	31	31.19
Sep.	4.07	4.07	200	30	24.42
Oct.	3.13	3.13	200	31	19.41
Nov.	2.04	2.04	200	30	12.24
Dec.	1.60	1.60	200	31	9.92
	MAX TOTAL ANNUAL OUTPUT FOR 1 PANEL (kWh/panel/year)				**273.98**

This maximum annual output per panel which is noted in the above table must be reduced to account for the actual reflectivity of the roof. As mentioned previously, Solyndra recommends the use of a white TPO roof for maximum gain, but the design of the Fuel Cell Facility calls for a standing seam metal roof. During my contact with a Solyndra representative, Anthony Anello, I was able to acquire information

which approximates the reflectivity of different roof surfaces. This information can be seen in Appendix G, on the page labeled Albedo Reflectivity vs. Annual Energy Yield. The chart on the left side of this page then equates the roof reflectivity values to annual energy yield as a percentage of the maximum. As can be seen on the chart, metal roofs have 45% reflectivity and would therefore be able to produce about 88% of the maximum energy output which was calculated earlier.

273.98 kWh/panel/year x 88% = **241 kWh/panel/year**

The value calculated in the above equation represents the approximate amount of electrical energy that can be produced in one year by a single panel. To determine the total power output of the array of panels for a year, it is necessary to multiply simply by the number of panels which was determined earlier.

241 kWh/panel/year x 1014 panels = **244,374 kWh/year**

ELECTRICAL USAGE AND COST

In order to determine an estimated cost of electricity for the building, it is first necessary to determine how much energy the building will use. Since the Fuel Cell Facility is somewhat of an uncommon type of building, there is little information available concerning average energy usage. However, the existing hangar to the East of the Fuel Cell Facility is similar in size and equipment. By contacting the Contracting Officer for the project, I found that the existing hangar used approximately 2380 kWh in the hangar space, but that the existing hangar is larger than the Fuel Cell Facility. The estimated quantity of power usage in the hangar space was determined as shown below.

2,380 kWh x (67,620SF/80,560SF) = 1998 kWh;

where 67,620SF is the area of the Fuel Cell Facility hangar area, and 80,560 is the hangar area of the existing structure.

Since the hangar space makes up only a portion of the building, it was also necessary to separately estimate the power usage in the office spaces of the Fuel Cell Facility. To accomplish this I researched average electricity usage for office spaces on the Department of Energy's website. The DOE reported that offices use, on average, 18.9 kWh/SF/year. To apply this quantity to the Fuel Cell Facility office space, required finding the area of the office space and simple multiplication.

78,825SF (total building area) – 67,620SF (area of hangar space) = 11,205SF

11,205SF x 18.9 kWh/SF/year = 211,775 kWh/year

TOTAL USAGE = 1998 + 211,775 = **213,773 kWh/year**

It may be noted that the total usage approximation is less than the total production approximation, meaning that the Solyndra system could produce more than enough power to sustain the building without using power from the local grid.

The next step to determining the approximate cost of electricity for the building, on an annual basis, is to find how much electricity costs in the area. Through research, it was found that the state of West Virginia's average electricity cost is 6.64 cents per kilowatt-hour, which happens to be fairly inexpensive in comparison to the national average which is 9.89 cents per kilowatt-hour. The approximate annual cost of electricity for the Fuel Cell Facility is as follows:

213,773 kWh/year x $0.0664/kWh = **$14,195/year**

Since it was already determined that the Solyndra system can produce more than enough electricity for the building, this $14,195 would be saved each year. The additional electricity could most likely be sold back to the power company as well which would add further value to the system. This will be explored further in the payback period section.

COST OF ADDING SOLYNDRA SYSTEM

Through contact with Anthony Anello, a Solyndra sales representative, I found that the higher end panels cost about $7/Watt/panel. This price includes purchasing of the system as well as installation of the system based on Solyndra's historical data. As mentioned previously, the 200 Watt panels were chosen to be used for this analysis. The cost of procuring and installing this system would be as follows:

$7/Watt/panel x 200 Watts x 1014 panels = **$1,419,600**

PAYBACK PERIOD

When considering the addition of most products which promote sustainability, the lifecycle cost of the building is very important. The calculation of a payback period is often a key factor in determining whether or not the system should be added, and therefore should be completed to analyze the Solyndra system. As mentioned previously in the *Electrical Usage and Cost* section, the approximated production of the Solyndra system is greater than the approximated usage of the building. The additional electricity could then be sold back to the power company which would, in a sense, increase lifecycle savings. Although the rate that the power company would pay to acquire the additional electricity is most likely lower than what they charge to sell it, the average cost that was presented above will be used for simplicity. To find the total approximate annual savings, the cost of electricity must be multiplied by the amount of electricity expected to be produced each year.

$0.0664 x 244,374 kWh/year = **$16,226/year**

The payback period is calculated as follows:

$1,419,600 / $16,226/year = **87.5 years**

SCHEDULE AND PRODUCTIVITY IMPACT

To determine the impact that adding the Solyndra solar collection system would have on the schedule, it is first necessary to figure out when the installation would occur. Most certainly, the system could not be installed until the metal roof has been installed. Since the panels will only be on a portion of the roof, it is not necessary for the entire metal roof to be completed but may be helpful in terms of congestion of workers in the area. If the area becomes too congested, the productivity of the workers will decrease, potentially causing delays in the schedule for multiple activities. As can be seen on the Detailed Project Schedule in Appendix C, all work for the Metal Roof Panel Installation should be completed on 1/13/10. However it is also necessary to examine what other activities will be occurring simultaneously, specifically ones that might be taking place in the same area and could again cause congestion. According to the project schedule, other activities occurring at this time are site work, slab-on-grade preparations, and MEGA Door installation. The first two should not disrupt the Solyndra installation, but the door installation might. If the Solyndra system installation commences on 1/25/10, all activities in the area should be completed and productivity should be at a maximum.

Based on research concerning installation of the system, as well as examination of the project schedule with respect to the metal roof panel installation, the Solyndra installation should have approximately an 8-day duration. This includes staging the panels to the roof via crane, as was done for the roof panels, attachment done by hand, and electrical connections. The electrical connections are likely to be the only portion of the installation process that will negatively affect the schedule, since it will require the electrician to complete additional activities beyond his original scope of work. All other Solyndra installation activities would occur within the timeframe of critical path activities taking place at the same time. It would be suggested to bring in additional electrical workers to ensure that the overall project schedule is not delayed.

CONSTRUCTABILITY REVIEW

The main points to focus on when reviewing the potential for installation of the Solyndra system are: the amount of electricity that can be produced compared to the amount of energy used by the building; the cost of installing the system; the payback period; and the schedule impact of installing the system. It was found that the electricity produced is greater than the electricity used by the building, a positive. It was also discovered through the quantity of electricity produced and the cost of electricity, as compared to the cost of installing the system that the payback period is approximately 87.5 years, a negative. Finally, the project schedule was determined to be minimally impacted by the addition of this system, a positive. The key is to determine whether or not the positives outweigh the negatives.

CONCLUSIONS

As was mentioned in the *Background Information* section, I feel that the government should lead the way in promoting sustainable technology usage and if feasible should implement its usage. However, after personally completing the constructability review for the addition of the Solyndra solar collection system, I must recommend that the system not be installed on the C-5 Fuel Cell Facility project. Based on the extreme payback period which was calculated, it is not a worthwhile investment for this particular project. It is important to note that one of the primary reasons for the payback period being so long is the low cost of electricity in the region that this project is located. In a higher cost region such as Washington D.C., the payback period would be greatly reduced thus making the installation of this system more feasible. Government leadership in the support of sustainable technologies is important for this country, but leadership in the smart spending of monetary funds is also important, particularly in the midst of the current economy.

ANALYSIS 2: PRECAST CONCRETE WALLS

BACKGROUND INFORMATION

Due to schedule acceleration techniques that were necessary to make up time, masonry work which was originally not supposed to begin until steel erection was complete, was taking place during the erection process. This created some site congestion issues and also forced the masons to work more quickly than initially scheduled. On the façade of the building, these conditions along with adverse weather conditions caused some problems with the quality of the finished product, including broken CMU's and the appearance of efflorescence in many locations around the building. Site congestion was also experienced during the construction of the interior CMU walls since other activities such as MEP rough-in were taking place simultaneously. These are problems that commonly occur with on-site construction, especially when the schedule must be accelerated.

The use of precast concrete walls for both the exterior façade and the interior walls would lessen the impact of these conditions. For the exterior façade, one of the most important factors to be considered when looking at the precast wall system is whether it is possible to match the aesthetic features that are present in the design with CMU's. The two existing hangars of almost identical design as the Fuel Cell Facility feature the same CMU façade around the bottom portion of the exterior walls, and it is critical that this design feature be maintained on this building. For the interior load-bearing walls, aesthetics is far less of an issue. The key factor for these will be the necessary thickness of the walls to handle the current loading. It is important that additional thickness is not necessary; otherwise valuable floor space will be consumed by a wall.

Based on discussions in various classes, some of the major benefits of using a prefabricated or precast system are the improved quality that can be obtained since the construction is done in a controlled environment, as well the reduction of site congestion since a portion of the work is taking place off-site. Another benefit which has been explained in class is the increase in productivity. Under controlled conditions the product can be built much more quickly, and then once the product arrives on site it is installed more quickly than if masons had been constructing it on-site. The validity of these potential benefits will be examined in the following analysis.

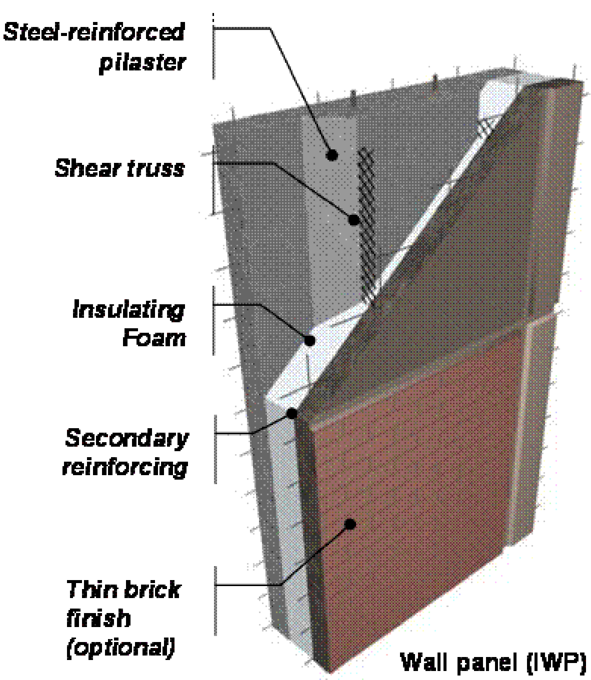
GOAL OF ANALYSIS

A Cost vs. Value review will be used to determine whether or not precast concrete would be a better option than the chosen option of CMU for the wall construction of the exterior façade and the interior load-bearing walls. Arrival of this decision is the main goal for this topic of analysis. The Cost vs. Value review will be based upon the pros and cons of the precast system as compared to the CMU system. Particular areas of comparison include: quality of the final product; cost impact; potential for added value; and schedule impact with respect to productivity and site congestion issues.

CARBON CAST PANELS

The portion of the exterior façade for the Fuel Cell Facility that is currently constructed with split-face CMU plays an important aesthetic role for the building. As mentioned above, there are two existing hangars of very similar design on the base, both of which implement the split-face CMU façade. Deviating from that style is not an acceptable option, thus making the usage of precast concrete walls somewhat restricted. The change in the system cannot cause a change in the architectural features. To be sure that a precast concrete wall could be made to look identical to the CMU wall that was designed, it was necessary to research various precast companies.

The results of this research were that a true precast concrete wall would not be able to match. However, several precast concrete companies also construct prefabricated walls which are composed of steel reinforcement, insulating foam, concrete, and a "thin brick" face. Specifically I chose to contact High Concrete Group LLC, located in Lancaster County, PA. High Concrete is a supplier of CarbonCast insulated wall panels, which is an example of the prefabricated wall system described above. According to my contact at High Concrete, the "thin brick" usage allows the façade to meet practically any set of specifications that a CMU wall can meet. A cutaway diagram of the CarbonCast system is shown below.



As mentioned in the *Background Information* section above, one of the major benefits of using a prefabricated system is the improvement in the quality of the product. The exterior façade of a building is the only part that many people ever see, thus making it very important that the impression it gives off is one of a quality-constructed building. Schedule acceleration and weather conditions were some of the causes of a reduced quality product in the CMU wall construction for the façade, both of which would not be factors in the construction of the CarbonCast wall system. The prefabricated system would be created in a controlled environment; one which has ideal temperature for working, ideal curing conditions for the concrete, and one which is not being rushed by the accelerated schedule on-site. Prefabricated construction of this type would also be done under much more stringent quality control requirements. Another benefit of using the prefabricated wall system is the increased productivity which would occur within the controlled environment. This is largely due to the fact that there are skilled workers performing repetitive activities; a learning curve is set and the workers will continuously be able to complete the work more quickly while maintaining the same quality. Productivity for the installation of the system on-site will be discussed in later sections of this analysis.

STRUCTURAL BREADTH STUDY

While changing the façade system for the Fuel Cell Facility has little affect on the structural demands of the building, changing the interior load-bearing masonry walls to precast requires structural analysis. As was briefly discussed in the *Background Information* section, one of the keys in switching to a precast concrete system is making sure the wall thickness is not increased. Due to the relatively low loads that these walls must support, the ideal situation would be to decrease the wall thickness and increase the usable floor space. There are two different conditions for the interior load-bearing walls, which are shown in the drawings included in Appendix I, but the only difference is the length of the joists which the walls must support. Therefore it was determined that the best solution would be to design for the two conditions separately concerning the wall thickness, and then use the more stringent condition for the design of the reinforcement. This design condition would then be applied for both sections of the wall in order to make construction uniform. The steps of the design process are discussed in the following sections.

LOAD DETERMINATION AND ASSUMPTIONS

The loads that the interior load-bearing walls must support were determined by contacting the Project Engineer for the 167th Airlift Wing, who happens to be an AE Structural Option graduate. I was informed that the loads could be assumed as follows:

Dead Load:	1-1/2" MTL Roof Deck	2.0 psf
	(2) layers of 5/8" Type X GWB	5.6 psf
	Suspended ACT	2.5 psf
	Collateral/Misc.	5.0 psf
	Steel Joists (avg. 4' oc spacing)	5.0 psf
	3" Batt Insulation	1.2 psf
	TOTAL DEAD LOAD	**21.3 psf**
Live Load:	Construction load	20 psf
	TOTAL LIVE LOAD	**20 psf**

Based on discussion with a fellow AE student in the Structural Option, the following assumptions were developed in order to complete the design of the interior concrete load-bearing walls:

Assumptions: Concrete wall is concentrically loaded – axial load only; horizontal load is carried by wide flange steel beam

Pinned-Pinned connection – k=1.0

$f'_c = 3000$ psi; $f'_y = 60{,}000$ psi

WALL DESIGN

It was determined that the most appropriate design method to use was LRFD or Strength Design and therefore the best load combination to use for each of the two conditions was:

1.2D + 1.6L

The complete calculations for design of each of the two conditions can be found in Appendix J, but the main parts of the design for Condition 1 are shown below. This condition is shown because it was determined to be the more stringent of the two conditions. The first step was to use the loads that were listed above and convert them into the axial load which the concrete wall is required to support.

P_D = 1193 lbs

P_L = 1120 lbs

$P_U = 1.2P_D + 1.6P_L$ = 3223 lbs = 3.22 kips

This calculated load is the amount that each of the steel joists is applying to the concrete wall at a 4' spacing. It was determined that the bearing plates on which the joists rest have an area of 67.5 inches squared each. It was also determined that the effective width for bearing is 38.75" based on a chosen wall thickness of 8". Next the wall was checked for both Bearing Capacity and Axial Load Capacity with respect to the ultimate load which was calculated above. These checks are as follows:

Bearing Capacity: $Pu \leq \emptyset 0.85 f'cA_b; \emptyset = 0.65$

0.65(.85)(3)(67.5) = 112 kips ≥ 3.22 kips OK

Axial Load Capacity: $P_u \leq \emptyset P_n = \emptyset 0.55 f'cA_g \left[1 - \left(\frac{kl_e}{32h}\right)^2\right]$

$$A_g = \text{effective width} \times h = 38.75 \times 8 = 310\ in^2; \emptyset = 0.70$$

$$\emptyset P_n = .70(.55)(3)(310)\left[1 - \left(\frac{16 \times 12}{32 \times 8}\right)^2\right]$$

$\emptyset P_n$= 157 kips ≥ 3.22 kips OK

Based on these results, a wall thickness of 8" is acceptable and capable in both bearing capacity and axial load capacity. From this point, it is now necessary to design the reinforcement for the wall. Although there is no steel reinforcement necessary to support the applied loads, there are minimum steel requirements that must be met. The calculations are included in Appendix J, but the resulting steel requirement for the concrete wall is as follows:

#4 reinforcing bars @ 18" oc in the vertical direction

#4 reinforcing bars @ 12" oc in the horizontal direction

INCREASED FLOOR SPACE

As was explained in the above calculations, a wall thickness of 8” was determined to be acceptable for meeting the design criteria. It can also be seen in the sections of the two different wall conditions that the CMU system requires a 12” wall thickness. A simple 4” reduction does not seem like much, yet when the length over which this 4” is gained is considered the additional floor space is fairly significant. The interior load-bearing walls have a length of approximately 356 lineal feet. When multiplied by the 4” reduction in wall thickness we find that 117 square feet of floor space is gained in the office areas. While 117 square feet still does not sound like much in comparison to the overall project, it becomes more significant when there is a price attached to it. According to the findings in the *Project Cost Evaluation* section, the Total Project Cost is $339.46 per square foot.

117SF x $339.46 = **$39,717**

The above equation shows that by decreasing the wall thickness from 12” with the CMU system to 8” with the precast concrete system, an additional $39,717 worth of usable floor space is gained. Though the aesthetic quality of the interior walls may not be as important as it was on the exterior façade, the same conditions leading to a quality product that were discussed previously still apply. The increased productivity benefits would be experienced for the precast interior wall system as well.

COST COMPARISON

It is no secret that one of the most important factors when considering a change of systems is the cost impact. To compare the costs of the system that was instituted on the Fuel Cell Facility project, the CMU system, to the costs of the prefabricated and precast wall systems, it was necessary to acquire information from individuals in the industry. The most accurate cost estimation for the implemented CMU system would be the actual construction costs, which were acquired from the Project Manager in the form of a Schedule of Values which can be found in Appendix K. It can be seen on this Schedule of Values that the total cost of all masonry work on this project is **$230,011** and even includes foundation work for which there is no precast concrete to compare with.

To create a cost estimate for the precast concrete and the prefabricated wall systems, I again conferred with my contact at High Concrete who provided me with a rough estimate for the two wall systems. The estimate I received stated that the production and installation of the two systems would average out at $38 per square feet of wall. The calculation for the total cost of the two wall systems is as follows:

$38/SF x (7622SF Façade + 5696SF Interior) = **$506,084**

It is apparent that the cost of the precast and prefabricated systems is far greater than that of the CMU system which was used on the Fuel Cell Facility. In fact the difference between the two options is $276,073. Stated in other terms, the precast and prefabricated combined system costs more than twice as much as the masonry system. However, to take a step back and look at this from a distance, this price differential is just slightly more than 1% of the total project cost.

SCHEDULE IMPACT

The affect that changing from a masonry system to a precast concrete system has on the schedule of the project must be examined in multiple dimensions. First of all, the duration of activities on site must be compared for the two systems. Clearly the shorter the schedule is the lower costs will be, specifically due to General Conditions costs which were discussed earlier. It can be seen in the *Detailed Project Schedule* in Appendix C that the total duration of the masonry work for both the exterior façade and the interior load-bearing walls is 25 days. Based on information provided by my contact at High Concrete, the total duration for erection of precast and prefabricated panels on-site would be 15 days. This duration was developed according to an estimated 125 panels that would be constructed off-site and then erected by means of a truck crane. It is quite obvious that there is a 10 day difference in the duration of activities on-site, so one would assume that the overall schedule could be reduced by this amount. In the form that the project was originally scheduled, the *Project Summary Schedule* in Appendix C, this assumption would have held true. Unfortunately, due to necessary schedule acceleration, the masonry work overlapped with the steel erection, an activity which was on the critical path and lasted beyond the completion of masonry work. Therefore, the reduction in duration that occurs by switching to the precast and prefabricated system is essentially negligible for the overall project schedule.

Other than the duration of the work itself, it is also necessary to examine the schedule impact in terms of site congestion and productivity, two issues which go hand-in-hand. As was mentioned in the previous paragraph, no matter which option is selected, the activities will be taking place simultaneously with steel erection. This obviously creates some site congestion concerns, which was one of the primary reasons for completing this analysis. The more congested the site becomes with equipment and manpower, the greater the potential for losses in productivity. To compare the logistical issues on the project site for each of the two options for wall construction, site logistics plans have been developed, each of which accounts for the ongoing steel erection process. These plans can be found in Appendix L.

It can be seen in these plans that by implementing the precast and prefabricated wall system instead of the masonry wall system, all scaffolding around the building would be eliminated as well as the mortar mixing station. The forklift traffic which is noted on the Masonry Site Logistics Plan is also eliminated for the precast option, but is replaced by the truck crane and delivery truck traffic which is necessary for erecting the concrete panels. Based on the information explained in this *Schedule Impact* section and prior knowledge, the following conclusions have been made concerning productivity and site congestion issues:

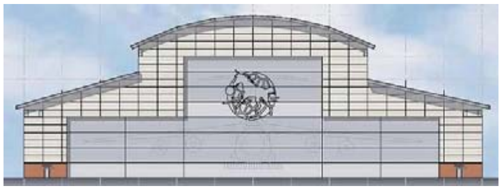
- The decreased duration on site means that site congestion does not last as long
- Fewer workers will be on-site for the precast erection than the masonry construction; less congestion and higher productivity
- Erection of interior walls during steel erection could cause significant congestion issues; more congestion and lower productivity
- Maneuvering the delivery truck and crane on the South end of the building may cause delays; productivity of the erection would be decreased

Overall, it seems that the site congestion level for the two options is almost equal. While the precast and prefabricated systems could be installed with fewer workers on-site and without the scaffolding, it would require the addition of two large vehicles to be maneuvering about the site. It seems reasonable to assume that the productivity rate of the precast and prefabricated system is still higher than that of the masonry system based strictly on the duration of the activities, and that productivity of other activities would be higher with a precast system since there would be less overlapping time.

CONCLUSIONS

As stated in the *Goal of Analysis* section, a Cost vs. Value review is necessary for determining whether or not the precast system is the best option for the Fuel Cell Facility. To do this, it is advisable to compare the pros and cons of changing to this system from the CMU system that was used. First, the main negative factor of switching systems is the additional cost of $276,073. The positive factors of the switch include: increased office floor space valued at $39,717; higher quality product for the façade; decreased duration of activity on site; and increased productivity. It is difficult to place a monetary value on quality as it is all a matter of perspective of the owner. However, since the owner seems to be happy with the final product that was achieved with masonry on the other two hangars, it is unlikely that they would attach a very high value to the improvement with the prefabricated system. As was mentioned earlier, the decreased duration does not affect the overall schedule and therefore does not provide any monetary savings through general conditions costs. The only chance of adding value through the increased productivity would be if other activities on-site were greatly affected and the overall project schedule would be decreased.

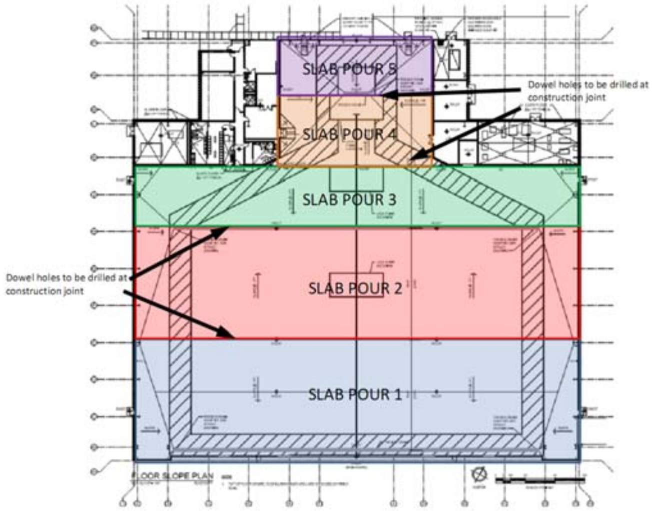
It seems that the use of precast concrete and prefabricated walls is not a better option than the masonry system that was used on the Fuel Cell Facility. Perhaps, if the CMU façade covered the entirety of the exterior walls instead of the base only, the cost of the prefabricated system would be more competitive. It is also possible that if there were a much greater amount of load-bearing walls, the increased floor space achieved through reduction in wall thickness would help overcome the increased cost. For the quantity of wall space on this project that could be potentially changed, it is clear that the design team chose wisely in selecting a masonry system rather than a precast concrete one.



ANALYSIS 3: HANGAR SLAB SEQUENCE

BACKGROUND INFORMATION

The hangar slab of the Fuel Cell Facility, as I have been informed by the project team, must meet specific requirements according to the ANG-ETL documents from the Air National Guard, specifically regarding the placement of dowels in the concrete. The document states that all construction joints require epoxy-coated dowels which shall be placed by means of drilling the previously placed concrete. To complete this process in the correct manner, a minimum of 3 days must pass from the time the concrete is placed until the drilling can begin. In order to reduce the number of days that are spent waiting for drilling, the project team decided to complete the slab in as few sections as possible. The diagram below shows a rough plan of the different sections of the hangar slab, as constructed. The bottom two sections are each approximately 75 feet in width.



While this plan for placing the slabs certainly saves some time by eliminating the number of construction joints with dowels, it created many headaches for the project team when it came to determining effective finishing methods. The 75 feet sections are much wider than most slab pours that Kinsley Construction typically deals with on other projects. To complete the process, some of the intended finishing techniques must be modified and potentially compromised.

GOAL OF ANALYSIS

The goal of this analysis topic is to derive the most efficient sequence for the hangar slab construction for the C-5 Fuel Cell Facility project. The efficiency of the sequence will be primarily measured by cost and schedule impact, as well as productivity and expected quality of the finished product. Since the quality and productivity cannot truly be estimated by simply looking at a sequence diagram, it requires the use of historical data.

INDUSTRY SURVEY

As mentioned above, historical data was needed to perform this analysis. It was decided that the most useful form of historical data would be the experience of industry members who have actually been a part of completing large concrete pours such as the one present on the Fuel Cell Facility project. To gather the knowledge of industry members, a survey was created with a series of questions pertaining to their individual preferences for placing concrete and their observations from completing a variety of widths of concrete pours. The survey questions that were sent to the industry members are as follows:

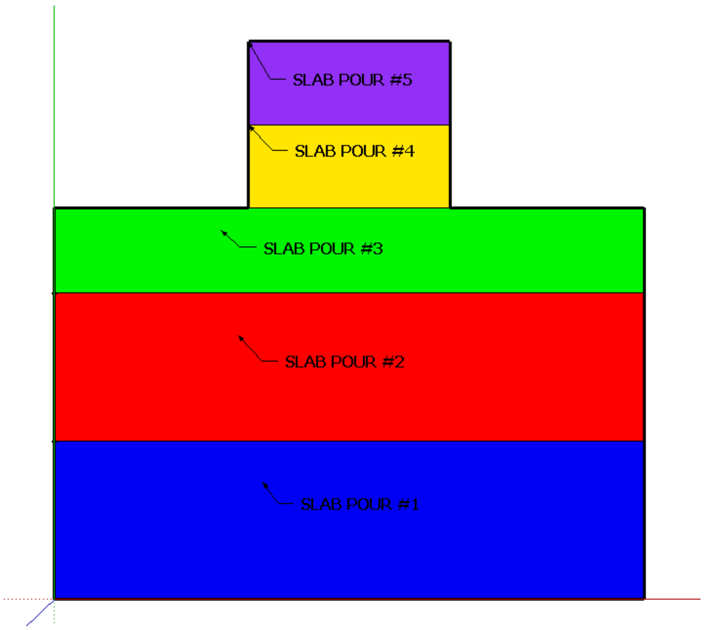
- When placing concrete, do you prefer fewer pours of larger sizes, or a greater number of pours with smaller sizes?
- Which of these options is typically completed with higher productivity?
- Based on experience, what is the largest width of a pour that can be done while maintaining maximum efficiency?
- How does the width of the pour affect the crew size that is necessary?
- How does the width of the pour affect the type of equipment that is necessary?

The responses were unanimously in favor of completing the project in fewer pours of a larger size, and each of the industry members surveyed stated that using larger widths of pours yields a higher productivity rate. For the question about the largest width of a pour with respect to maintaining maximum efficiency, a variety of answers was received; the range that was found was anywhere from 60' in width to 120' in width. Most of the surveyed industry members explained in their responses that using larger pour widths creates a need for a few extra workers as well as some extra finishing equipment.

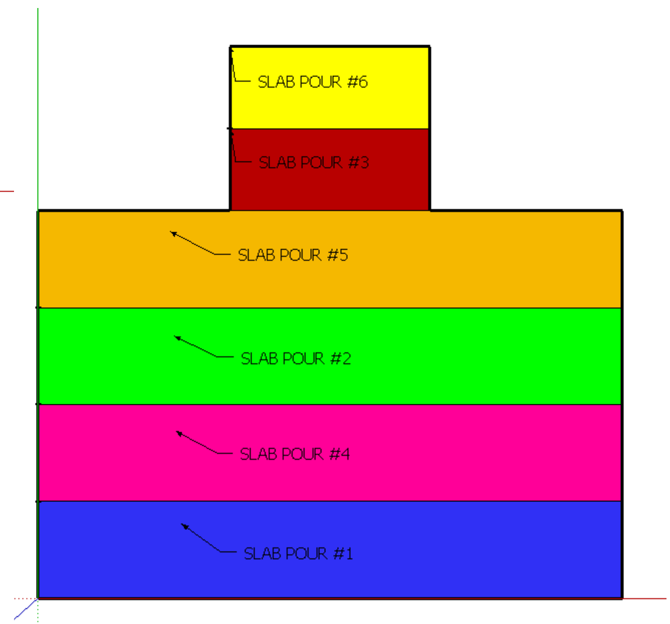
It is important to note that the responses that were received did not exactly match my personal thoughts and expectations. It was not surprising that the industry members preferred fewer pours of larger widths over the greater number of smaller pours. However, it was my expectation that the widths of pours that could be completed with maximum efficiency would have been significantly lower, based on discussion with the Project Manager for the Fuel Cell Facility project. During one of my site visits, it was explained that there were issues in how to complete the finishing stage of the concrete because of the large widths of 75', as was mentioned previously. From this discussion, and due to my lack of experience, my assumption was that a 75' width was much greater than the typical size for concrete placement. Since the results of the surveys differed from the hypothesis, it was necessary to tweak the method of analysis.

THREE SLAB SEQUENCES

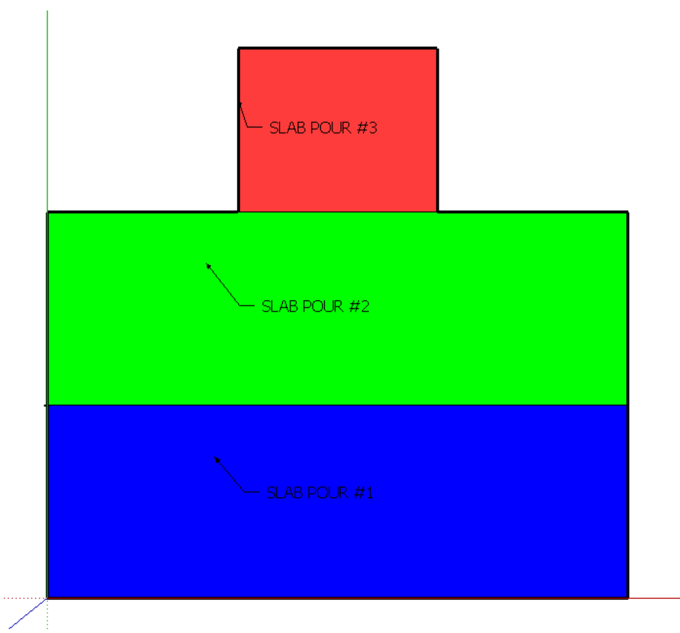
The original plan for this analysis was to use the responses from the third survey question and simply average the widths to determine an approximate maximum size concrete pour that could be expected to maintain peak productivity. This maximum size pour would then be implemented into a construction sequence to determine what would presumably be the most efficient sequence for the Fuel Cell Facility project. However, when the responses simply proved that the 75' width was average, the analysis had to be adjusted. Upon the suggestion of my advisor, Dr. Chris Magent, it was decided to design three potential sequences for the hangar slab construction and then complete a cost and duration comparison to determine the most efficient sequence. Images of the three sequences are shown below.



SEQUENCE #1



SEQUENCE #2



SEQUENCE #3

The first of the sequences is meant to be a rough equivalent of the sequence actually used for construction on the project. The actual design calls for an inward sloped piece around the edges of the hangar space, following the walls. However, for comparison purposes, it was decided to simplify the design since the cost of completing this portion of the slab construction would be approximately equal regardless of the sequence chosen. As can be seen in the image of Sequence #1 above, there are five separate pours of varying sizes. The first pour in the sequence has a width of the 80', the second is a 75' width section, the third pour has a 43' width, and the fourth and fifth pours each have a width of 42'. Clearly this sequence involves some pours that fall within the range of maximum width for peak productivity that was determined from the survey responses. It also includes slabs with widths below this maximum range. These slabs with the smaller width, based on the discussion with the Project Manager, were not of nearly as much concern in terms of finishing the concrete.

The second sequence of slab pours implements six different pours to be completed in alternating succession as can be seen in the image above. For this sequence, the different pours are much more similar in width; the four pours in the lower portion of the building are each 49.5' in width and the upper two are again 42' in width as in Sequence #1. The purpose of Sequence #2 is to look at completing the construction in more pours of a smaller width, as was the original intent of this analysis. Obviously the 49.5' width does not fall within the range of maximum widths that was found in the surveys, but due to the dimensions of the building, it was the most representative size to use for examining the lower end of the range while maintaining the idea of a greater number of pours. Use of this sequence would presumably allow for a higher quality finished product based on the information provided by the Project Manager.

Sequence #3 is based on the higher end of the range of maximum widths, but again was influenced by the dimensions of the building, as is any sequencing of activities. As seen in the image above, the larger widths allowed this sequence to be done in a fewer number of pours. The first two pours of this sequence each have a width of 90' and the third has a width of 84'. Using this sequence would further reduce the number of construction joints necessary, as well as the number of dowels to be drilled for, which was the reasoning by the project team for using larger width pours from the beginning. However, it also would most likely make the finishing process more difficult and potentially lower the quality of the finished product.

COST AND DURATION COMPARISON

To determine which of these three sequences is the most efficient requires comparison of some hard numbers. The quality impact of the different sequences, which was discussed in the previous paragraphs, is important but is difficult to quantify for measurement. Through the use of RS Means 2009 Construction Cost Data, an estimate for the cost of each of the three sequences was created as well as an approximate number of hours that would be required for completing the work. It is important to note before examining the estimated durations that they should not be associated directly with the construction schedule of the project. They have been derived by implementing the Crews that were included in Means and were not adjusted to meet the schedule since their creation was meant solely for comparison of the sequences against each other. These durations also do not include the 3 day waiting period necessary before drilling for the dowels.

The full estimate sheets can be found in Appendix M. The total cost and duration estimates for the three sequences are as follows:

Sequence #1: Total Cost = $408,290.78, Total Duration = 427.90 hours

Sequence #2: Total Cost = $414,533.98, Total Duration = 458.26 hours

Sequence #3: Total Cost = $401,025.78, Total Duration = 384.53 hours

The derivation of these values, as can be seen in the full estimate sheets, involved adjusting the Daily Output values to reflect the information that was provided in the surveys of industry members. Since the response to all surveys was that productivity increases with the width of the pour, as long as it is not above the maximum range, the Daily Output value provided by Means was adjusted up or down based on the width of the individual pour being analyzed. This adjustment and the quantities determined through a detailed take-off produced the results seen above. As mentioned earlier, the Total Duration values do not reflect the necessary 3 day waiting period necessary for drilling for the dowels at all construction joints in the concrete. In general, the durations of each of the three sequences would be increased when considering this factor, and though the additional time added would not be equal, the differences can be assumed to be negligible.

It is clear from the values of cost and duration listed above that the sequence with fewer pours of a larger size is cheaper and takes less time than the sequence with more pours of a smaller size. Sequence #1, which represents the as-built construction sequence falls almost right in the middle. To compare the cost of the two new sequences against the as-built sequence in terms of percentage, the numbers come out as follows:

Sequence #2: $(414{,}534 - 408{,}291)/_{408{,}291} = \mathbf{1.5\%\ higher}$

Sequence #3: $(401{,}026 - 408{,}291)/_{408{,}291} = \mathbf{1.8\%\ lower}$

These cost differences must also be correlated back to the difference in expected quality of the finished product. It is yet again proven that a higher quality product comes at the expense of more money and more time. Another element that may not be quite as obvious is that a higher quality product sometimes causes a reduction in productivity. To be certain that a finished product turns out well, specifically concrete in this case, extra time and care must be taken. This extra time required to be spent for a given quantity of work leads to the downfall of productivity. Maintaining both high quality and high productivity is a challenge that is presented every day in the construction industry.

CONCLUSIONS

The sequence of concrete pour sizes that was selected by the project team for the Fuel Cell Facility hangar slab construction seems to be the best option of the three sequences analyzed based on cost and duration, as well as the quality impact. It is possible that by implementing slightly larger pour widths, the cost and duration may be reduced through higher productivity, while maintaining the same level of quality. However, the dimensions and shape of the hangar area are not very conducive for creating many varieties of sequences. My recommendation, if this project were to be repeated, would be to use the same sequence and method for construction that was chosen by the project team. For other projects which may not have as much concern as far as the quality of the finish, utilizing larger pours may be more beneficial.

ANALYSIS 4: DESIGN-BUILD PRODUCTIVITY

BACKGROUND INFORMATION

The use of the design-build delivery method for construction has become more common over the years and there have been many advantages found by using this collaborative system. One of these advantages, as discussed in various classes in the AE curriculum, is that productivity in the field is improved due to a reduced number of Requests for Information and Change Orders. Since the contractor and the various engineers are working together in the design stages, fewer questions are left to be answered when it becomes time for the drawings on paper to become a building in the ground. It has been proven time and again that employing a design-build approach decreases the overall schedule of a project, primarily because construction often begins before the design stage is complete. A question to be answered is, does this approach create better efficiency for the designers and construction managers?

Productivity in the field is fairly simple to measure, whether it is how many cubic yards of concrete were placed in a day, or how many windows were installed in a week. However, quantifying productivity in the office requires further investigation. To analyze this topic, it is necessary to obtain information from industry members who have been involved with both the traditional delivery method of design-bid-build as well as the design-build delivery method. This information can primarily be acquired from construction professionals who have worked under both methods. It is also worthwhile to examine this topic from the owner's perspective, specifically an owner who has been involved with both delivery methods. Fortunately, as mentioned in previous documents for this thesis assignment, there are already two hangars on the base of the 167th Airlift Wing which are similar to the Fuel Cell Facility, one which was constructed using a traditional design-bid-build approach and one that was done under a design-build approach. The Contracting Officer for the Fuel Cell Facility project held the same role in each of the other two hangar construction projects, and is therefore a qualified individual to speak on the subject.

GOAL OF ANALYSIS

Finding the answer to the question asked above is the primary goal of this analysis. This answer will be derived through a variety of resources. As mentioned above, the experience and knowledge of industry members plays a key role. It is also necessary to explore how the design-build delivery method specifically affected this particular project, with regards to productivity and efficiency for the project team. Since not every project team is entirely familiar and comfortable with the design-build method of construction, simply due to lack of exposure, it is also necessary to analyze the potential benefits and restrictions that are presented with this delivery method when it is used as intended.

MEASUREMENTS OF ANALYSIS

A specific set of measurements must be employed in order to determine if design-build does indeed create better efficiency and productivity for the design and management teams of a particular project. There are no true numerical values to compare, only individuals' inputs and perspectives based on previous experiences. Since production rates for office work are rarely calculated, it is more of an abstract idea to analyze; hence the predetermined measurements which are listed below. These measurements will again be discussed to conclude this analysis after examination of the information provided.

- Time spent for preconstruction activities
  - Design
  - Estimating
  - Acquisition of subcontractors
- Amount of paperwork required to be completed during construction
  - Requests for Information
  - Change Orders
  - Submittals
- Ability to work ahead
  - Long lead item procurement
  - Permitting
  - Determining means and methods for construction
  - Subcontractors scheduling their labor and equipment in advance

PROJECT MANAGER SURVEY

To procure information from industry members who have been involved in the management of both design-bid-build projects and design-build projects, it was decided that survey would be the most efficient option. The following questions were sent to several professionals working in the realm of project management, with a variety of levels of experience.

1. How many design-build projects have you worked on? How many design-bid-build projects?
2. Which delivery method typically runs more smoothly from a management perspective?
3. In your opinion, is the productivity level higher within the management and design teams for one method over the other? If so which one is higher?
4. Have you noticed a significant difference in the number of RFI's and change orders for one method over the other? If so, which one typically has fewer?
5. Which delivery method do you prefer to work with? Please provide reasons.

The responses to these survey questions were mostly in favor of the design-build delivery method over design-bid-build. As mentioned, the level of experience of these individuals varied greatly, which became apparent when reviewing the responses to the first question. The preferences that were displayed through the responses to Question #2 were much more similar. Design-build was the clear leader as far as

how smoothly a project typically runs from the management perspective. One explanation for this decision is as follows:

> "There is less coordination during construction because the design-build contractors have designed, coordinated, and selected their material during design. It makes the submittal, procurement, and field coordination process smoother."

Another response to this question, though in favor of the design-build method, explained that this method requires a significantly greater amount of time spent by the management team due to involvement with the design process, rather than simply helping in the bidding stages of the project as is done with a design-bid-build method. One survey participant who was in favor of the design-bid-build approach stated that design-build does not run as smoothly due to the fact that the project team must deal with a design that is not fully developed, making it harder to manage the project.

Question #3 again received responses that were strongly in favor of using the design-build delivery method. Some examples that were provided to support the responses were as follows:

- Construction methods are decided during the design phase so the design is completed accordingly.

- Response time from the design team is better since they are contracted together.

- Submittal process is reduced by almost half since the design and construction teams choose the materials together. This means that the specifications are met the first time the paperwork is submitted.

- Costs are known upfront since estimating procedures take place simultaneously with design, rather than waiting until design is completely finished.

- Procurement of long lead items and permits can begin immediately after certain design phases are completed. In design-bid-build, the contractor must wait until they are awarded the job.

Clearly one of the repeating themes of these responses is saving time and beginning activities sooner. Reduction of the overall schedule of a project has been, and always will be, one of the major challenges in the construction industry.

The fourth question, which dealt with comparing the number of RFI's and change orders that occur for the two different delivery systems, received a unanimous response that design-build has fewer of each, as was expected. Most survey participants explained that RFI's are not truly present in the design-build system, at least not in the formal sense that they exist in design-bid-build. Instead, all questions are discussed openly at meetings since the contractor and designers work as a team. Change orders are also minimized since the design-builder and the subcontractors have a much better understanding of their scope of work and costs. The design-build team is responsible for having everything covered in the design documents from the start. The only change orders that occur are due to changes by the owner and unforeseen conditions that may arise during construction.

In regards to the question concerning the preferred delivery method to work with, mixed responses were received. Some said that they have no real preference since they believe there are pros and cons to each method. One response stated that the traditional design-bid-build system is better because there is less gray area, while another explained that design-build is preferred because it gives the contractor greater control in directing the progress of the project. A theme that was repeated in most responses though, was that the right individuals can make either system work.

OWNER PERSPECTIVE

As mentioned in the *Background Information* section, the Contracting Officer for the 167th Airlift Wing for the Fuel Cell Facility project was also involved in the construction of each of the other two C-5 aircraft hangars on the base. Lt. Col. Burkhart was willing to grant me a phone interview to discuss delivery method differences from his perspective in the project. If there was one resounding point that the Lt. Col. made clear in our discussion, it was that the delivery method is only as successful as the contractor who is implementing it. From his experiences in dealing with both design-bid-build and design-build projects, the contractor is the most important variable in the equation.

He explained that he has found the traditional method to be very successful, especially if the design documents are well done. However, he also stated that if the design documents are unclear, life as the owner representative can be a nightmare. In the design-bid-build methodology, the contractor has minimal say in the design process and therefore is subject to the drawings they receive. In summary the traditional method, from the Lt. Col.'s perspective, is more dependent on the design professional and takes away some of the control that the contractor has on the project.

In the design-build method, the contractor is able to be a part of the design phase and in that sense has much greater control over the quality of the design documents which they will be using. The Lt. Col. specifically noted that the design-build delivery method forces the contractor to be much more knowledgeable since they are involved in the design. He stated that the contractor needs to "do their homework" to be sure they understand the project much earlier on in the process than is required in the traditional method. It was also acknowledged that projects such as the Fuel Cell Facility and other government-funded projects typically have a different process that must be followed as well as some slightly different standards which can make life difficult for both the contractor and owner if the contractor is unfamiliar with that type of work. This accentuates the point of the contractor needing to work ahead of time to be sure to understand the project.

The final factor that the Lt. Col. addressed concerning the use of design-build methodology is the necessity of the owner to know what he or she wants. He explained that, while the contractor needs to put in the extra time to understand the project, the owner is accountable for assisting the contractor and design teams when questions arise. If the owner is indecisive and incapable of expressing the needs and desires for the project, the contractor and design team will be delayed and possibly produce something that is not satisfactory. The overall knowledge gained from the interview with Lt. Col. Burkhart was that the productivity, or efficiency, of a delivery method is restricted by the capabilities of the contractor selected for the project, and the efficiency of that contractor can only be as good as the resources he is allowed to work with.

CAUSES OF DELAYS

It is also important to take a look at how using the design-build delivery method may or may not have affected the productivity on the C-5 Fuel Cell Facility project. A brief discussion with the Project Manager for the project provided some insight into this topic. It had been brought to my attention early on in my studies of this project that it had fallen behind the original schedule by a significant amount of time and this was due in large part to the design of the structural steel system. Since the erection of steel was the driving factor of the critical path, it became apparent that schedule acceleration techniques were necessary. This topic was discussed in Technical Assignment #3 and will not be explained in detail at this time.

The driving point of the conversation with the PM was determining what the exact cause was for the delays in the steel design, and whether or not it was a function of the delivery method. When asked if he felt the delays were related to the design-build method being used, for example due to unfamiliarity with the process, the PM was pretty adamant that this was not the cause. Rather he explained that the major cause of delays in the structural design phase was a lack of familiarity with designing structures like that of the Fuel Cell Facility. I was informed that TranSystems was selected as the structural design firm by Kinsley Construction because of their experience with hangar design. Unfortunately, TranSystems is a nationwide firm and the designers having experience with hangar design resided in a different office than the one working on the Fuel Cell Facility. Help was eventually provided by the more experienced offices, but until the schedule had already suffered significant delays. In other words, the potential for high productivity in design due to previous experience was never realized.

The Project Manager also explained that another opportunity for improved efficiency that was not realized came in the design of the MEP systems. This was especially disappointing considering the design of all MEP systems was completed by a single firm, again TranSystems. It is not the intent of this analysis to “pick on” this company, simply to point out room for potential improvement from an educational standpoint. It was explained to me that all of the MEP subcontractors were brought into the project early for a design-assist role, which is very common in design-build, and worked with the design team to create an efficient construction process. Regrettably, the MEP design teams did not coordinate well with each other and many issues still occurred during construction. It might be assumed that, had this project not implemented a design-build delivery method, the coordination issues could have been even greater for the MEP trades.

As far as coordination between the design teams and the project management team, the PM stated that he did not feel there were any issues. His only regret was that he did not become more involved in the design phase, particularly the structural design since he has a strong background in this area. He explained that his knowledge of structural design did come in useful for the foundation design as far as simplifying an over-designed system. The main problem that arose with the structural design process was that by getting behind early the design team was forced to react to new issues rather than being proactive and coming up with more efficient designs. In summary, several potential chances for improved efficiency through the design-build method were never fulfilled. The PM did express his personal feeling that the design-build method yields better productivity within the design and management teams if those opportunities are realized.

POTENTIAL BENEFITS AND RESTRICTIONS

In the research of this topic, there were instances in which opposing arguments occurred. For example, one source provided information about accountability being greater in the design-build method, explaining that the system reduces finger-pointing between the contractor and design team since they all work together to meet the owner's needs. Another source discussed how accountability is reduced because there is no process of checks and balances between the design team and contractor since they are all working as one entity. Both are valid points and emphasize what has already been discussed earlier, the efficiency and effectiveness of the design-build method is highly dependent on the contractor, or more specifically the design-builder.

There were several other examples of both benefits and restrictions which reiterated information presented earlier in this analysis. Some examples of benefits include: the ability of the contractor to control the cost of the project through the design process; the capability of procuring long lead items early on; and the almost complete elimination of change orders. Examples of restrictions include: the need for a knowledgeable and decisive owner, and the need for coordination between members of the design-build team.

CONCLUSIONS

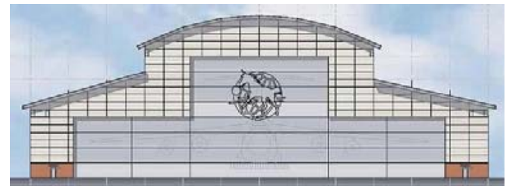
To summarize the information that has been discussed in the previous sections, it is necessary to review the predetermined measurements of analysis and see what the studies of this topic have found. Based on what was found, it appears that the preconstruction time is capable of being reduced, but is highly dependent on the knowledge and experience of the design team as well as the focus on coordination between parts of the design team. It was determined that the design phase can be completed more efficiently because of the ability for subcontractors to assist the design team and reduce the number of changes that occur later in the project. Also, because cost estimating can be completed simultaneously with design, there is not an extended period of time spent for take-off. Cost comparison of materials is handled as the systems are selected, and overall cost is known much earlier so there is a reduced likelihood of exceeding the budget. The design-builder is also able to select subcontractors much earlier in the process through prequalification, and allow the subs to assist in design.

The amount of paperwork, and time spent reviewing it, was proven to be greatly reduced for the design-build method based on the survey responses. All participants explained that Requests for Information are far fewer since the subcontractors helped in the design phase. They also expressed that Change Orders are almost completely eliminated except for owner changes and unforeseen conditions. Finally the participants agreed that the submittal process is greatly shortened because the specifications are defined with the aid of the subcontractors and are therefore typically met with the first submission.

In regards to being able to work ahead, it can be surmised from the information already discussed that the design-build method is much better than the traditional method. Design-build allows the contractor to begin the procurement process for long lead items much earlier since they are helping choose materials in the design process. Permits can also be purchased earlier since the contractor knows they have been awarded the project before the design is complete. This reduces delays which can often

occur in the permitting process. It is also easier for the subcontractors to plan ahead. Since they are likely to be involved in the design phase, unlike for design-bid-build construction, the means and methods of construction can be decided on sooner. In fact many methods of construction can be considered during the design process in order to improve efficiency in the field. The subcontractors are also able to use their advanced knowledge to schedule their labor force and equipment to be sure delays do not occur in construction.

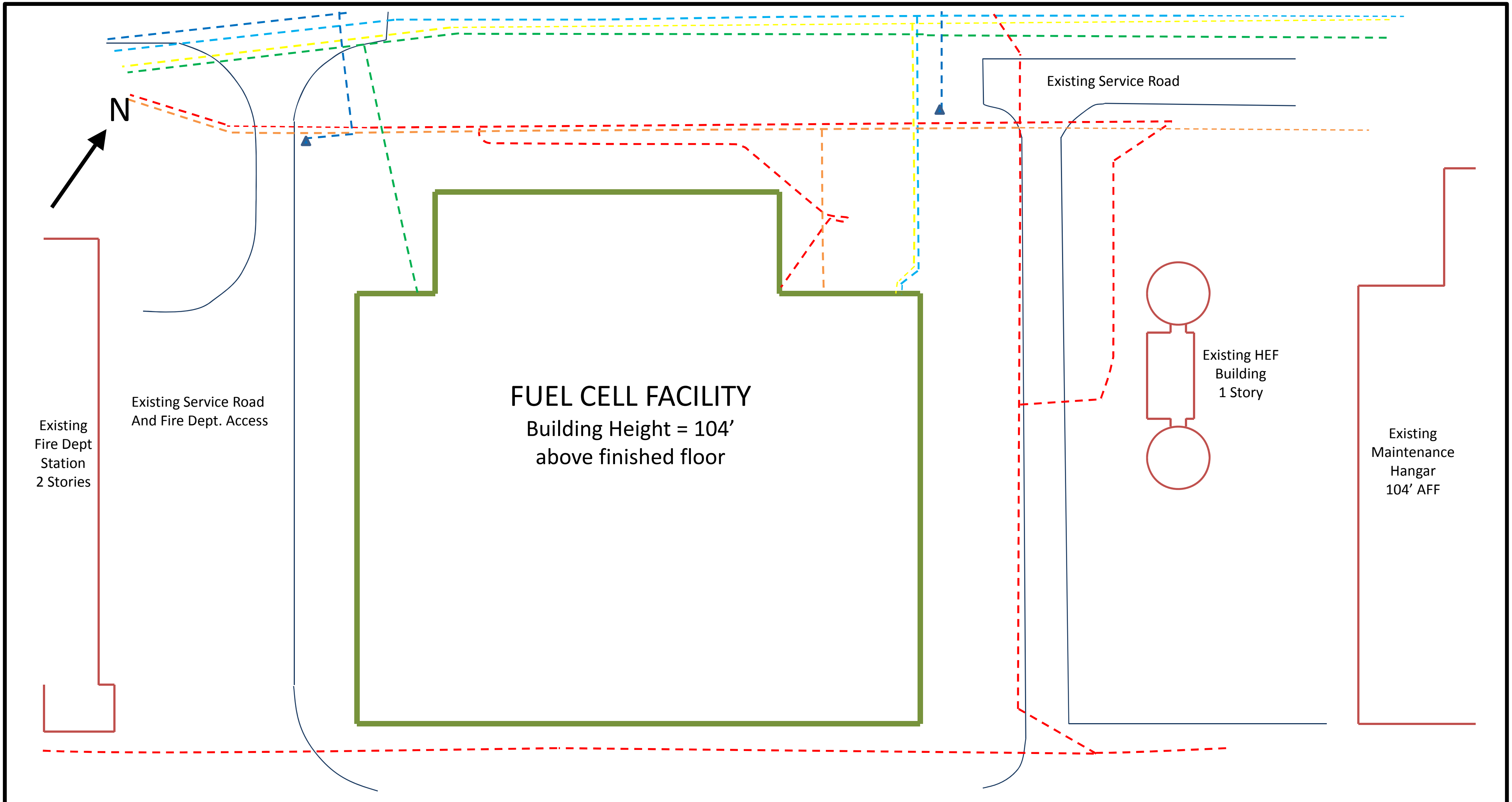
According to the measurements that were determined and the information that was found, it seems quite obvious that using the design-build delivery method can indeed improve productivity for the management and design teams. It is important to understand and make special note of the repeated theme in this analysis, that the productivity and efficiency of this method is highly dependent on the team that is selected for the project. If the contractor or design team is not knowledgeable of the owner's desires for the project, the design-build method will not be effective. The same result will occur if the owner is unable to express their needs and wants for the project. However, these restrictions are just as important to a successful project with the design-bid-build method. It is the *potential* for efficiency that can be achieved by the two delivery methods that must be compared, and it has been shown that design-build has greater potential.



Appendix A

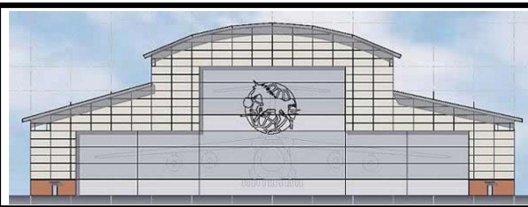
C-5 Fuel Cell Facility

Site Plans of Existing Conditions



C-5 Fuel Cell Facility
Martinsburg, WV
Kyle Goodyear
Construction Management

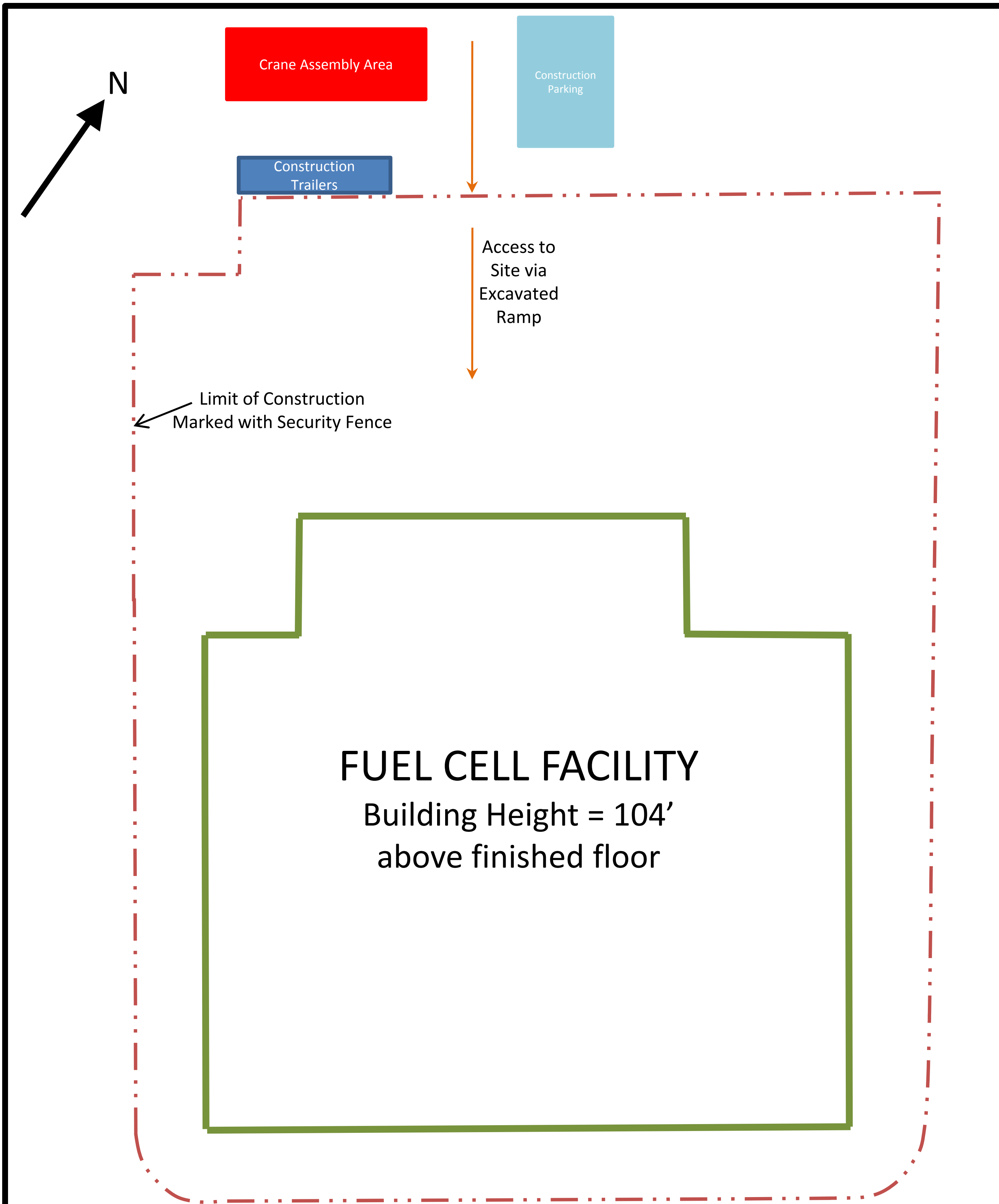
October 1, 2009



Gas	Fire Line
Water	Sanitary
Electric	Fire Hydrant
Communications	

Site Utilities Plan

NTS



C-5 Fuel Cell Facility
Martinsburg, WV
Kyle Goodyear
Construction Management

October 1, 2009

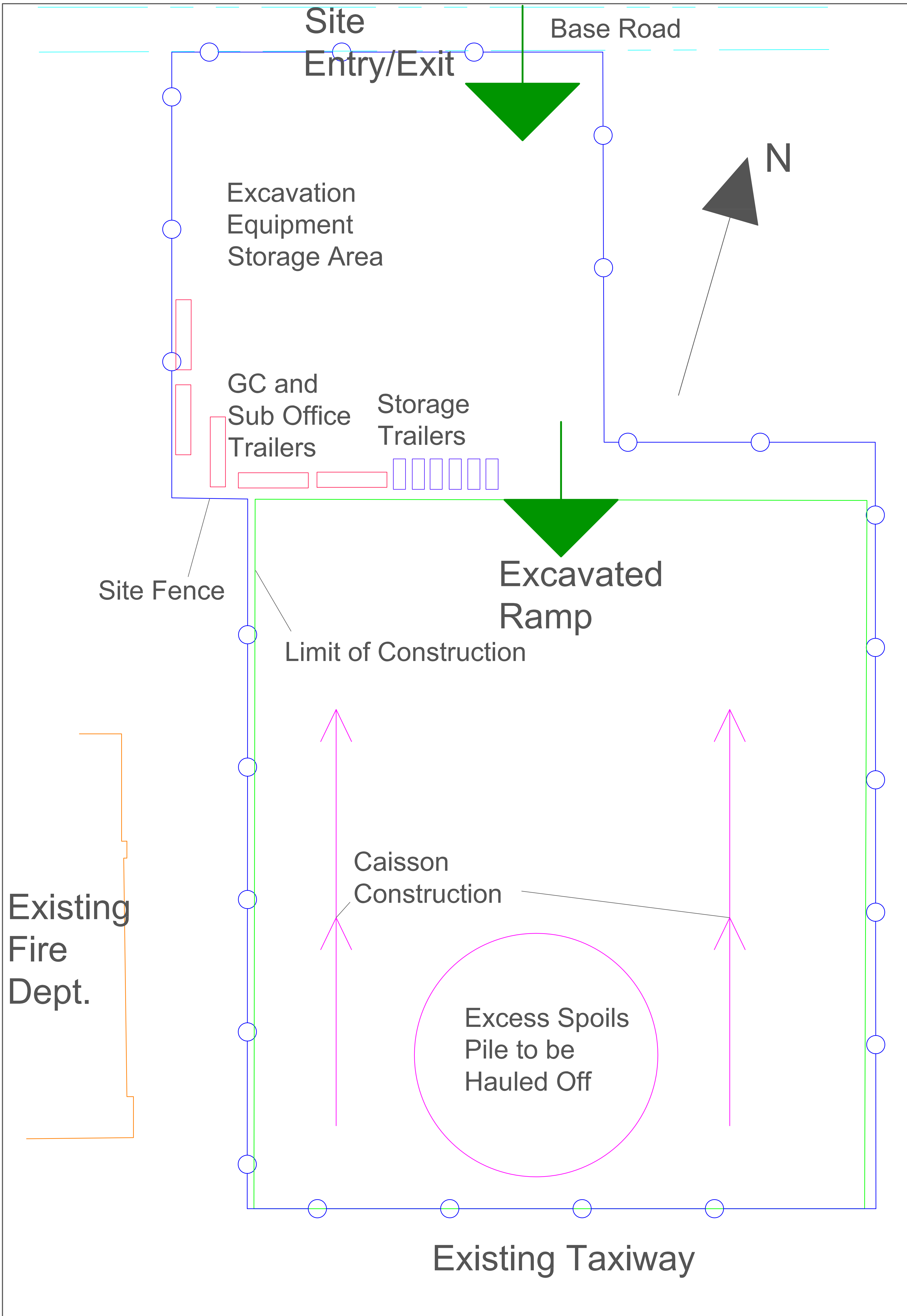
Site Layout Plan

NTS

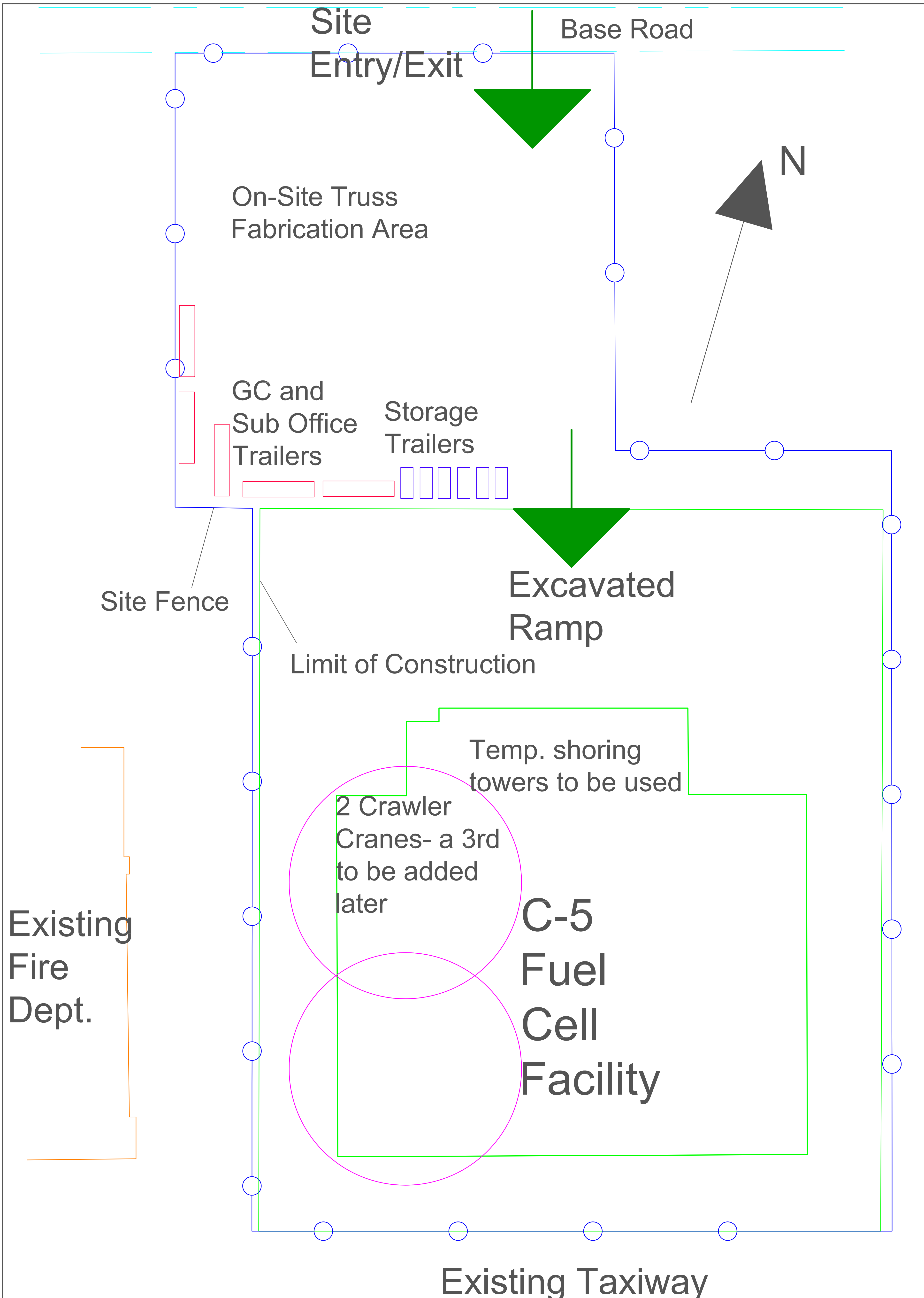
Appendix B

C-5 Fuel Cell Facility

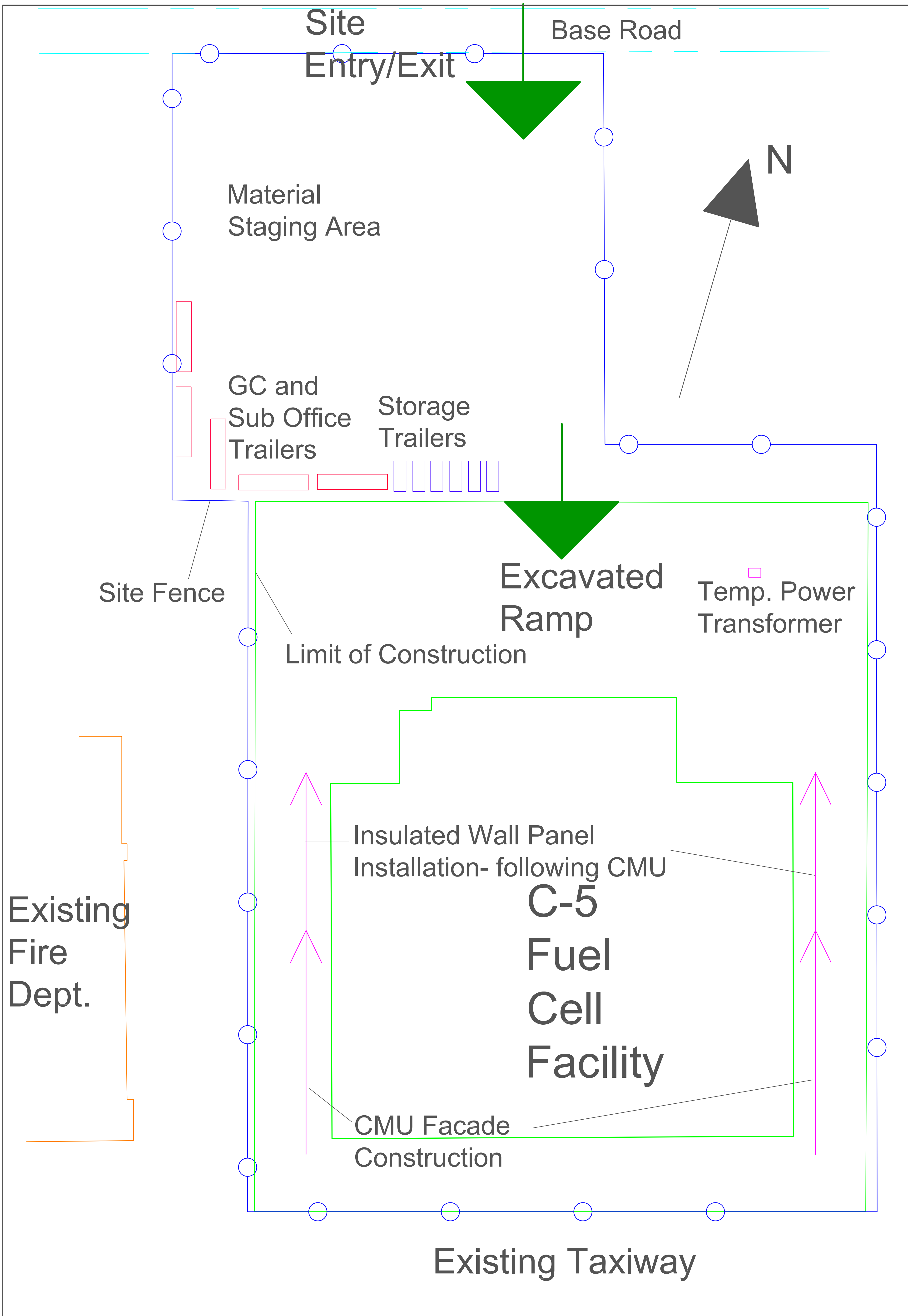
Site Layout Plans



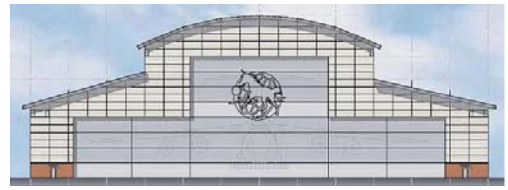
C-5 Fuel Cell Facility Martinsburg, WV Kyle Goodyear Construction Management	Excavation and Foundation Site Layout Plan 1"=60' October 25, 2009



C-5 Fuel Cell Facility Martinsburg, WV Kyle Goodyear Construction Management	Steel Erection Site Layout Plan 1"=60' October 25, 2009



C-5 Fuel Cell Facility Martinsburg, WV Kyle Goodyear Construction Management	Building Enclosure Layout Plan 1"=60' October 25, 2009

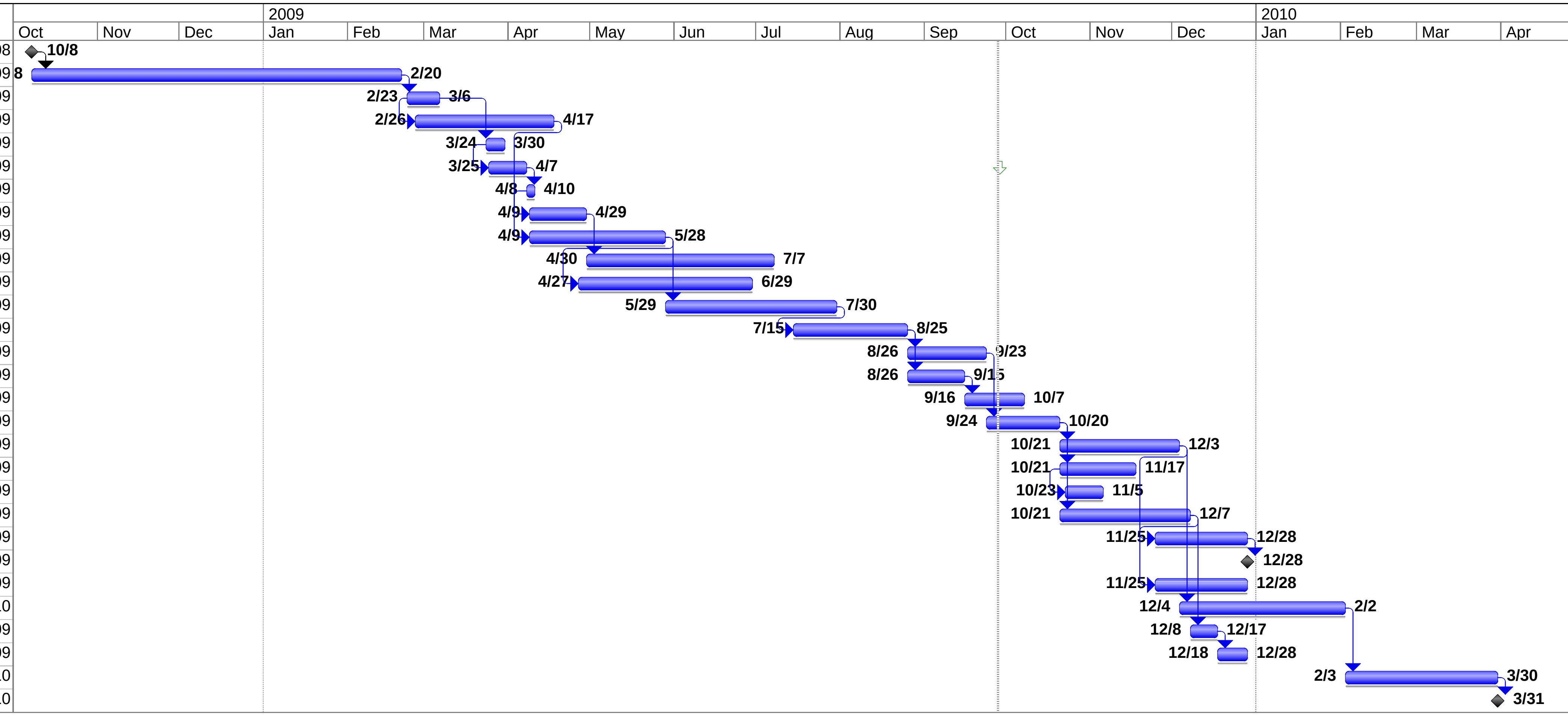


Appendix C

C-5 Fuel Cell Facility

Project Schedules

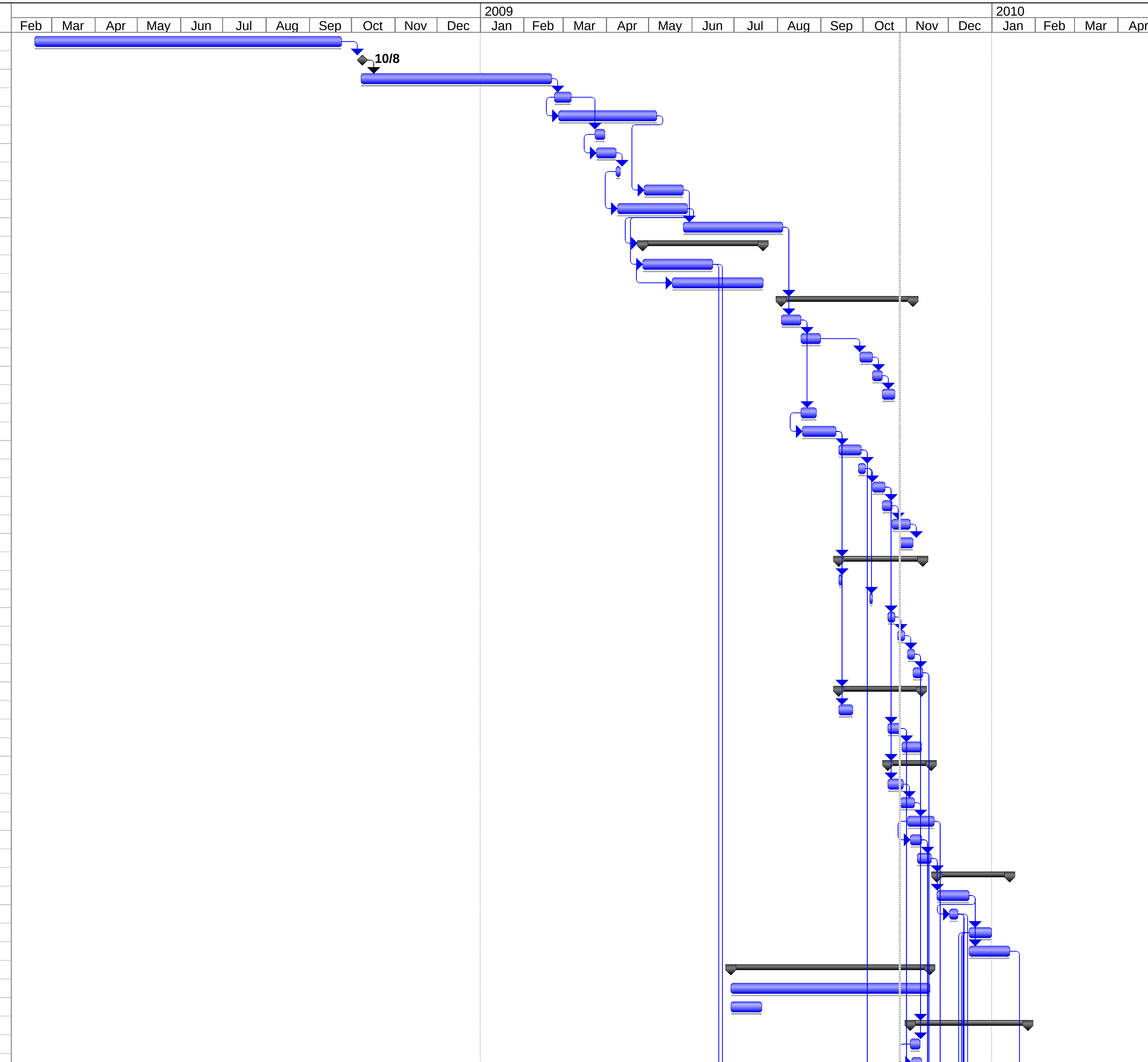
ID	Task Name	Duration	Start	Finish
1	Notice to Proceed	0 days	Wed 10/8/08	Wed 10/8/08
2	Design Phase	98 days	Wed 10/8/08	Fri 2/20/09
3	100% Design Document Review	10 days	Mon 2/23/09	Fri 3/6/09
4	Structural Shop Drawings	37 days	Thu 2/26/09	Fri 4/17/09
5	Office Mobilization	5 days	Tue 3/24/09	Mon 3/30/09
6	Issue Construction Documents	10 days	Wed 3/25/09	Tue 4/7/09
7	Initial Layout and Stakeout	3 days	Wed 4/8/09	Fri 4/10/09
8	Approve Structural Shop Dwgs	15 days	Thu 4/9/09	Wed 4/29/09
9	Site-Stormwater and Grading for Bldg	36 days	Thu 4/9/09	Thu 5/28/09
10	Fabricate Structural Steel and Joists	49 days	Thu 4/30/09	Tue 7/7/09
11	Construct Foundations	46 days	Mon 4/27/09	Mon 6/29/09
12	Underground Utilities	45 days	Fri 5/29/09	Thu 7/30/09
13	Steel Erection	30 days	Wed 7/15/09	Tue 8/25/09
14	Construct Roof	21 days	Wed 8/26/09	Wed 9/23/09
15	Masonry Walls	15 days	Wed 8/26/09	Tue 9/15/09
16	Install Insulated Metal Panels	16 days	Wed 9/16/09	Wed 10/7/09
17	Floor Slab	19 days	Thu 9/24/09	Tue 10/20/09
18	MEP Rough-In Overhead	32 days	Wed 10/21/09	Thu 12/3/09
19	Construct Interior Partition Walls	20 days	Wed 10/21/09	Tue 11/17/09
20	MEP Rough-In in Walls	10 days	Fri 10/23/09	Thu 11/5/09
21	Site Asphalt and Concrete	34 days	Wed 10/21/09	Mon 12/7/09
22	Install Hangar Door	24 days	Wed 11/25/09	Mon 12/28/09
23	Building Enclosed	0 days	Mon 12/28/09	Mon 12/28/09
24	Complete MEP Systems	24 days	Wed 11/25/09	Mon 12/28/09
25	Fire Alarm and Security System	43 days	Fri 12/4/09	Tue 2/2/10
26	Complete Sevice Road- Wearing and Paint	8 days	Tue 12/8/09	Thu 12/17/09
27	Landscaping	7 days	Fri 12/18/09	Mon 12/28/09
28	Testing and Commissioning	40 days	Wed 2/3/10	Tue 3/30/10
29	Project Complete	0 days	Wed 3/31/10	Wed 3/31/10



Project: C-5 Summary Schedule.mpp
Date: Mon 9/28/09

Task | Progress | Milestone | Summary | Rolled Up Task | Rolled Up Milestone | Rolled Up Progress | Split | External Tasks | Project Summary | Group By Summary | Deadline

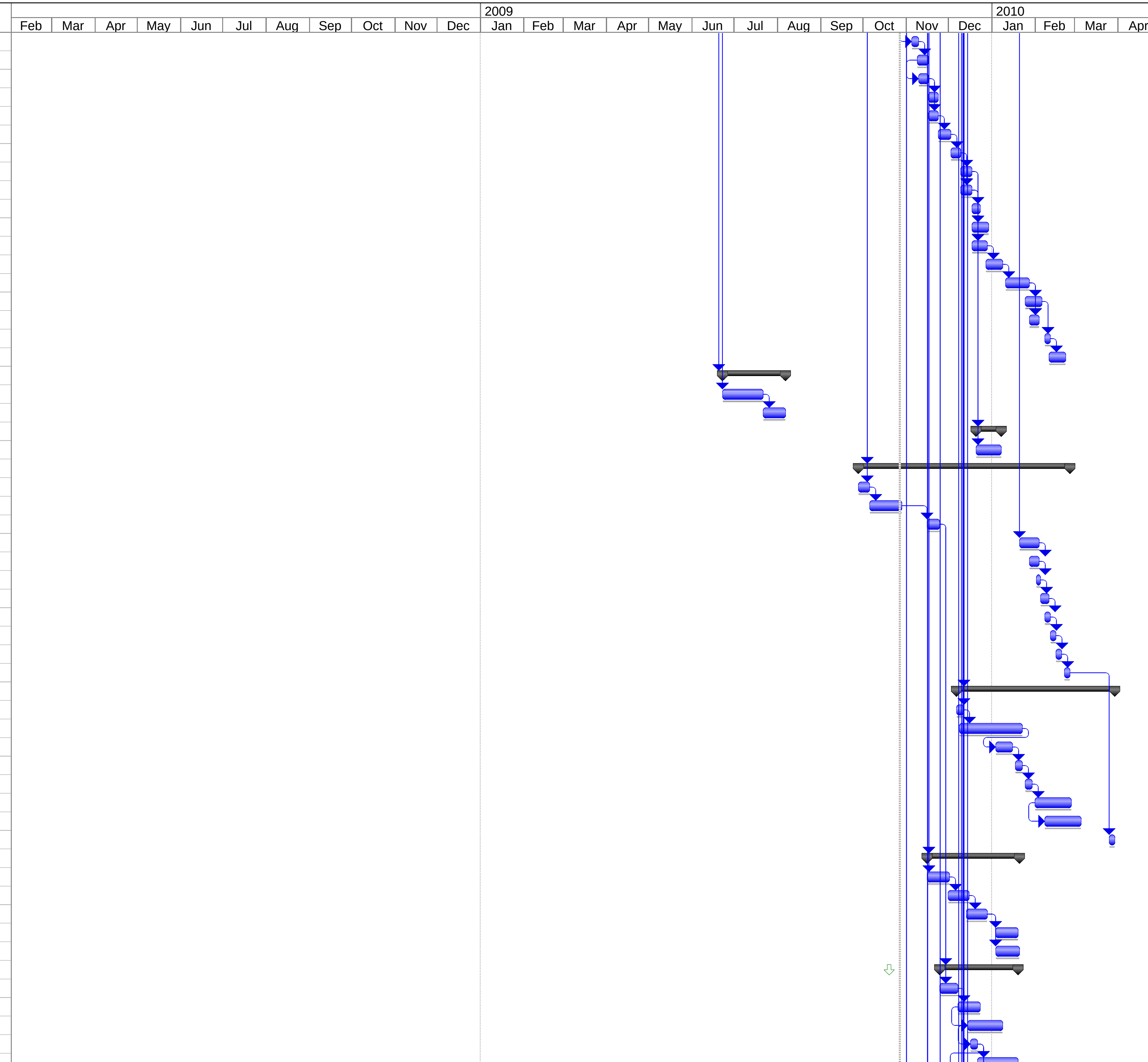
ID	Task Name	Duration	Start	Finish	Predecessors
1	Bidding/Selection Period	157 days	Mon 2/18/08	Tue 9/23/08	
2	**Notice to Proceed**	**0 days**	**Wed 10/8/08**	**Wed 10/8/08**	**1FS+11 days**
3	Design Phase	98 days	Wed 10/8/08	Fri 2/20/09	2FS-1 day
4	100% Design Document Review	10 days	Mon 2/23/09	Fri 3/6/09	3
5	Structural Shop Drawings	50 days	Thu 2/26/09	Wed 5/6/09	4SS+3 days
6	Office Mobilization	5 days	Tue 3/24/09	Mon 3/30/09	4FS+11 days
7	Issue Construction Documents	10 days	Wed 3/25/09	Tue 4/7/09	6SS+1 day
8	Initial Layout and Stakeout	3 days	Wed 4/8/09	Fri 4/10/09	7
9	Structural Shop Dwg Approval	20 days	Tue 4/28/09	Mon 5/25/09	5FS-7 days
10	Site- Stormwater and Grading for Bldg	36 days	Thu 4/9/09	Thu 5/28/09	8SS+1 day
11	Structural Steel Fabrication	51 days	Tue 5/26/09	Tue 8/4/09	9
12	**Foundation Construction**	**62 days**	**Mon 4/27/09**	**Tue 7/21/09**	**10FS-24 days**
13	Caisson Construction	36 days	Mon 4/27/09	Mon 6/15/09	10FS-24 days
14	Pier Caps & Grade Beams	47 days	Mon 5/18/09	Tue 7/21/09	13SS+15 days
15	**Steel Erection & Detailing**	**68 days**	**Tue 8/4/09**	**Thu 11/5/09**	**11FS-1 day**
16	Build Trusses on Site- Seq 1A, 1B	10 days	Tue 8/4/09	Mon 8/17/09	11FS-1 day
17	Build Trusses on Site- Seq 2A, 2B	10 days	Tue 8/18/09	Mon 8/31/09	16
18	Build Trusses on Site- Seq 3A	7 days	Tue 9/29/09	Wed 10/7/09	17FS+20 days
19	Build Trusses on Site- Seq 3B	5 days	Thu 10/8/09	Wed 10/14/09	18
20	Build Trusses on Site- Seq 3C	7 days	Thu 10/15/09	Fri 10/23/09	19
21	Erect & Detail- Seq 1A	9 days	Tue 8/18/09	Fri 8/28/09	16
22	Erect & Detail- Seq 1B	18 days	Wed 8/19/09	Fri 9/11/09	21SS+1 day
23	Erect & Detail- Seq 2A	12 days	Mon 9/14/09	Tue 9/29/09	22
24	Erect & Detail- Seq 2B	5 days	Mon 9/28/09	Fri 10/2/09	23FS-2 days
25	Erect & Detail- Seq 3A	7 days	Thu 10/8/09	Fri 10/16/09	24FS+3 days
26	Erect & Detail- Seq 3B	5 days	Thu 10/15/09	Wed 10/21/09	25FS-2 days
27	Erect & Detail- Seq 2C	9 days	Thu 10/22/09	Tue 11/3/09	26
28	Erect & Detail- Seq 3C	8 days	Tue 10/27/09	Thu 11/5/09	27FS-6 days
29	**Roof Deck Installation**	**44 days**	**Mon 9/14/09**	**Thu 11/12/09**	**22**
30	Roof Deck- Seq 1A, 1B	2 days	Mon 9/14/09	Tue 9/15/09	22
31	Roof Deck- Seq 2A, 2B	2 days	Tue 10/6/09	Wed 10/7/09	24FS+1 day
32	Roof Deck- Seq 3A	5 days	Mon 10/19/09	Fri 10/23/09	25
33	Roof Deck- Seq 3B	5 days	Mon 10/26/09	Fri 10/30/09	32
34	Roof Deck- Seq 2C	5 days	Mon 11/2/09	Fri 11/6/09	33
35	Roof Deck- Seq 3C	5 days	Fri 11/6/09	Thu 11/12/09	34FS-1 day
36	**Masonry Wall**	**43 days**	**Mon 9/14/09**	**Wed 11/11/09**	**22**
37	Masonry 1A, 1B	8 days	Mon 9/14/09	Wed 9/23/09	22
38	Masonry 2A, 2B	7 days	Mon 10/19/09	Tue 10/27/09	25
39	Masonry Walls Admin Area	10 days	Thu 10/29/09	Wed 11/11/09	38FS+1 day
40	**Insulated Wall Panels**	**23 days**	**Mon 10/19/09**	**Wed 11/18/09**	**25**
41	Wall Panels 1A, 1B	9 days	Mon 10/19/09	Thu 10/29/09	25
42	Wall Panels 2A, 2B	8 days	Wed 10/28/09	Fri 11/6/09	41FS-2 days
43	Clerestory Siding	15 days	Mon 11/2/09	Fri 11/20/09	42FS-5 days
44	Wall Panels South Elev	6 days	Wed 11/4/09	Wed 11/11/09	43SS+2 days
45	Wall Panels North Elev	8 days	Mon 11/9/09	Wed 11/18/09	44FS-3 days
46	**Metal Roof Panel Installation**	**38 days**	**Mon 11/23/09**	**Wed 1/13/10**	**45FS+2 days**
47	High Roof Panels	17 days	Mon 11/23/09	Tue 12/15/09	45FS+2 days
48	Admin Area Roof Panels	4 days	Wed 12/2/09	Mon 12/7/09	47FS-10 days
49	Low Roof Panels	12 days	Wed 12/16/09	Thu 12/31/09	47
50	Gutters & Downspouts	21 days	Wed 12/16/09	Wed 1/13/10	47
51	**Major Equipment & Systems Fabrication**	**102 days**	**Mon 6/29/09**	**Tue 11/17/09**	
52	Megadoor Fabrication & Delivery	102 days	Mon 6/29/09	Tue 11/17/09	
53	Oil/Water Separator	16 days	Mon 6/29/09	Mon 7/20/09	
54	**Sitework**	**60 days**	**Wed 11/4/09**	**Tue 1/26/10**	**34FS-3 days**
55	Install Fire Hydrants	5 days	Wed 11/4/09	Tue 11/10/09	34FS-3 days
56	Install Sanitary Sewer	5 days	Thu 11/5/09	Wed 11/11/09	55SS+1 day



Project: Detailed Project Schedule.mp
Date: Tue 10/27/09

Task		Progress		Summary		External Tasks		Deadline	
Split		Milestone		Project Summary		External Milestone			

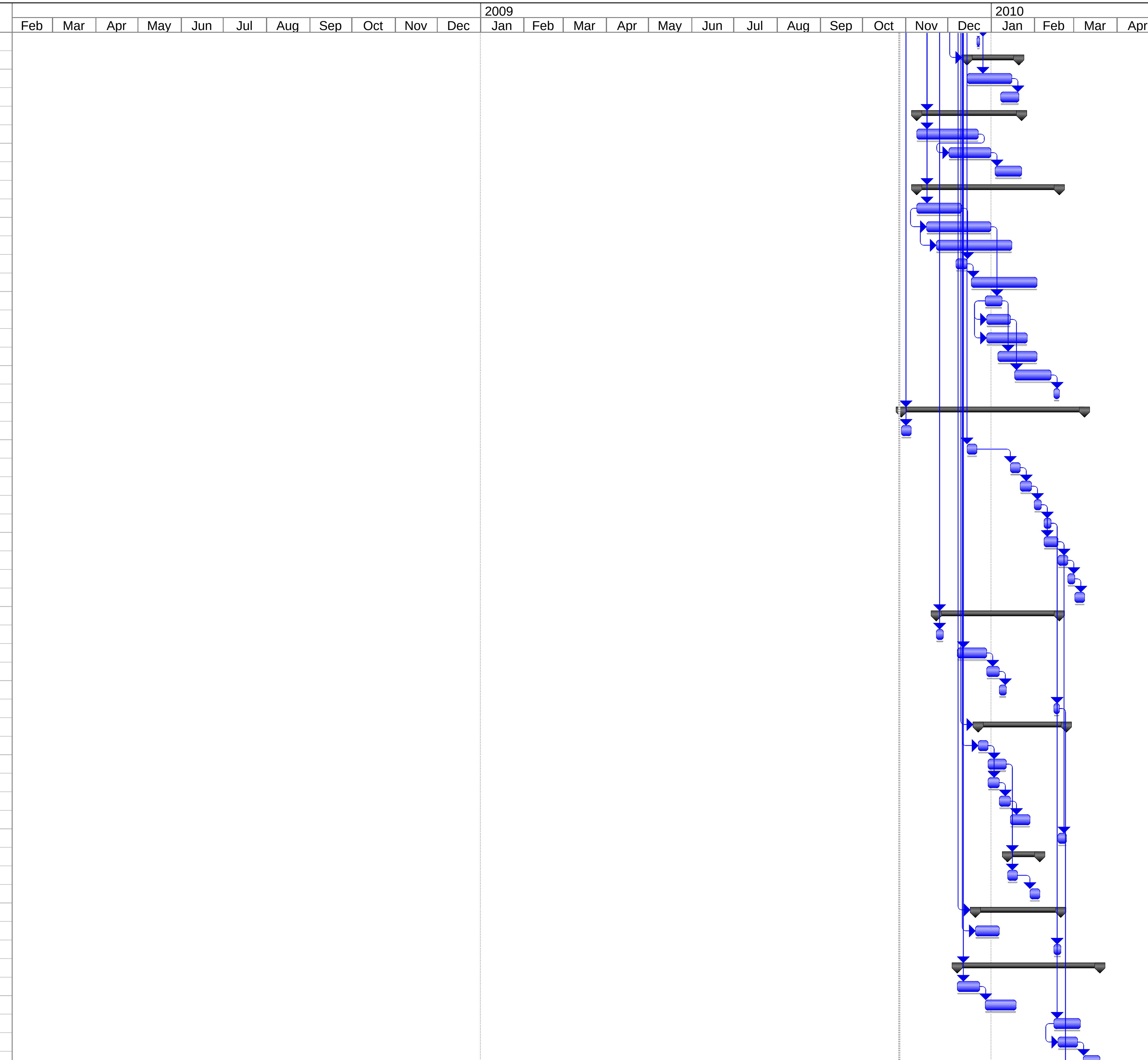
ID	Task Name	Duration	Start	Finish	Predecessors
57	Apron Subdrain	3 days	Thu 11/5/09	Mon 11/9/09	55SS+1 day
58	Oil/Water Separator	6 days	Mon 11/9/09	Mon 11/16/09	57FS-1 day
59	Grade/Stone Base for Apron	5 days	Tue 11/10/09	Mon 11/16/09	58SS+1 day
60	Domestic Water Installation	5 days	Tue 11/17/09	Mon 11/23/09	59
61	Prep/Pour Apron	5 days	Tue 11/17/09	Mon 11/23/09	59
62	Install HEF Line	7 days	Tue 11/24/09	Wed 12/2/09	61
63	Install Gas Line	5 days	Thu 12/3/09	Wed 12/9/09	62
64	Electrical Ductbank & Transformer	6 days	Thu 12/10/09	Thu 12/17/09	63
65	Install Storm Drain	6 days	Thu 12/10/09	Thu 12/17/09	63
66	Communication Ductbank	4 days	Fri 12/18/09	Wed 12/23/09	65
67	Install Roof Leader Pipe	8 days	Fri 12/18/09	Tue 12/29/09	65
68	Drainage Swales	7 days	Fri 12/18/09	Mon 12/28/09	65
69	Site Lighting	10 days	Mon 12/28/09	Fri 1/8/10	68FS-1 day
70	Final Site Grading & Topsoil	13 days	Mon 1/11/10	Wed 1/27/10	69
71	Asphalt Base & Binder	10 days	Mon 1/25/10	Fri 2/5/10	70FS-3 days
72	Install Perimeter Fence	5 days	Thu 1/28/10	Wed 2/3/10	70
73	Asphalt Wearing	4 days	Mon 2/8/10	Thu 2/11/10	71
74	Landscaping	8 days	Thu 2/11/10	Mon 2/22/10	73FS-1 day
75	**Underground Mechanical**	**33 days**	**Tue 6/23/09**	**Thu 8/6/09**	**13FS+5 days**
76	Underground Sanitary Hanger	21 days	Tue 6/23/09	Tue 7/21/09	13FS+5 days
77	Underground Plumbing	12 days	Wed 7/22/09	Thu 8/6/09	76
78	**Underground Electrical**	**14 days**	**Mon 12/21/09**	**Thu 1/7/10**	**64FS+1 day**
79	Electrical Grounding in SOG	14 days	Mon 12/21/09	Thu 1/7/10	64FS+1 day
80	**Slab on Grade**	**109 days**	**Mon 9/28/09**	**Thu 2/25/10**	**23FS-2 days**
81	Stone Base Admin Area SOG	6 days	Mon 9/28/09	Mon 10/5/09	23FS-2 days
82	Prep/Pour Admin Area SOG	17 days	Tue 10/6/09	Wed 10/28/09	81
83	Form/Pour B-Line Trench Drain	7 days	Mon 11/16/09	Tue 11/24/09	82FS+12 days
84	Stone Base Hangar SOG	10 days	Thu 1/21/10	Wed 2/3/10	50FS+5 days
85	Form/Pour H-Line Trench Drain	5 days	Thu 1/28/10	Wed 2/3/10	84FS-5 days
86	Prep/Pour Jacking Points- Part 1	3 days	Tue 2/2/10	Thu 2/4/10	85FS-2 days
87	Prep/Pour SOG#1	4 days	Fri 2/5/10	Wed 2/10/10	86
88	Prep/Pour SOG #2	4 days	Mon 2/8/10	Thu 2/11/10	87FS-3 days
89	Prep/Pour SOG #3 (Jacking Points Part 2)	2 days	Fri 2/12/10	Mon 2/15/10	88
90	Prep/Pour SOG #4	4 days	Tue 2/16/10	Fri 2/19/10	89
91	Prep/Pour SOG #5	4 days	Mon 2/22/10	Thu 2/25/10	90
92	**Building Finishes- Hangar**	**81 days**	**Mon 12/7/09**	**Mon 3/29/10**	**48FS-1 day**
93	Overhead Doors	5 days	Mon 12/7/09	Fri 12/11/09	48FS-1 day
94	MegaDoor Installation	33 days	Wed 12/9/09	Fri 1/22/10	93FS-3 days
95	GWB/Plywood Roof Sheathing	10 days	Mon 1/4/10	Fri 1/15/10	94FS-15 days
96	Paint GWB/CMU	5 days	Mon 1/18/10	Fri 1/22/10	95
97	Misc. Metals	5 days	Mon 1/25/10	Fri 1/29/10	96
98	Paint Structure	20 days	Mon 2/1/10	Fri 2/26/10	97
99	Paint Pipe Systems	20 days	Mon 2/8/10	Fri 3/5/10	98SS+5 days
100	Hangar Floor Striping	2 days	Fri 3/26/10	Mon 3/29/10	91FS+20 days
101	**Mechanical- Hangar**	**48 days**	**Mon 11/16/09**	**Wed 1/20/10**	**35FS+1 day**
102	Spiral Duct	12 days	Mon 11/16/09	Tue 12/1/09	35FS+1 day
103	Louvers	11 days	Tue 12/1/09	Tue 12/15/09	102FS-1 day
104	Exhaust Fans	11 days	Mon 12/14/09	Mon 12/28/09	103FS-2 days
105	Exhaust System	12 days	Mon 1/4/10	Tue 1/19/10	104FS+4 days
106	Ductwork	13 days	Mon 1/4/10	Wed 1/20/10	104FS+4 days
107	**Plumbing- Hangar**	**40 days**	**Wed 11/25/09**	**Tue 1/19/10**	**83**
108	Trench Exhaust	9 days	Wed 11/25/09	Mon 12/7/09	83
109	Compressed Air Lines	12 days	Tue 12/8/09	Wed 12/23/09	108
110	Breathable Air	19 days	Tue 12/15/09	Fri 1/8/10	109SS+5 days
111	Vent Risers	3 days	Thu 12/17/09	Mon 12/21/09	110SS+2 days
112	Domestic Water Piping	21 days	Tue 12/22/09	Tue 1/19/10	111



Project: Detailed Project Schedule.mp
Date: Tue 10/27/09

Task | Progress | Summary | External Tasks | Deadline
Split | Milestone | Project Summary | External Milestone

ID	Task Name	Duration	Start	Finish	Predecessors
113	Hose Reels	2 days	Tue 12/22/09	Wed 12/23/09	111
114	**Heating- Hangar**	**27 days**	**Tue 12/15/09**	**Wed 1/20/10**	**111FS-5 days**
115	Infrared Heater Piping	24 days	Tue 12/15/09	Fri 1/15/10	111FS-5 days
116	Infrared Heaters	9 days	Fri 1/8/10	Wed 1/20/10	115FS-6 days
117	**Fire Protection- Hangar**	**55 days**	**Mon 11/9/09**	**Fri 1/22/10**	**44FS-3 days**
118	Wet Sprinkler System	32 days	Mon 11/9/09	Tue 12/22/09	44FS-3 days
119	HEF System Piping	22 days	Wed 12/2/09	Thu 12/31/09	118FS-15 days
120	Install Foam Generators	15 days	Mon 1/4/10	Fri 1/22/10	119FS+1 day
121	**Electrical- Hangar**	**74 days**	**Mon 11/9/09**	**Thu 2/18/10**	**44FS-3 days**
122	Megadoor Power	24 days	Mon 11/9/09	Thu 12/10/09	44FS-3 days
123	HEF and Fire Alarm System	34 days	Mon 11/16/09	Thu 12/31/09	122SS+5 days
124	Lighting & Emergency Lighting	40 days	Mon 11/23/09	Fri 1/15/10	123SS+5 days
125	Wire Overhead Doors	6 days	Mon 12/7/09	Mon 12/14/09	122FS-4 days
126	Electric Cable	33 days	Fri 12/18/09	Tue 2/2/10	125FS+3 days
127	Wire HVAC Hose Reels	10 days	Mon 12/28/09	Fri 1/8/10	123FS-4 days
128	Wire HVAC Purge System	13 days	Tue 12/29/09	Thu 1/14/10	127SS+1 day
129	HVAC Equipment Wiring	21 days	Tue 12/29/09	Tue 1/26/10	127SS+1 day
130	Motorized Hose & Cable Reels	20 days	Wed 1/6/10	Tue 2/2/10	127FS-3 days
131	Cable Trays & Telecomm Wiring	20 days	Mon 1/18/10	Fri 2/12/10	128FS+1 day
132	Switches, Plugs, etc.	4 days	Mon 2/15/10	Thu 2/18/10	131
133	**Building Finishes- Admin Area**	**93 days**	**Thu 10/29/09**	**Mon 3/8/10**	**38FS+1 day**
134	HM Frames	5 days	Thu 10/29/09	Wed 11/4/09	38FS+1 day
135	Aluminum Frames/Glass	5 days	Tue 12/15/09	Mon 12/21/09	48FS+5 days
136	Aluminum Storefront	5 days	Fri 1/15/10	Thu 1/21/10	135FS+18 days
137	GWB Ceilings	6 days	Fri 1/22/10	Fri 1/29/10	136
138	Paint CMU Walls/GWB Ceilings	5 days	Mon 2/1/10	Fri 2/5/10	137
139	Acoustical Grid	5 days	Mon 2/8/10	Fri 2/12/10	138
140	Ceramic Tile	8 days	Mon 2/8/10	Wed 2/17/10	138
141	Lockers	5 days	Thu 2/18/10	Wed 2/24/10	140
142	Toilet Partitions/Specialties	3 days	Thu 2/25/10	Mon 3/1/10	141
143	Doors & Hardware	5 days	Tue 3/2/10	Mon 3/8/10	142
144	**Mechanical- Admin Area**	**64 days**	**Mon 11/23/09**	**Thu 2/18/10**	**43**
145	Louvers	5 days	Mon 11/23/09	Fri 11/27/09	43
146	Ductwork	15 days	Tue 12/8/09	Mon 12/28/09	48
147	Exhaust System	7 days	Tue 12/29/09	Wed 1/6/10	146
148	Exhaust Fans	3 days	Thu 1/7/10	Mon 1/11/10	147
149	Registers/Grilles/Diffusers	4 days	Mon 2/15/10	Thu 2/18/10	139
150	**Plumbing- Admin Area**	**45 days**	**Wed 12/23/09**	**Tue 2/23/10**	**49SS+5 days**
151	Vent Risers	5 days	Wed 12/23/09	Tue 12/29/09	49SS+5 days
152	Domestic Water Piping	9 days	Wed 12/30/09	Mon 1/11/10	151
153	Gas Lines	6 days	Wed 12/30/09	Wed 1/6/10	151
154	Compressed Air Lines	6 days	Thu 1/7/10	Thu 1/14/10	153
155	Pipe Insulation	10 days	Fri 1/15/10	Thu 1/28/10	154
156	Plumbing Fixtures	4 days	Thu 2/18/10	Tue 2/23/10	140
157	**Heating- Admin Area**	**17 days**	**Wed 1/13/10**	**Thu 2/4/10**	**152FS+1 day**
158	Heat Piping	5 days	Wed 1/13/10	Tue 1/19/10	152FS+1 day
159	Pipe Insulation	5 days	Fri 1/29/10	Thu 2/4/10	158FS+7 days
160	**Fire Protection- Admin Area**	**45 days**	**Mon 12/21/09**	**Fri 2/19/10**	**49SS+3 days**
161	Sprinkler Piping	13 days	Mon 12/21/09	Wed 1/6/10	49SS+3 days
162	Sprinkler Heads	5 days	Mon 2/15/10	Fri 2/19/10	139
163	**Electrical- Admin Area**	**74 days**	**Tue 12/8/09**	**Fri 3/19/10**	**48**
164	Conduit Rough-In	12 days	Tue 12/8/09	Wed 12/23/09	48
165	Cable- Conductors	16 days	Mon 12/28/09	Mon 1/18/10	164FS+2 days
166	Lighting & Emergency Lighting	15 days	Mon 2/15/10	Fri 3/5/10	139
167	Lavatory Low Voltage Control	10 days	Thu 2/18/10	Wed 3/3/10	166SS+3 days
168	Switches & Plugs	10 days	Mon 3/8/10	Fri 3/19/10	167FS+2 days

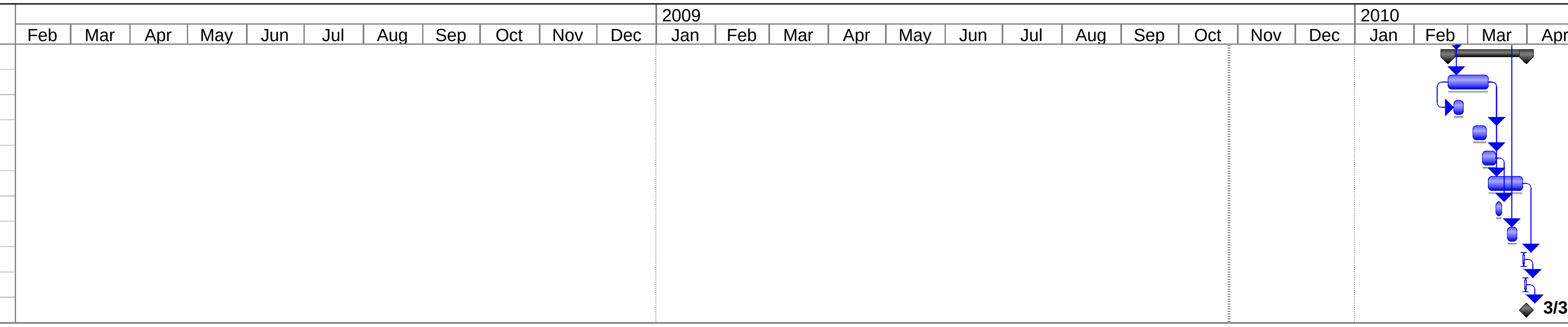


Project: Detailed Project Schedule.mp
Date: Tue 10/27/09

Task		Progress		Summary		External Tasks	
Split		Milestone	◆	Project Summary		External Milestone	◆

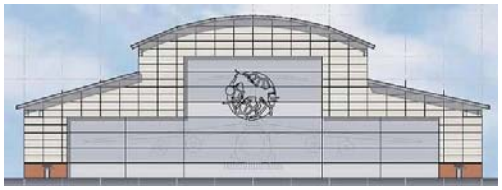
Deadline ⇩

ID	Task Name	Duration	Start	Finish	Predecessors
169	**Testing & Close-out**	**29 days**	**Fri 2/19/10**	**Wed 3/31/10**	**149**
170	Test, Adjust, & Balance	15 days	Fri 2/19/10	Thu 3/11/10	149
171	Sprinkler System Testing	5 days	Mon 2/22/10	Fri 2/26/10	170SS+1 day
172	Plumbing Testing	5 days	Thu 3/4/10	Wed 3/10/10	170FS-6 days
173	HEF System Testing	5 days	Tue 3/9/10	Mon 3/15/10	170FS-3 days
174	PVT- HVAC	12 days	Fri 3/12/10	Mon 3/29/10	170
175	Fire Alarm Testing	3 days	Tue 3/16/10	Thu 3/18/10	173
176	Electrical Systems Testing	5 days	Mon 3/22/10	Fri 3/26/10	168
177	Final Inspection	1 day	Tue 3/30/10	Tue 3/30/10	174
178	Building Acceptance/Occupancy	1 day	Wed 3/31/10	Wed 3/31/10	177
179	**Project Complete**	**0 days**	**Wed 3/31/10**	**Wed 3/31/10**	**178**



Project: Detailed Project Schedule.mp
Date: Tue 10/27/09

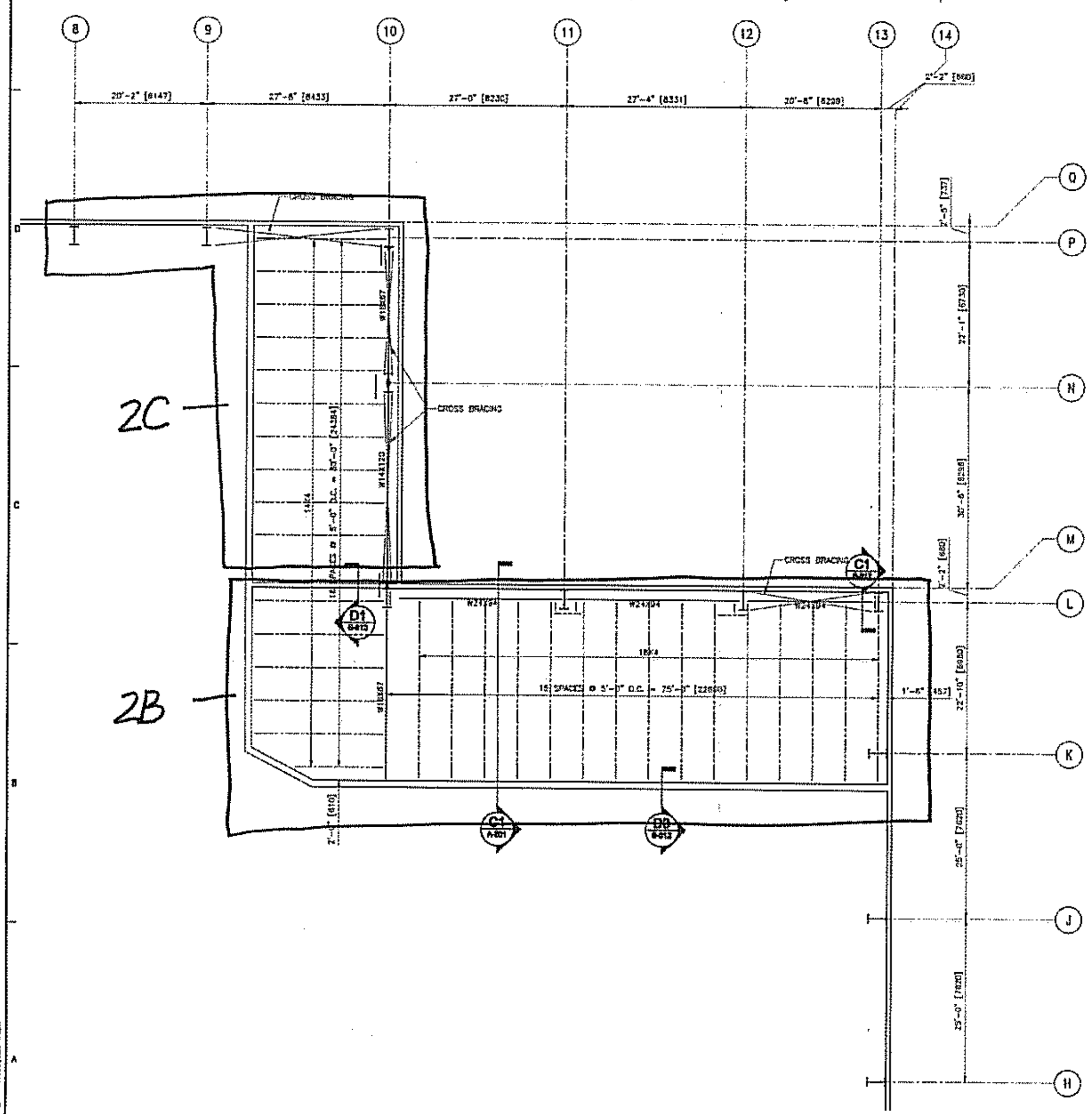
Task | Split | Progress | Milestone | Summary | Project Summary | External Tasks | External Milestone | Deadline



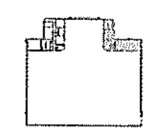
Appendix D

C-5 Fuel Cell Facility

Steel Erection Sequencing



A3 ENLARGED LOWER ROOF FRAMING PLAN
SCALE: 1/8" = 1'-0"



A KEY PLAN
NO SCALE

REVISIONS:

MARK	DATE	DESCRIPTION
-	12/31/08	ISSUED FOR 95% COMPLETED
-	11/05/08	ISSUED FOR 35% COMPLETE DD

C-5 FUEL CELL FACILITY
167th AIRLIFT WING
Project No. PJVY000074
Contract No. W912L8-08-C-0015
MARTINSBURG, WEST VIRGINIA
BERKELEY COUNTY
WEST VIRGINIA

KINSLEY CONSTRUCTION
2700 WATER STREET
YORK, PA 17403
PHONE: 717-741-3841

lscdesign
architects engineers
1111 EAST PRINCESS STREET
YORK, PA 17403
PHONE: 717-845-6383

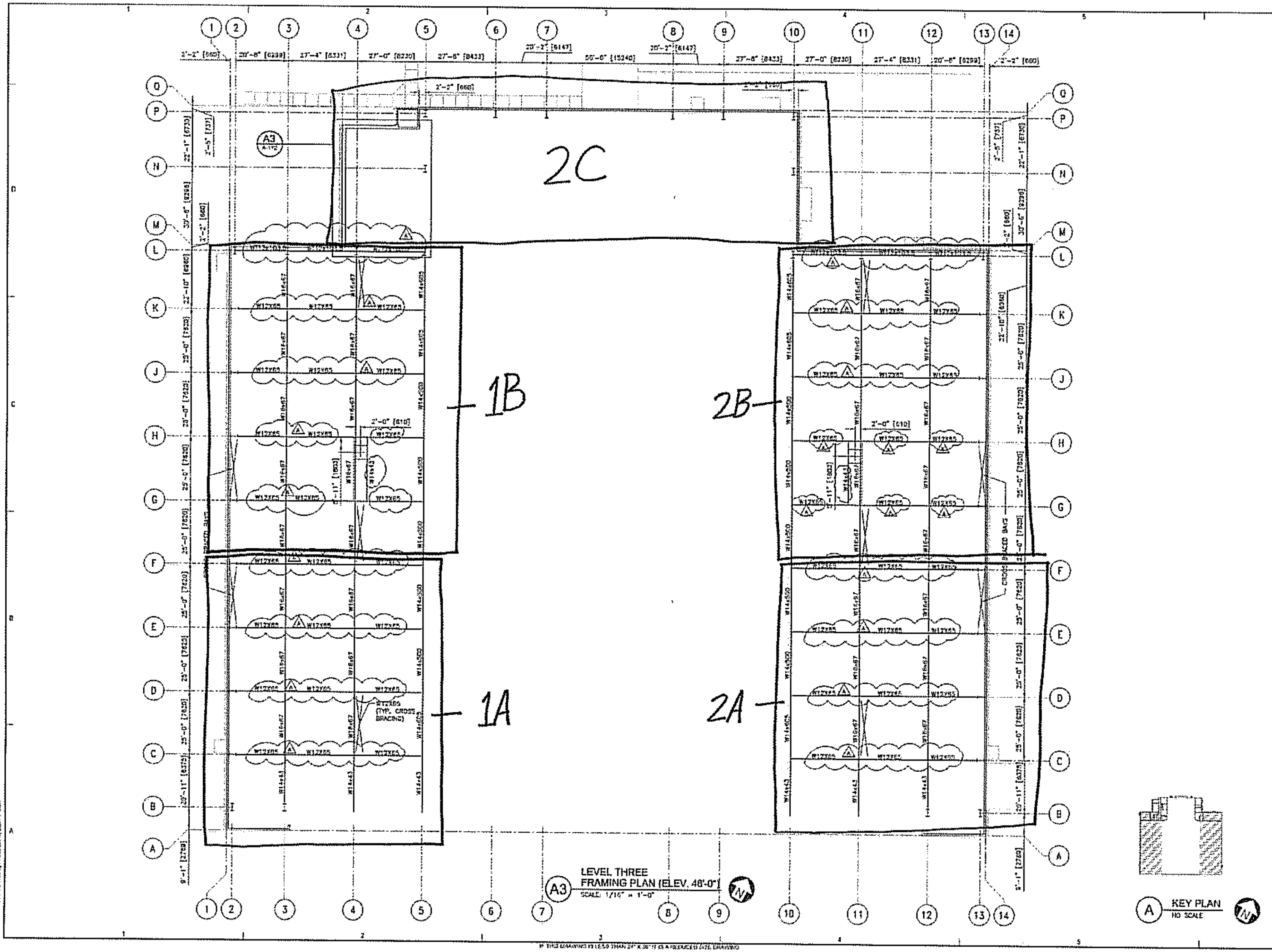
PRELIMINARY SUBMITTAL
NOT FOR CONSTRUCTION OR PERMIT

TranSystems
220 ST. CHARLES WAY
SUITE 100
YORK, PA 17402
PHONE: 717.854.3861
FAX: 717.843.7256

SCALE: AS NOTED
DATE: 11/05/08
DESIGNED BY: TWK
DRAWN BY: EMK
CHECKED BY:

SHEET TITLE:
ENLARGED LEVEL TWO FRAMING PLAN 'B'

SHEET NO.
S112



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KINSLEY CONSTRUCTION

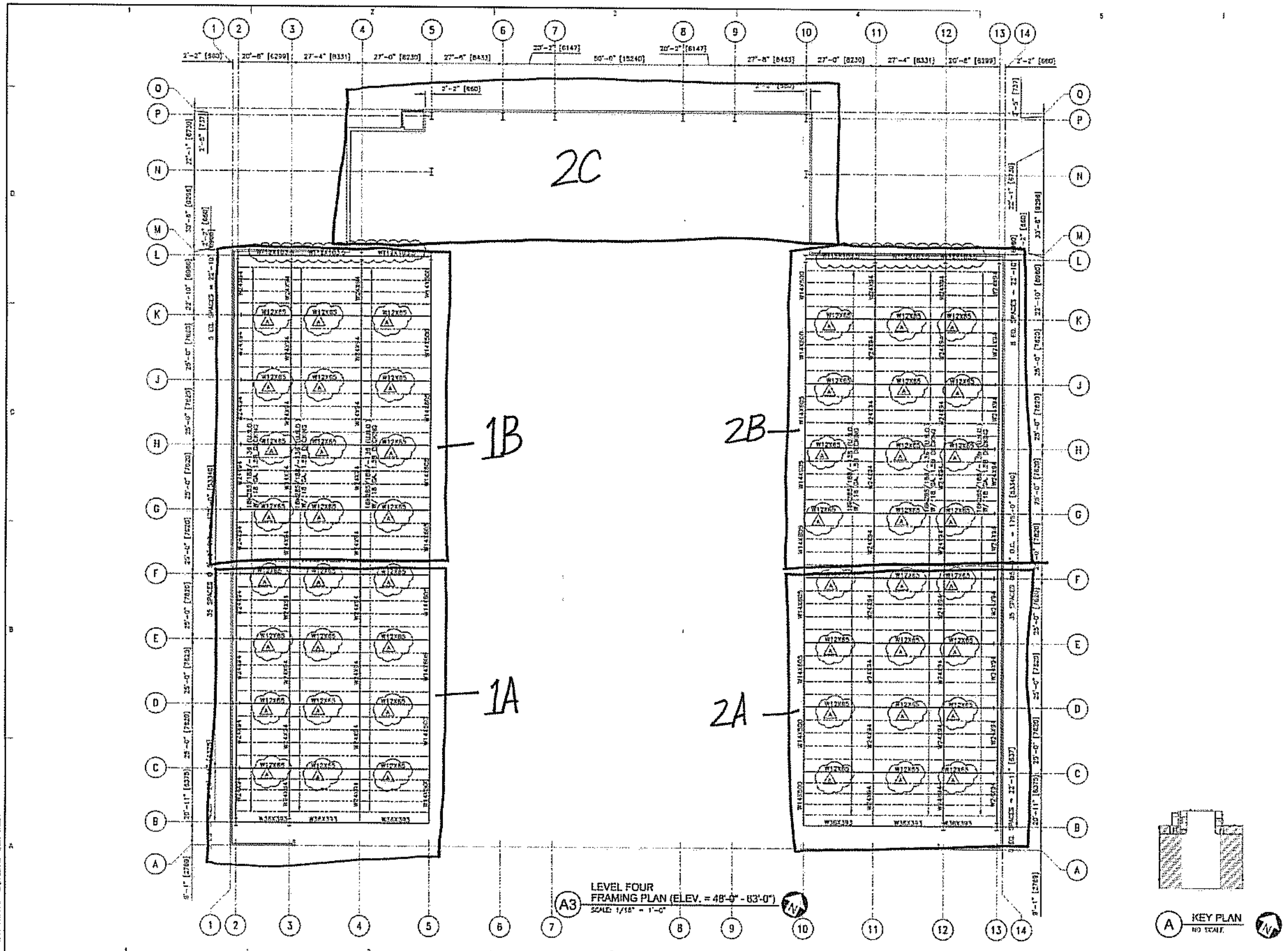
TranSystems

C-5 FUEL CELL FACILITY
167th AIRLIFT WING
MARTINSBURG, WEST VIRGINIA
BERKELEY COUNTY
WEST VIRGINIA

REVISIONS

SHEET TITLE:
LEVEL THREE FRAMING PLAN

SHEET NO
S113



TranSystems
220 ST. CHARLES WAY
SUITE 150
YORK, PA 17402
PHONE: 717 851 2281
FAX: 717 845 7258

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1110 EAST PRINCESS STREET
YORK, PA 17403
PHONE: 717 845 6393

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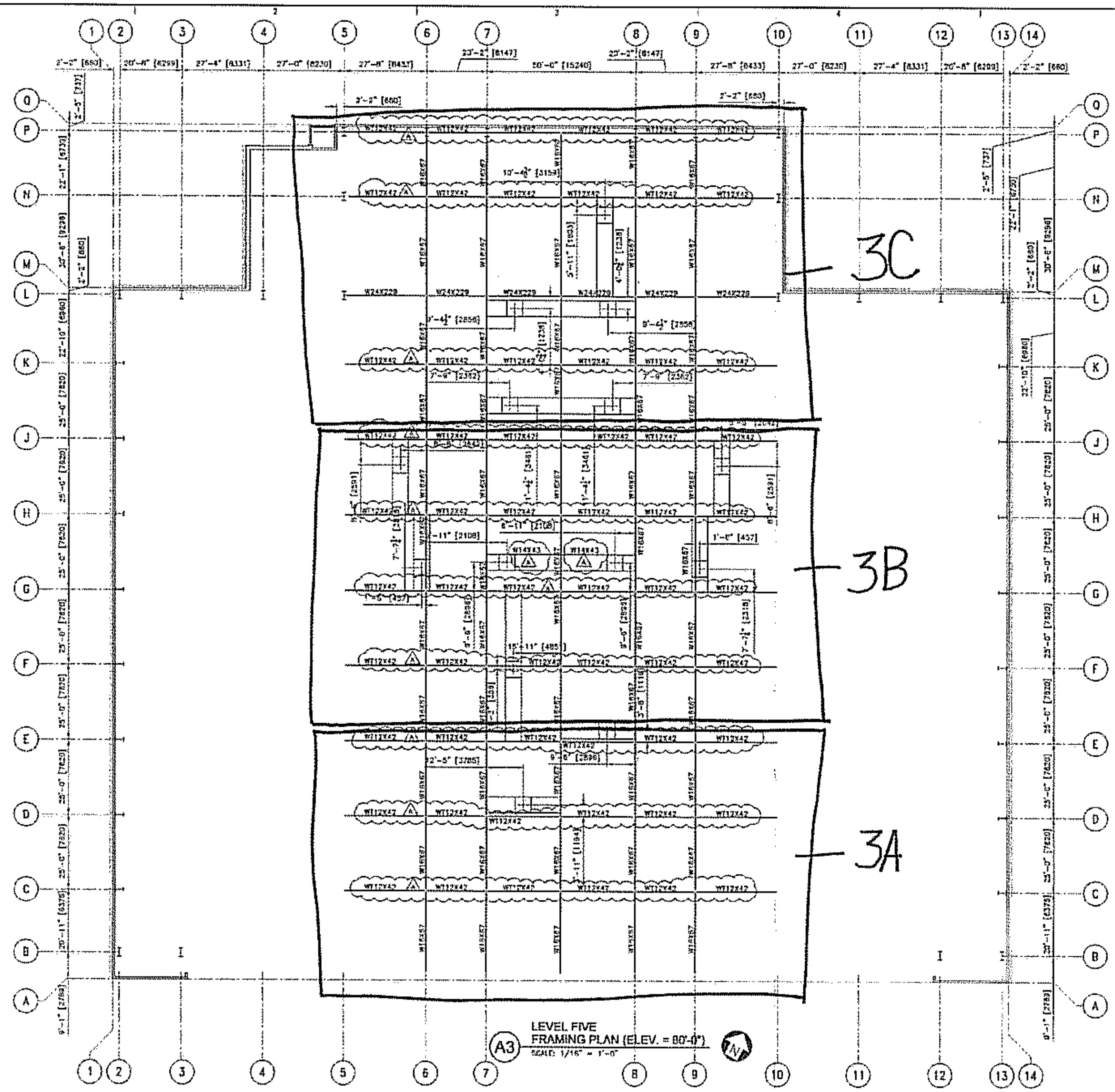
C-5 FUEL CELL FACILITY
167th AIRLIFT WING
MARTINSBURG, WEST VIRGINIA
BERKELEY COUNTY
WEST VIRGINIA

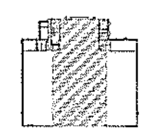
REVISIONS
CHANGED STEEL SIZES
ISSUED FOR 65% COMPLETE CD
ISSUED FOR 35% COMPLETE CD
DESCRIPTION

SHEET TITLE:
LEVEL FOUR FRAMING PLAN

SHEET NO.
S114



A3 LEVEL FIVE FRAMING PLAN (ELEV. = 80'-0")
SCALE: 1/16" = 1'-0"



A KEY PLAN
NO SCALE

TranSystems

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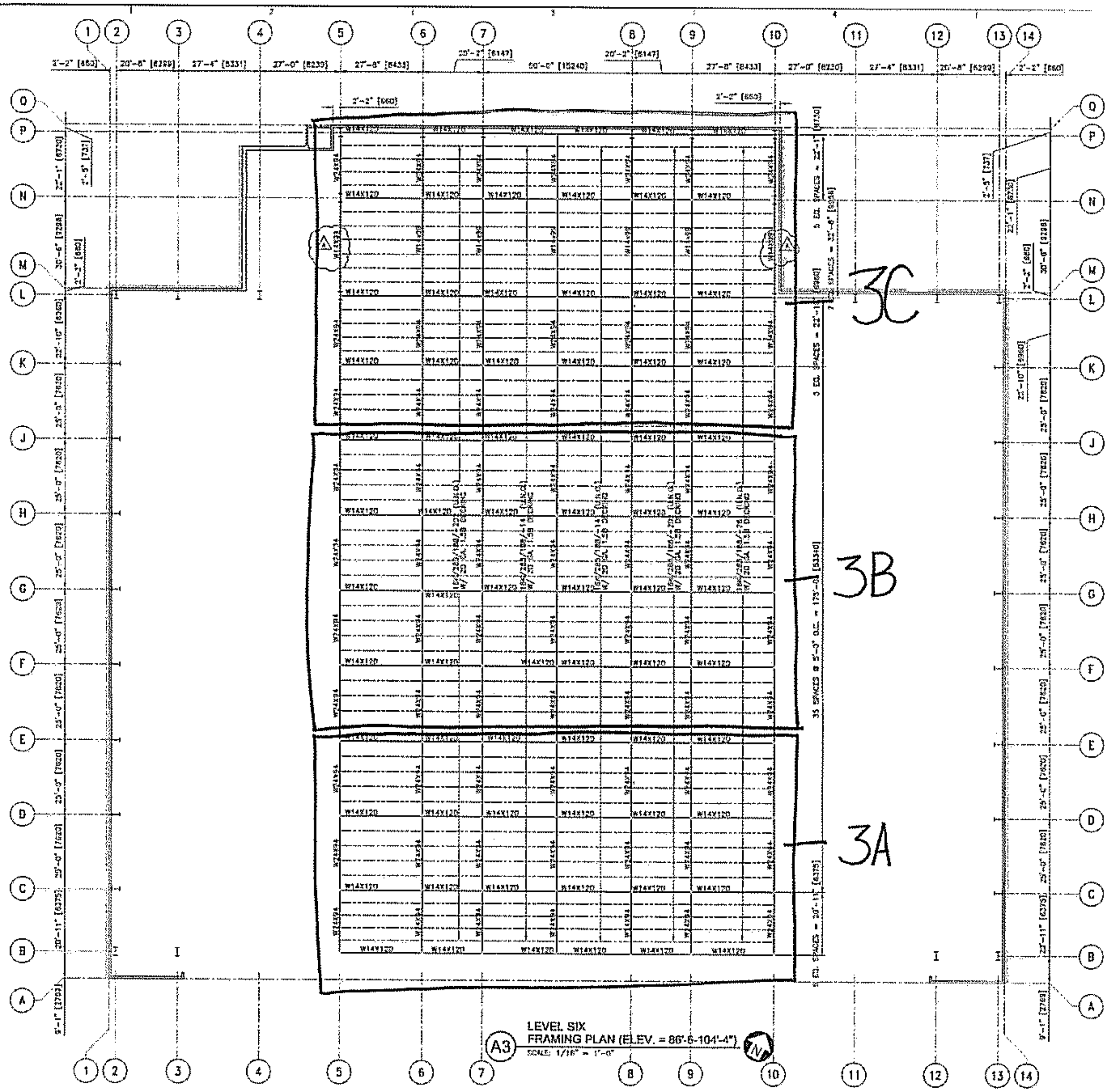
architects engineers

KINSLEY CONSTRUCTION

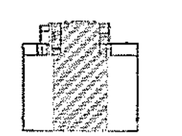
C-5 FUEL CELL FACILITY
167th AIRLIFT WING
MARTINSBURG, WEST VIRGINIA
BERKELEY COUNTY
WEST VIRGINIA

SHEET TITLE:
LEVEL FIVE FRAMING PLAN

SHEET NO.
S115



A3 LEVEL SIX FRAMING PLAN (ELEV. = 86'-6-104'-4")
SCALE: 1/16" = 1'-0"



A KEY PLAN
NO SCALE

IF THIS DRAWING IS LESS THAN 21" X 30" IT IS A REDUCED SIZE DRAWING

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SUITE 150
YORK, PA 17402

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1112 EAST PRINCESS STREET
YORK, PA 17403

KINSLEY CONSTRUCTION
2700 WATER STREET
YORK, PA 17403

C-5 FUEL CELL FACILITY
167th AIRLIFT WING
MARTINSBURG, WEST VIRGINIA
BERKELEY COUNTY
WEST VIRGINIA

REVISIONS

SCALE: AS NOTED
DESIGNED BY: TWH
DRAWN BY: SMK
CHECKED BY:

SHEET TITLE:
LEVEL SIX FRAMING PLAN

SHEET NO.
S116

Appendix E

C-5 Fuel Cell Facility

General Conditions Estimate

Description	Quantity	Units	Unit Cost	Total Cost
Project Supervision				
Superintendent	60	WKS	$2,975	$178,500
Asst. Superintendent	60	WKS	$2,750	$165,000
Job Engineer	60	WKS	$1,800	$108,000
Quality Control Supervisor	60	WKS	$1,800	$108,000
Mechanical QC Manager	52	WKS	$1,800	$93,600
Electrical QC Manager	52	WKS	$1,800	$93,600
				$746,700
Office Trailer-Double Wide	5	EA	$5,915	$29,575
Office Phones (5 trailers)	13	MOS	$440	$5,720
Office Equipment (5 trailers)	13	MOS	$1,323	$17,193
Job Photos	7	DAY	$1,525	$10,675
				$63,163
Mobilization				
Initial	30	CD	$610	$18,300
Equipment	20	WKS	$810	$16,200
Concrete Equipment	16	WKS	$2,100	$33,600
Material	52	WKS	$200	$10,400
				$78,500
Equipment Maintenance				
Equipment Maintenance	52	WKS	$140	$7,280
Concrete Equipment	16	WKS	$380	$6,080
				$13,360
Misc. Job Support Allowance	1	LS	$5,500	**$5,500**
Scheduling	1	LS	$10,704	**$10,704**
Layout				
Building Layout	70	MSF	$120	$8,400
Field Survey	87	MSF	$250	$21,750
Layout Sub	1	LS	$6,000	$6,000
				$36,150
Temp Toilets	13	MOS	$550	**$7,150**
Temp Utilities				
Temp Electric	13	MOS	$100	$1,300
Temp Water	13	MOS	$10	$130
				$1,430

Winter Protection/Heat				
Temp Heat	4	MOS	$8,700	$34,800
Snow & Ice Removal	3	MOS	$5,500	$16,500
Concrete Protection	4	MOS	$4,700	$18,800
Masonry Heating	3	MOS	$3,800	$11,400
				$81,500
Temp Floor Protection	864	CSF	$25	**$21,600**
Temp Storage Trailers- Owned	6	EA	$130	**$780**
Temp Roads	500	SY	$15	**$7,500**
Temp Fencing	2,000	LF	$6	**$12,000**
Dewatering/Pumping	5	MOS	$1,500	**$7,500**
Permits	1	LS	$6,690	**$6,690**
Bonds				
Payment Bond	1	LS	$80,274	$80,274
Performance Bond	1	LS	$160,547	$160,547
				$240,821
Builder's Risk Insurance	1	LS	$64,219	**$64,219**
Testing	1	LS	$106,000	**$106,000**
Cleanup				
Weekly Cleanup	80	MSF	$600	$48,000
Final Cleanup	80	MSF	$100	$8,000
				$56,000
Dumpster/Trash Removal	13	MOS	$650	**$8,450**
Safety				
General Building Safety	58	WKS	$275	$15,950
Safety Supervisor	58	WKS	$2,475	$143,550
				$159,500
As-Built Drawings	1	LS	$6,000	**$6,000**
Punch-out	1	LS	$5,500	**$5,500**
		GRAND TOTAL		**$1,746,717**

Appendix F

C-5 Fuel Cell Facility

Structural Systems Estimate

STRUCTURAL SYSTEM ESTIMATE

C-5 Fuel Cell Facility

CONCRETE

		Quantity	Unit	Unit Cost	Total Cost
	3' dia. Caisson	340	VLF	$ 75.23	$ 25,578.20
	6' dia. Caisson	386	VLF	$ 210.31	$ 81,179.66
	Pier Caps	426	CY	$ 237.43	$ 101,145.18
	Grade Beams	104	CY	$ 250.34	$ 26,035.36
	Strip Footing	10	CY	$ 250.34	$ 2,503.40
	6" Slab on Grade	197	CY	$ 217.14	$ 42,776.58
	8" Slab on Grade	1109	CY	$ 217.14	$ 240,808.26
	14" Slab on Grade	875	CY	$ 217.14	$ 189,997.50
	Jacking Points Slab	53	CY	$ 217.14	$ 11,508.42
	Trench Drain Slab	489	CY	$ 217.14	$ 106,181.46
			Concrete Total		**$ 827,714.02**

MASONRY

		Quantity	Unit	Unit Cost	Total Cost
	8" CMU bearing wall	2998	SF	$ 7.65	$ 22,934.70
	12" CMU bearing wall	2880	SF	$ 11.15	$ 32,112.00
			Masonry Total		**$ 55,046.70**

STEEL

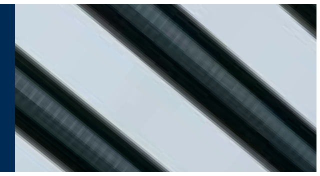
		Quantity	Unit	Unit Cost	Total Cost
	Columns	334.48	Ton	$ 4,330.66	$ 1,448,519.16
	Support Areas	62.15	Ton	$ 4,330.66	$ 269,150.52
	Wind Girts	127.96	Ton	$ 4,330.66	$ 554,151.25
	Truss Structure	1348.19	Ton	$ 4,330.66	$ 5,838,552.51
	24LH Joists	1792	LF	$ 31.65	$ 56,716.80
	14K Joists	1260	LF	$ 10.60	$ 13,356.00
	16K Joists	12,888	LF	$ 10.20	$ 131,457.60
	18K Joists	1456	LF	$ 11.38	$ 16,569.28
	18 Ga. Metal Roof Deck	37,320	SF	$ 3.42	$ 127,634.40
	20 Ga. Metal Roof Deck	42,032	SF	$ 2.75	$ 115,588.00
			Steel Total		**$ 8,571,695.51**
			Structural Total		**$ 9,454,456.23**

Appendix G

C-5 Fuel Cell Facility

Solyndra Specifications

Product Specifications



Electrical Data

Measured at Standard Test Conditions (STC) irradiance of 1000 W/m^2, air mass 1.5, and cell temperature 25° C

Model Number		SL-001-150	SL-001-157	SL-001-165	SL-001-173	SL-001-182	SL-001-191	SL-001-200 Release Date TBD
PowerRating (P_{mp})	Wp	150 Wp	157 Wp	165 Wp	173 Wp	182 Wp	191 Wp	200 Wp
Power Tolerance (%)	%/Wp	+4, -5	+/-4	+/-4	+/-4	+/-4	+/-4	+/-4
V_{mp} (Voltage at Maximum Power)	Volts	65.7 V	67.5 V	69.6 V	71.7 V	73.9 V	76.1 V	78.3 V
I_{mp} (Current at Maximum Power)	Amps	2.28 A	2.33 A	2.37 A	2.41 A	2.46 A	2.51 A	2.55 A
V_{oc} (Open Circuit Voltage)	Volts	91.4 V	92.5 V	93.9 V	95.2 V	96.7 V	98.2 V	99.7 V
I_{sc} (Short Ciruit Current)	Amps	2.72 A	2.73 A	2.74 A	2.75 A	2.76 A	2.77 A	2.78 A
Temp. Coefficient of V_{oc}	%/˚C	-.24						
Temp. Coefficient of I_{sc}	%/˚C	-.02						
Temp. Coefficient of Power	%/˚C	-.26						

System Information

Cell type	Cylindrical CIGS
Maximum System Voltage	Universal design: 1000V (IEC) & 600V (UL) systems
Dimensions	Panel: 1.82 m x 1.08 m x 0.05 m Height: 0.3 m to top of panel on mounts
Mounts	Non-penetrating, powder-coated Aluminum Up to 2.17 mounts per panel
Connectors	4 Tyco Solarlok; 0.20 m cable
Series Fuse Rating	23 Amps
Roof Load	16 kg/m^2 (3.3 lb/ft^2) panel and mounts
Panel Weight	31 kg (68 lb) without mounts
Snow Load Maximum	2800 Pa (58.5 lb/ft^2)
Wind Performance	208 km/h (130 mph) maximum Self-ballasting with no attachments
Operating and Storage Temp	-40˚C to +85˚C
Normal Operating Cell Temperature (NOCT)	41.7˚C at 800 W/m^2, Temp = 20˚C, Wind = 1m/s
Certifications/Listings	UL1703, IEC 61646, CEC listing IEC 61730, IEC 61646, CE Mark Application Class A per IEC 61730-2 Fire Class C
Warranty	25 year limited power warranty 5 year limited product warranty

Solyndra's panels come with all of the mounts, grounding connectors, lateral clips, and fasteners required to build a standard array.

Specifications subject to change without notice.

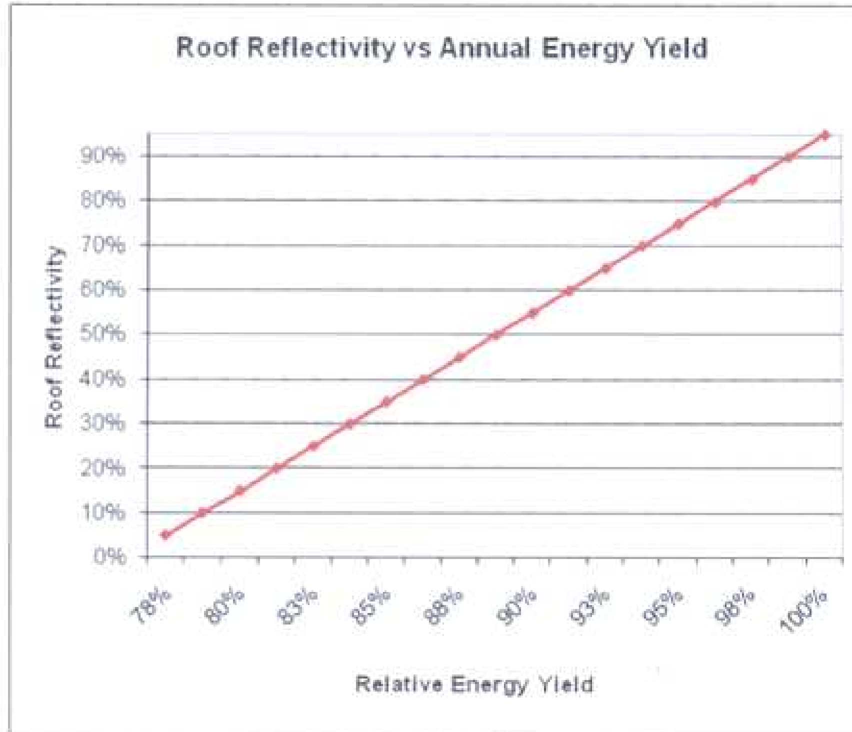
SOLYNDRA™
The new shape of solar™

Solyndra, Inc. • 47700 Kato Road • Fremont, CA • www.solyndra.com

Albedo Reflectivity vs. Annual Energy Yield

- Energy with White Membrane: 80% Top / 20% Bottom
- Rule of thumb: 4% drop in reflectivity = 1% annual energy yield loss

Example Roof Types	Roof Reflectivity	Annual Energy Yield
White "Cool Roof" Membrane or Reflective Field Applied Coatings	95%	100%
	90%	99%
	85%	98%
	80%	96%
	75%	95%
	70%	94%
Tan Membrane	65%	93%
	60%	91%
Light Grey Membrane	55%	90%
Light Green Membrane	50%	89%
Metal	45%	88%
	40%	86%
Dark Green Membrane	35%	85%
Grey Membrane	30%	84%
Dark Grey Bitumen	25%	83%
	20%	81%
	15%	80%
Tar / Black EPDM	10%	79%
	5%	78%
	1%	77%



Graph is for demonstration purposes, not actual data

SOLYNDRA

Appendix H

C-5 Fuel Cell Facility

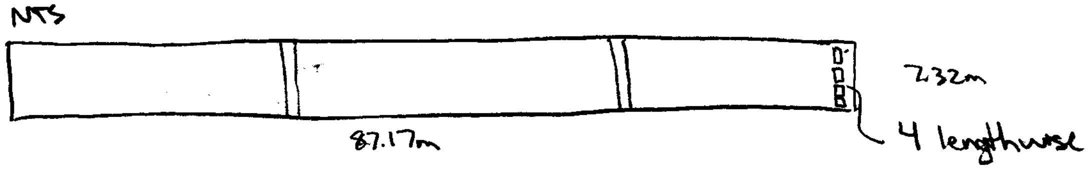
Solyndra Calculations

1 foot = 0.3048 m

Roof Dimensions

Panel Dimensions: 1.82m × 1.08m

2 sections 286' × 24'
→ 87.17m × 7.32m



7.32m / 1.82m/panel = 4.02 → 4 panels

2 sections 286' × 20'
→ 87.17m × 6.10m

6.10m / 1.82m/panel = 3.35 → 3 panels

2 sections 286' × 38'
→ 87.17m × 11.58m

11.58m / 1.82m/panel = 6.36 → 6 panels

For 87.17 m direction break into 3 sections with space between for maintenance

- (2) 1 meter strips dividing into 3 equal sections
- ~.5 meter strips at edges → precisely 0.46m for exactly 26 panels to fit

87.17m − 3m = 84.17m

84.17m / 3 sections = 28.06m/section

28.06m/section ÷ 1.08m/panel ≈ 26 panels/section across

26 panels/section × 3 = 78 panels across

2 × 78 panels × 4 panels = 624 panels

2 × 78 panels × 3 panels = 468 panels

2 × 78 panels × 6 panels = 936 panels

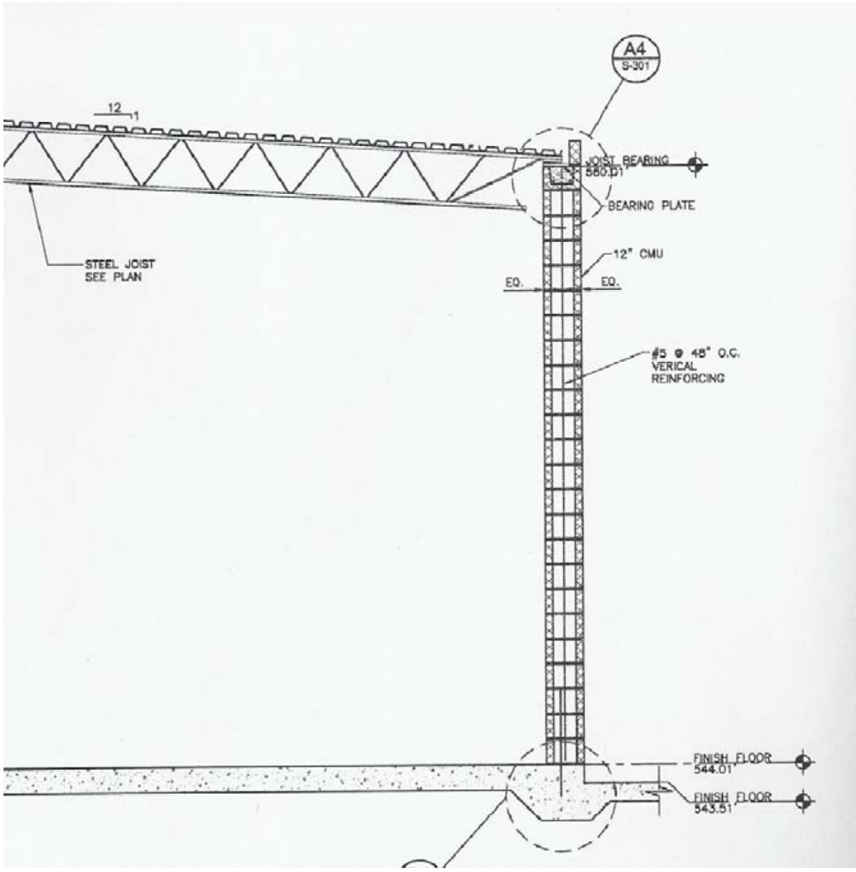
2028 panels total — only use 1 side due to orientation of building — **1014 panels**

Appendix I

C-5 Fuel Cell Facility

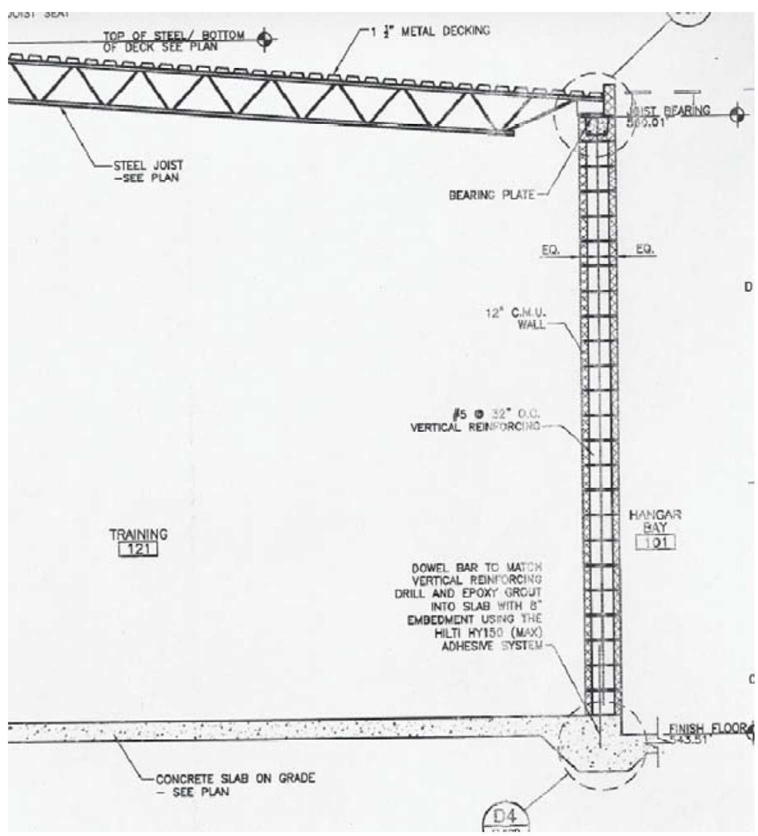
Structural Drawings

STRUCTURAL DRAWINGS



Condition #1

Condition #2



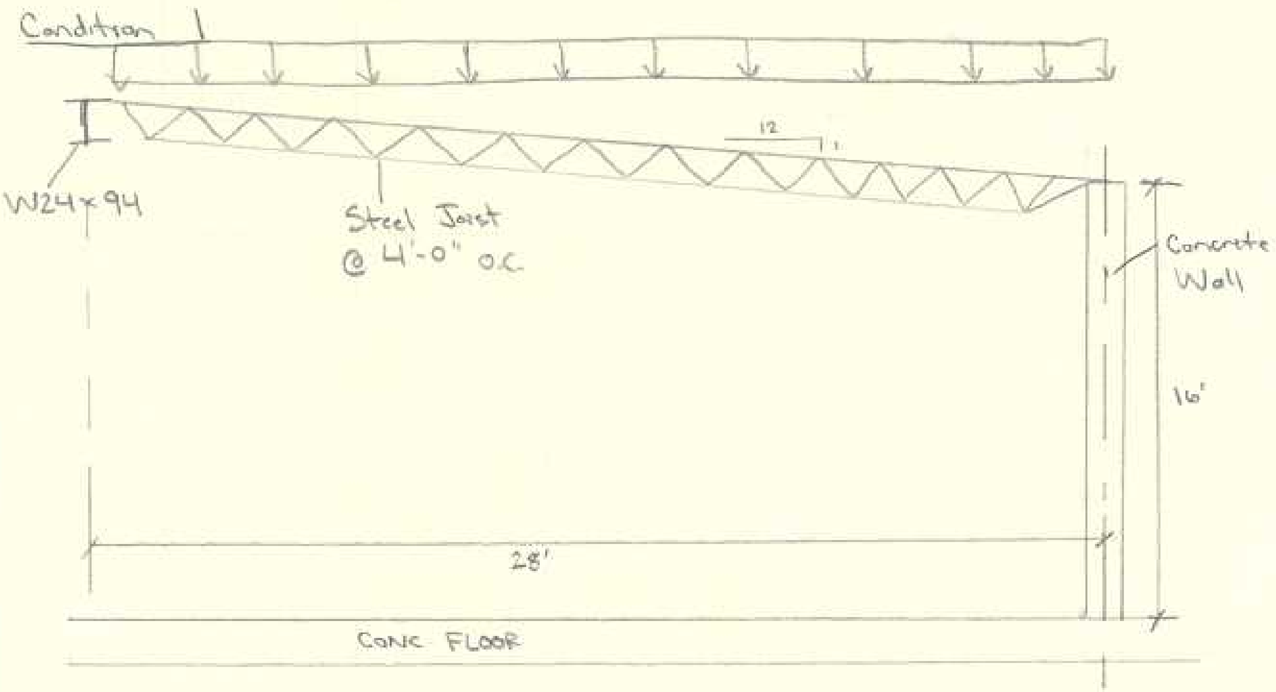
Appendix J

C-5 Fuel Cell Facility

Structural Calculations

Interior Load Bearing Wall

- 2 Conditions to examine
  1) C1 - S-301 → 28' from wall to beam
  2) C3 - S-302 → 21' from wall to beam
  } Loading per SF is same for both



Assumptions: Concrete Wall is concentrically loaded → axial load only ; horizontal load is carried by W24x94

Pinned - Pinned connection → $K = 1.0$

$f'_c = 3000$ psi
$f'_y = 60$ ksi
Loading as follows:
Dead = 21.3 psf from joists and ceiling materials
Live = 20 psf construction load (Roof Live)

- Using strength design load combination $1.2D + 1.6L_r$

- Solve both conditions for bearing and axial load capacity, then use more stringent condition for the reinforcement design.

Tributary area for a single joist onto the wall:

$4' \times 14' = 56\,ft^2$

Load for each joist onto wall

$P_D = 21.3\,psf \times 56\,ft^2 = 1193\,lb$

$P_L = 20\,psf \times 56\,ft^2 = 1120\,lb$

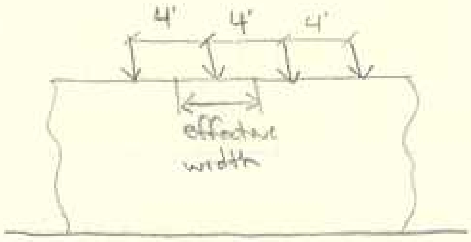
$P_u = 1.2(1193) + 1.6(1120) = 3223\,lb = 3.22\,k$

Select wall thickness, h

$h \geq \frac{\ell_c}{25} = \frac{16' \times 12''}{25} = 7.68'' \rightarrow$ use 8" thickness

or

$\geq 4''$



Bearing Plates: $6\frac{3}{4}'' \times 10'' = 67.5\,in^2$

Effective Width $\leq 4' \times 12'' = 48''$

$\leq 6\frac{3}{4}'' + 4 \times 8'' = \underline{38.75''}$ ← governs

Bearing Capacity: $P_u \leq \phi .85 f'_c A_b$; $\phi = 0.65$

$\phi(.85 f'_c A_b) = 0.65(.85)(3)(67.5) = 112k \gg 3.22k = P_u$ ✓ ok

Axial Load Capacity: $P_u \leq \phi P_n$

$\phi P_n = \phi .55 f'_c A_g \left[1 - \left(\frac{k \ell_c}{32h}\right)^2\right]$; A_g = effective width × h = $38.75'' \times 8''$ $= 310\,in^2$

$\phi = 0.70$

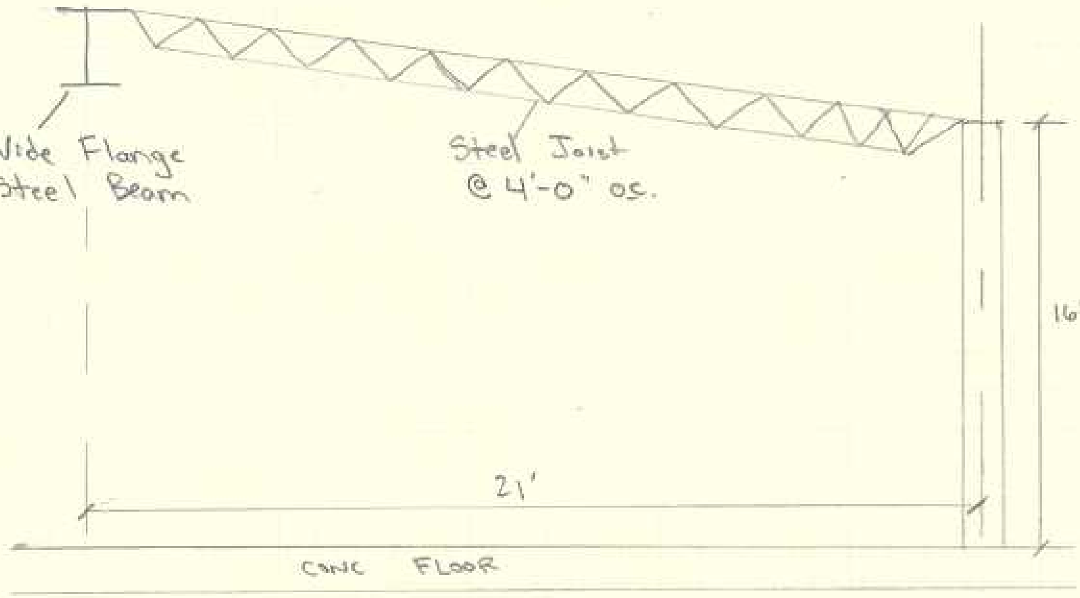
$\phi P_n = 0.70(.55)(3)(310)\left[1 - \left(\frac{1 \times 16 \times 12}{32 \times 8}\right)^2\right]$

$= 358[.4375]$

$\phi P_n = 157\,k \gg 3.22k = P_u$ ok

Thickness of 8" is ok

Condition 2



Assumptions: Same as Condition 1

Strength Design Load Combination: $1.2D + 1.6L_r$

Tributary Area for a single joist onto the wall:

$4' \times 10.5' = 42 ft^2$

Load for each joist onto wall:

$P_D = 21.3 psf \times 42 ft^2 = 895 lb$

$P_L = 20 psf \times 42 ft^2 = 840 lb$

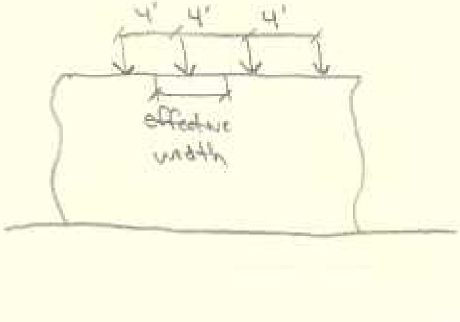
$P_u = 1.2(895) + 1.6(840) = 2418 lb = 2.42k$

Select wall thickness, h

$h \geq \frac{l}{25} = \frac{16' \times 12"}{25} = 7.68"$ → use 8" thickness

or

$\geq 4"$



Bearing Plates: $6\frac{3}{4}" \times 10" = 67.5 in^2$

Effective Width $\leq 4' \times 12" = 48"$

$\leq 6\frac{3}{4}" + 4 \times 8" = \underline{38.75"}$ ← governs

Bearing Capacity: $P_u \le \phi\, 0.85 f'_c A_b$; $\phi = 0.65$

$$\phi(.85 f'_c A_b) = 0.65(.85)(3)(67.5\,in^2) = 112k \gg 2.42k = P_u \checkmark \text{ ok}$$

Axial Load Capacity: $P_u \le \phi P_n$

$$\phi P_n = \phi .55 f'_c A_g\left[1 - \left(\frac{k\ell_c}{32h}\right)^2\right] \quad ; \quad \phi = 0.70$$

$$= 0.70(.55)(3)(38.75'' \times 8'')\left[1 - \left(\frac{1.0 \times 16 \times 12}{32 \times 8}\right)^2\right]$$

$$\phi P_n = 157k \gg 2.42k = P_u \text{ ok}$$

8" thickness is ok

Reinforcement

Vertical: $A_v = .0012 \times 12'' \times 8'' = .115\ in^2$

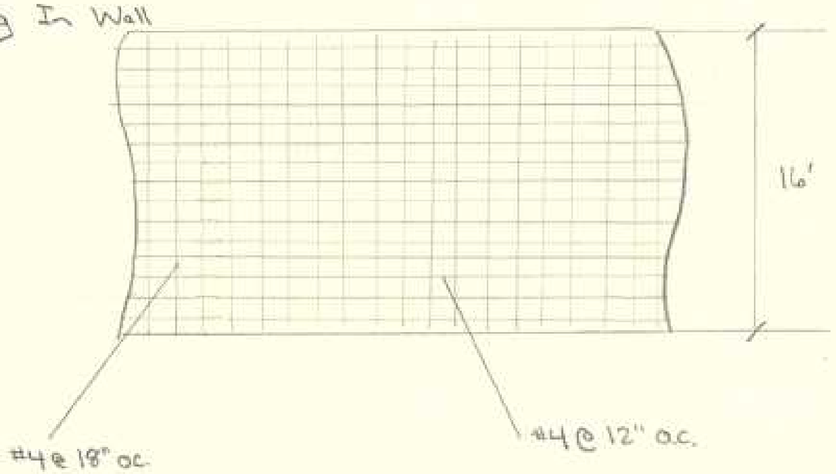
Horizontal: $A_v = .0020 \times 12'' \times 8'' = .192\ in^2$

Spacing: $s \le 3h = 3(8'') = 24''$
$\le 18''$ – governs

Use #4 @ 18" o.c. for vertical → .133 in²/ft > .115 in²/ft ok

Use #4 @ 12" o.c. for horizontal → .200 in²/ft > .192 in²/ft ok

Reinforcing In Wall



Appendix K

C-5 Fuel Cell Facility

Masonry Schedule of Values

AIA Type Document
Application and Certification for Payment

TO (OWNER): 2700 Water St.
York, PA 17403-9306

PROJECT: C-5 Hanger
2700 Water St.
York, PA 17403-9306

APPLICATION NO: 5
PERIOD TO: 1/31/2010

DISTRIBUTION TO:
_ OWNER
_ ARCHITECT
_ CONTRACTOR

FROM (CONTRACTOR): RALPH E. TOLBERT MASONRY, INC.
950 Hollywell Ave
Chambersburg, PA 17201

VIA (ARCHITECT):

ARCHITECT'S PROJECT NO:

CONTRACT FOR:

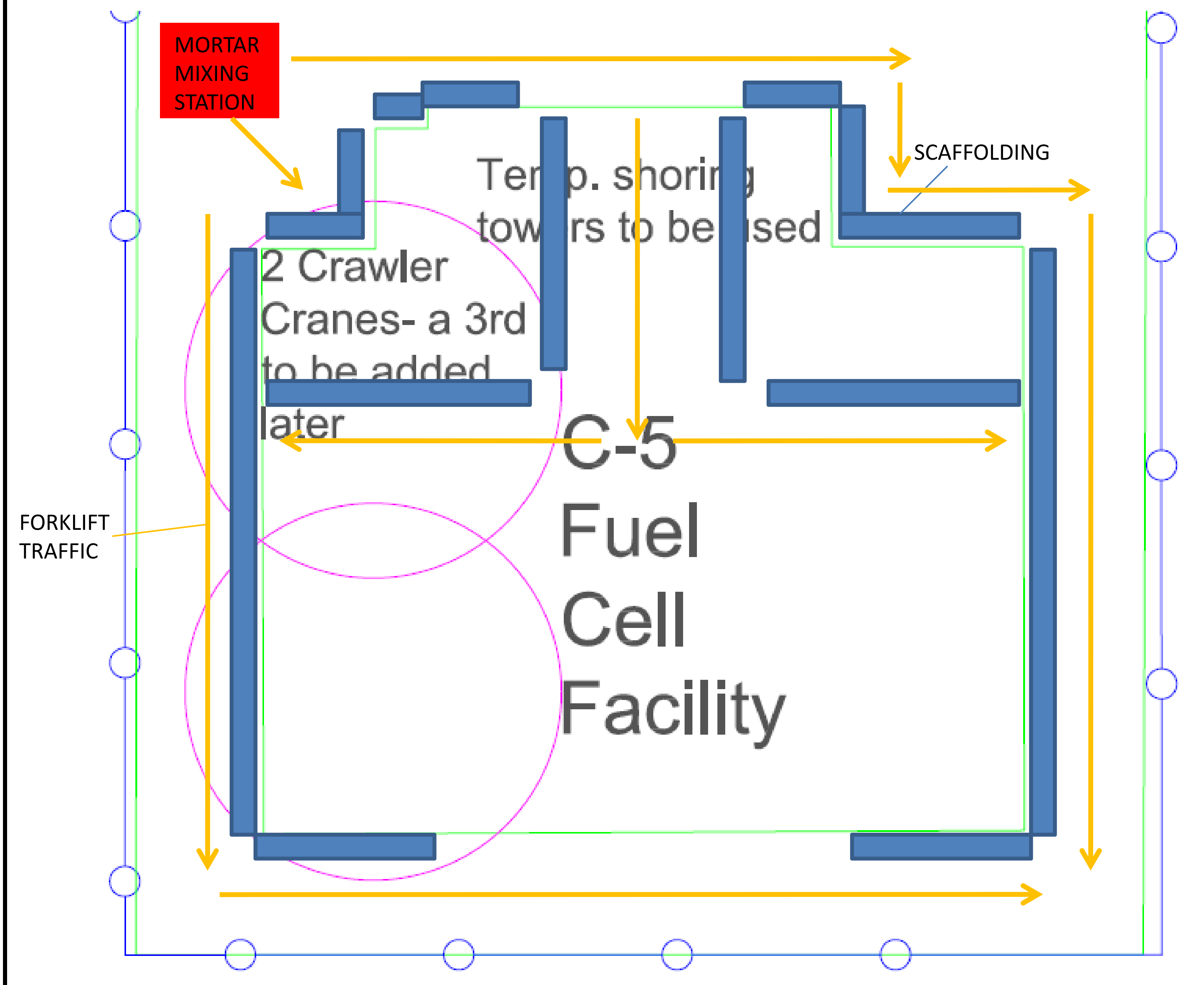
CONTRACT DATE:

ITEM	DESCRIPTION	SCHEDULE VALUE	PREVIOUS APPLICATIONS	COMPLETED THIS PERIOD	STORED MATERIAL	COMPLETED STORED	%	BALANCE	RETAINAGE
1	Foundation CMU Labor	1,700.00	1,700.00	0.00	0.00	1,700.00	100.00	0.00	170.00
2	Foundation CMU Material	1,500.00	1,500.00	0.00	0.00	1,500.00	100.00	0.00	150.00
3	Exterior CMU Labor	2,900.00	2,900.00	0.00	0.00	2,900.00	100.00	0.00	290.00
4	Exterior CMU Material	3,200.00	3,200.00	0.00	0.00	3,200.00	100.00	0.00	320.00
5	Interior CMU Labor	67,000.00	43,550.00	23,450.00	0.00	67,000.00	100.00	0.00	6,700.00
6	Interior CMU Material	23,100.00	20,790.00	2,310.00	0.00	23,100.00	100.00	0.00	2,310.00
7	Splitface Labor	36,500.00	36,500.00	0.00	0.00	36,500.00	100.00	0.00	3,650.00
8	Splitface Material	36,300.00	36,300.00	0.00	0.00	36,300.00	100.00	0.00	3,630.00
9	Grout Labor	20,000.00	19,000.00	1,000.00	0.00	20,000.00	100.00	0.00	2,000.00
10	Grout Material	7,000.00	7,000.00	0.00	0.00	7,000.00	100.00	0.00	700.00
11	Miscellaneous	19,800.00	19,800.00	0.00	0.00	19,800.00	100.00	0.00	1,980.00
12	C/O#1 Addtl Foundation Work	11,011.00	11,011.00	0.00	0.00	11,011.00	100.00	0.00	1,101.10
	REPORT TOTALS	$230,011.00	$203,251.00	$26,760.00	$0.00	$230,011.00	100.00	$0.00	$23,001.10

Appendix L

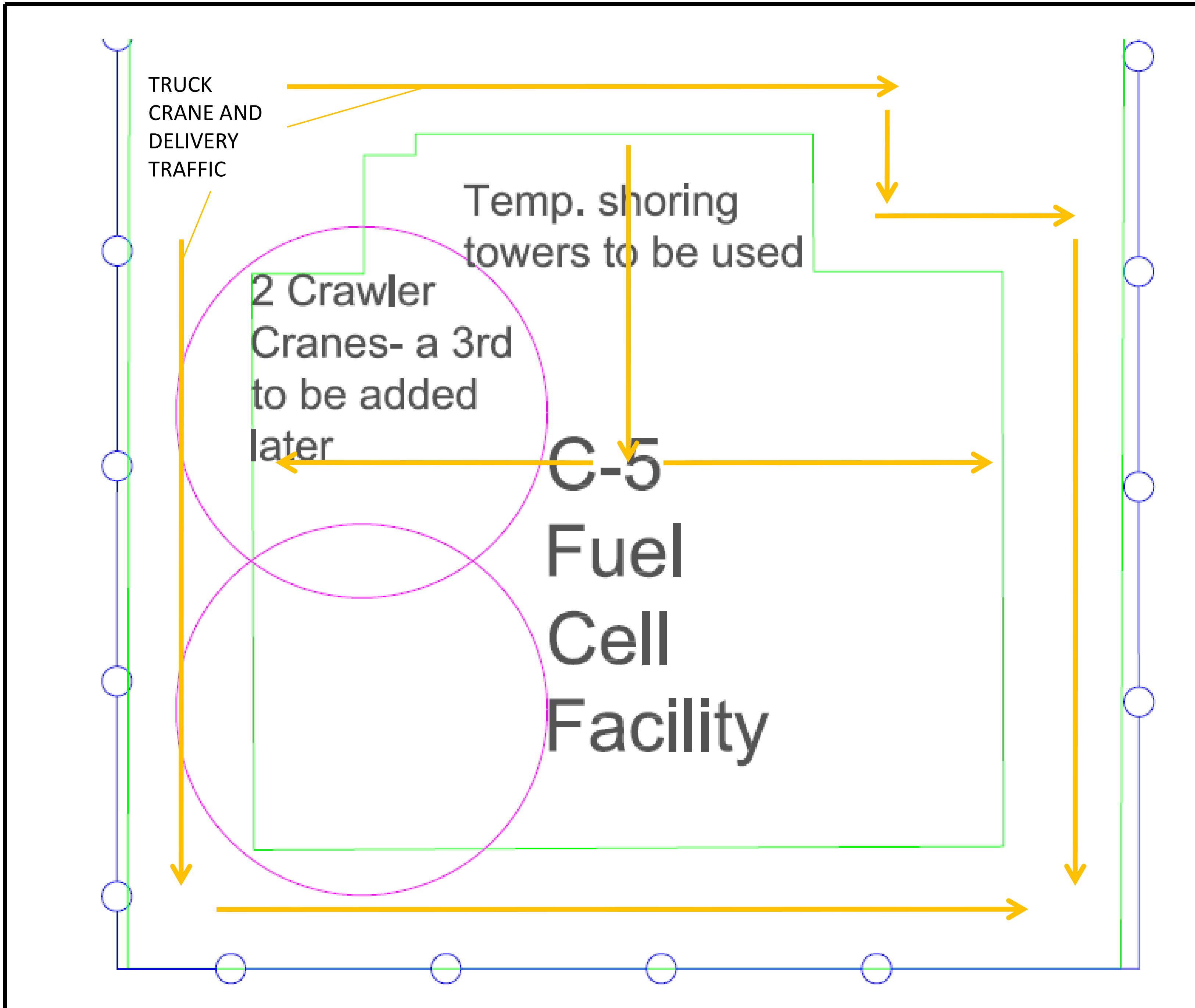
C-5 Fuel Cell Facility

Site Logistics Plans



C-5 FUEL CELL FACILITY
Martinsburg, WV

MASONRY CONSTRUCTION DURING STEEL ERECTION
SITE LOGISTICS PLAN



C-5 FUEL CELL FACILITY
Martinsburg, WV

PRECAST ERECTION DURING STEEL
ERECTION
SITE LOGISTICS PLAN

Appendix M

C-5 Fuel Cell Facility

Slab Sequence Estimates

HANGAR SLAB SEQUENCE COMPARISON										
	Daily Output	Quantity	Unit	Material Cost	Labor Cost	Equip. Cost	Total Cost	Total Incl. O&P	Estimated Cost	Duration (hours)
As-Built Hangar Slab Sequence										
80', 75', 43', 42', 42'										
031113 Forms- 8" high steel forms	960	1,200.00	LF	4.26	1.26	0	5.52	6.65	$ 7,980.00	10.00
032110 Reinforcing- #4 @14"oc										
80' Pour	2.3	13.71	Ton	1475	620	0	2095	2650.00	$ 36,331.50	47.69
75' Pour	2.3	12.88	Ton	1475	620	0	2095	2650.00	$ 34,132.00	44.80
43' Pour	2.3	7.36	Ton	1475	620	0	2095	2650.00	$ 19,504.00	25.60
42' Pour	2.3	2.46	Ton	1475	620	0	2095	2650.00	$ 6,519.00	8.56
42' Pour	2.3	2.46	Ton	1475	620	0	2095	2650.00	$ 6,519.00	8.56
032110 Dowels- #1, 18" long	110	800	EA	2.62	6.5	0	9.12	13.50	$ 10,800.00	58.18
req. at all constr. joints (12"oc)										
3 day wait before adjacent pour										
033053 Slab- 8" w/textured finish										
80' Pour	2500	23,840.00	SF	2.68	0.86	0.01	3.55	4.24	$ 101,081.60	76.29
75' Pour	2400	22,350.00	SF	2.68	0.86	0.01	3.55	4.24	$ 94,764.00	74.50
43' Pour	2320	12,814.00	SF	2.68	0.86	0.01	3.55	4.24	$ 54,331.36	44.19
42' Pour	2320	4,284.00	SF	2.68	0.86	0.01	3.55	4.24	$ 18,164.16	14.77
42' Pour	2320	4,284.00	SF	2.68	0.86	0.01	3.55	4.24	$ 18,164.16	14.77
								TOTAL COST/HOURS	$ 408,290.78	427.90

Assumptions: daily ouput for placement of concrete increases with width of pour (based on survey results from industry members)

HANGAR SLAB SEQUENCE COMPARISON

	Daily Output	Quantity	Unit	Material Cost	Labor Cost	Equip. Cost	Total Cost	Total Incl. O&P	Estimated Cost	Duration (hours)
Proposed Sequence #1										
(4) 49.5', (2) 42'										
031113 Forms- 8" high steel forms	960	1,498.00	LF	4.26	1.26	0	5.52	6.65	$ 9,961.70	12.48
032110 Reinforcing- #4 @14"oc										
49.5' Pour	2.3	8.51	Ton	1475	620	0	2095	2650.00	$ 22,551.50	29.60
49.5' Pour	2.3	8.51	Ton	1475	620	0	2095	2650.00	$ 22,551.50	29.60
49.5' Pour	2.3	8.51	Ton	1475	620	0	2095	2650.00	$ 22,551.50	29.60
49.5' Pour	2.3	8.51	Ton	1475	620	0	2095	2650.00	$ 22,551.50	29.60
42' Pour	2.3	2.46	Ton	1475	620	0	2095	2650.00	$ 6,519.00	8.56
42' Pour	2.3	2.46	Ton	1475	620	0	2095	2650.00	$ 6,519.00	8.56
032110 Dowels- #1, 18" long	110	1,098	EA	2.62	6.5	0	9.12	13.50	$ 14,823.00	79.85
req. at all constr. joints (12"oc)										
3 day wait before adjacent pour										
033053 Slab- 8" w/textured finish										
49.5' Pour	2350	14,751.00	SF	2.68	0.86	0.01	3.55	4.24	$ 62,544.24	50.22
49.5' Pour	2350	14,751.00	SF	2.68	0.86	0.01	3.55	4.24	$ 62,544.24	50.22
49.5' Pour	2350	14,751.00	SF	2.68	0.86	0.01	3.55	4.24	$ 62,544.24	50.22
49.5' Pour	2350	14,751.00	SF	2.68	0.86	0.01	3.55	4.24	$ 62,544.24	50.22
42' Pour	2320	4,284.00	SF	2.68	0.86	0.01	3.55	4.24	$ 18,164.16	14.77
42' Pour	2320	4,284.00	SF	2.68	0.86	0.01	3.55	4.24	$ 18,164.16	14.77

TOTAL COST/HOURS	$ 414,533.98	458.26

Assumptions: daily ouput for placement of concrete increases with width of pour (based on survey results from industry members)

HANGAR SLAB SEQUENCE COMPARISON

	Daily Output	Quantity	Unit	Material Cost	Labor Cost	Equip. Cost	Total Cost	Total Incl. O&P	Estimated Cost	Duration (hours)
Proposed Sequence #2										
(2) 99', 84'										
031113 Forms- 8" high steel forms	960	800.00	LF	4.26	1.26	0	5.52	6.65	$ 5,320.00	6.67
032110 Reinforcing- #4 @14"oc										
99' Pour	2.3	16.93	Ton	1475	620	0	2095	2650.00	$ 44,864.50	58.89
99' Pour	2.3	16.93	Ton	1475	620	0	2095	2650.00	$ 44,864.50	58.89
84' Pour	2.3	5.31	Ton	1475	620	0	2095	2650.00	$ 14,071.50	18.47
032110 Dowels- #1, 18" long	110	400	EA	2.62	6.5	0	9.12	13.50	$ 5,400.00	29.09
req. at all constr. joints (12"oc)										
3 day wait before adjacent pour										
033053 Slab- 8" w/textured finish										
99' Pour	2550	29,502.00	SF	2.68	0.86	0.01	3.55	4.24	$ 125,088.48	92.56
99' Pour	2550	29,502.00	SF	2.68	0.86	0.01	3.55	4.24	$ 125,088.48	92.56
84' Pour	2500	8,568.00	SF	2.68	0.86	0.01	3.55	4.24	$ 36,328.32	27.42

TOTAL COST/HOURS	$ 401,025.78	384.53

Assumptions: daily ouput for placement of concrete increases with width of pour (based on survey results from industry members)