JGC

Challenges in Structural Redundancy Analysis in Complicated Modules

Enhancing planetary health

PFPNet Conference Amsterdam

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Structure: K.Fukumizu

PFPNet
PASSIVE FIRE PROTECTION NETWORK

CONTENTS

1. JGC Introduction

Company Profile

JGC HOLDINGS CORPORATION

Established: **1928**	Total Group Manpower: Approx. **8,100** *EPC Business only
Project Record: **20,000** projects, In over **80** countries	Zero Accidents Record: **130** million hours *For the total duration of the Qatar gas processing project from July 12, 2012 to March 25, 2014
Net Sales: US$ **3.50** billion, FY 2021 (April 1, 2021 – March 31, 2022)	Overseas Sales Ratio: Approx. **68** % FY 2021 (April 1, 2021 – March 31, 2022)

Business Area

EPC Business

Functional Materials Manufacturing

Energy and Environmental Consulting

EPC Business Area (1/2)

Up & Mid Stream

Refineries

LNG Liquefaction

Petrochemicals & Chemicals

Gas Processing

Non-Ferrous Metals

EPC Business Area (2/2)


LNG/LPG Terminal (Onshore)


LNG Terminal (FSRU)


Nuclear Power


Railway


Geothermal


Mega Solar


Wind Power


Biomass


Water Treatment Plant

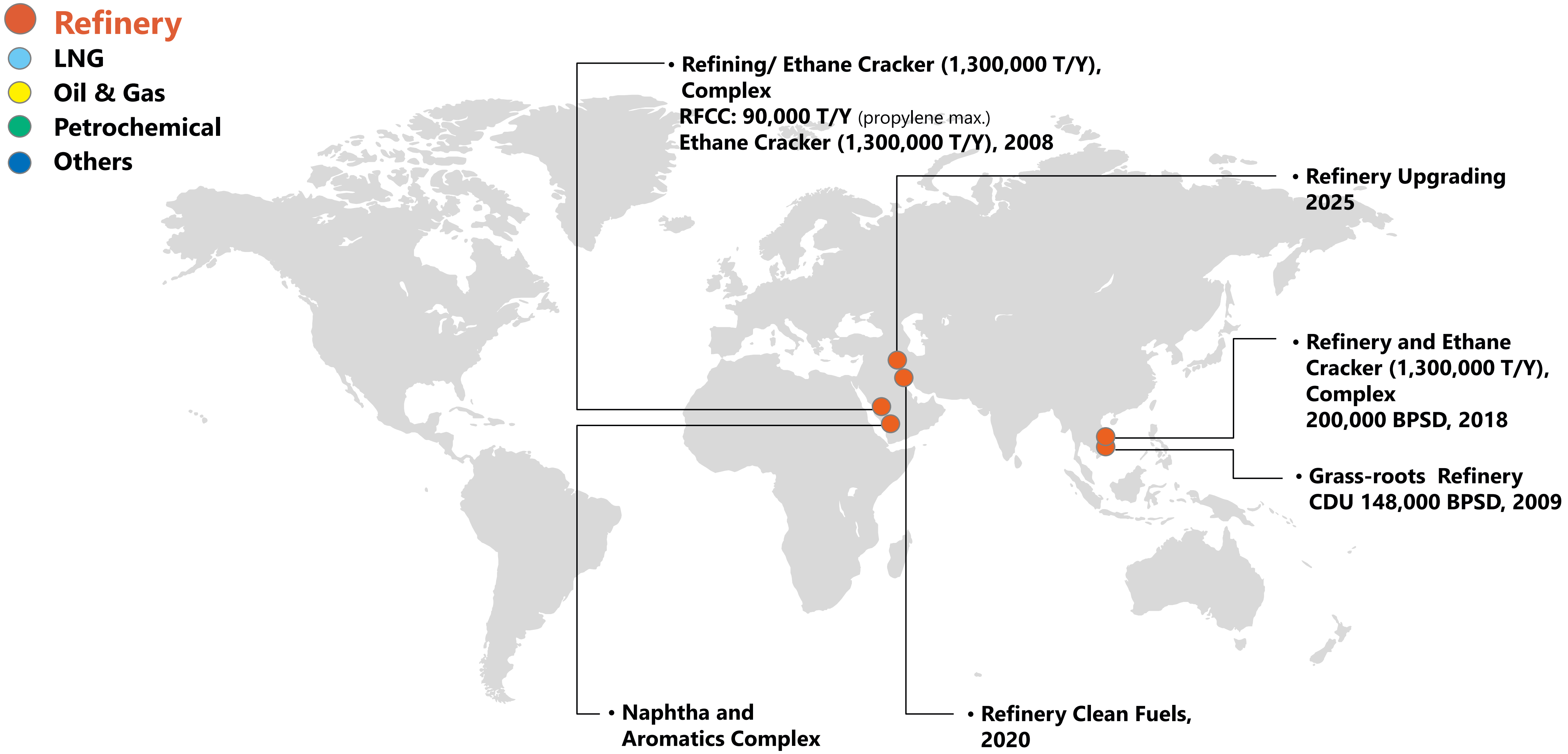

Health Care & Hospital


Pharmaceutical


Food & Beverage

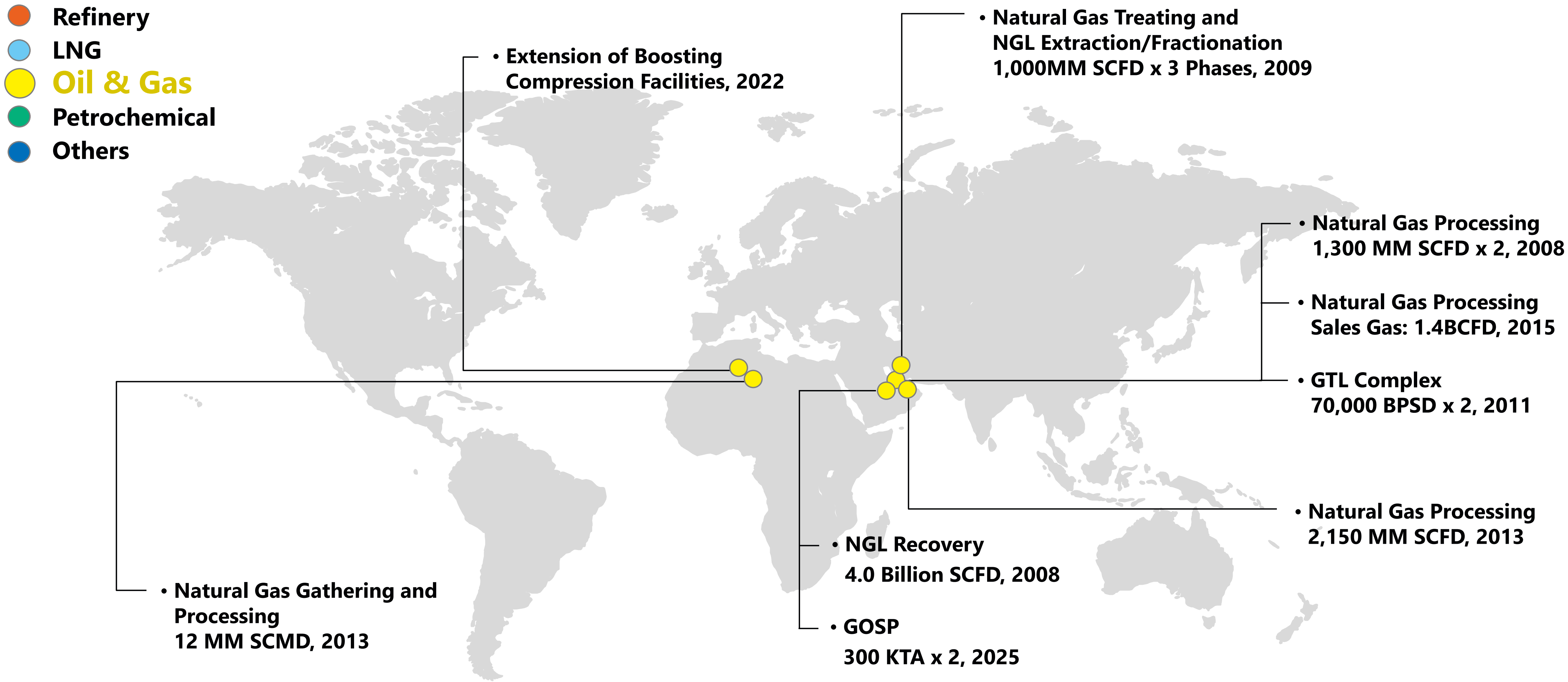
Large Projects (Refineries)

Last 15 Years



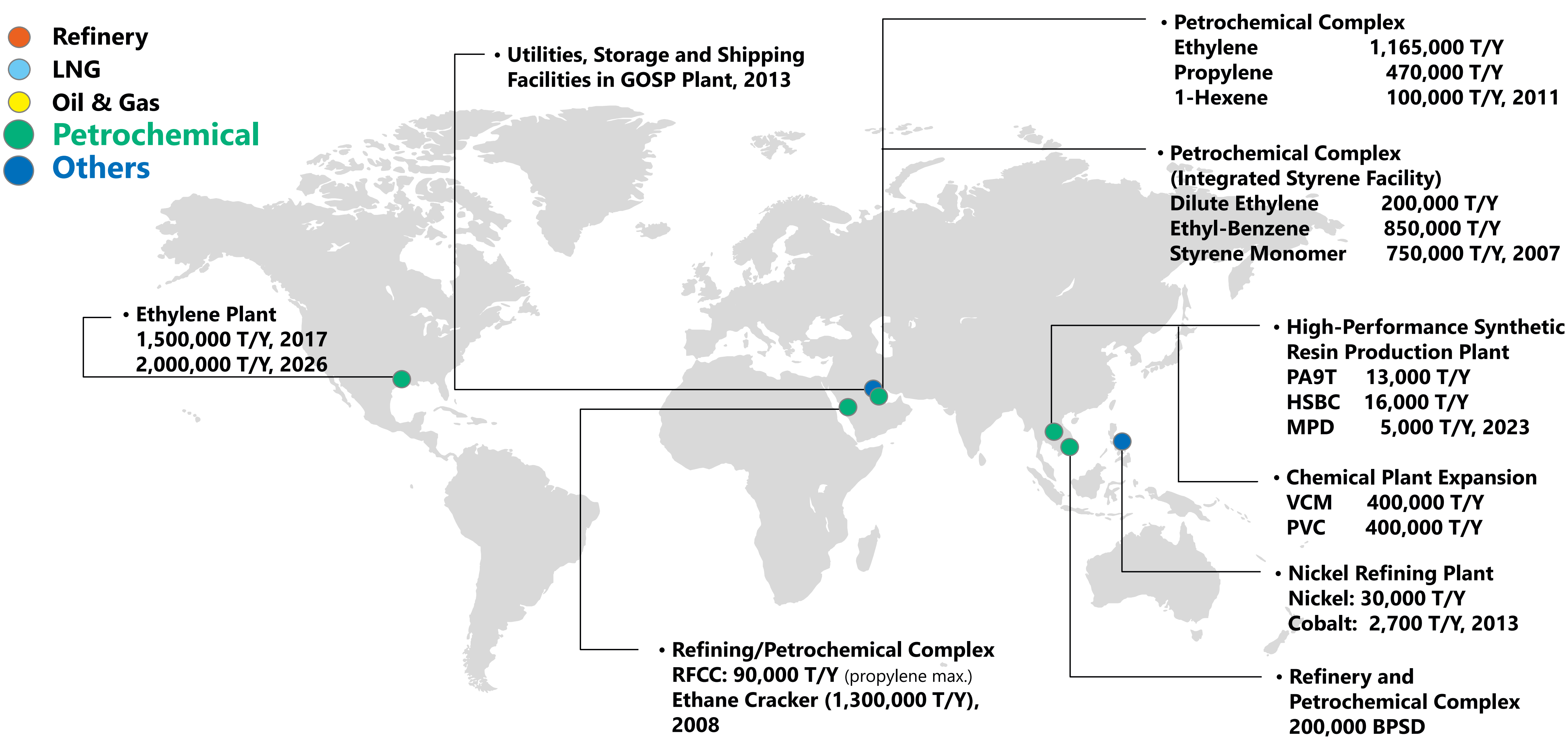
Large Projects (Oil & Gas)

Last 15 Years



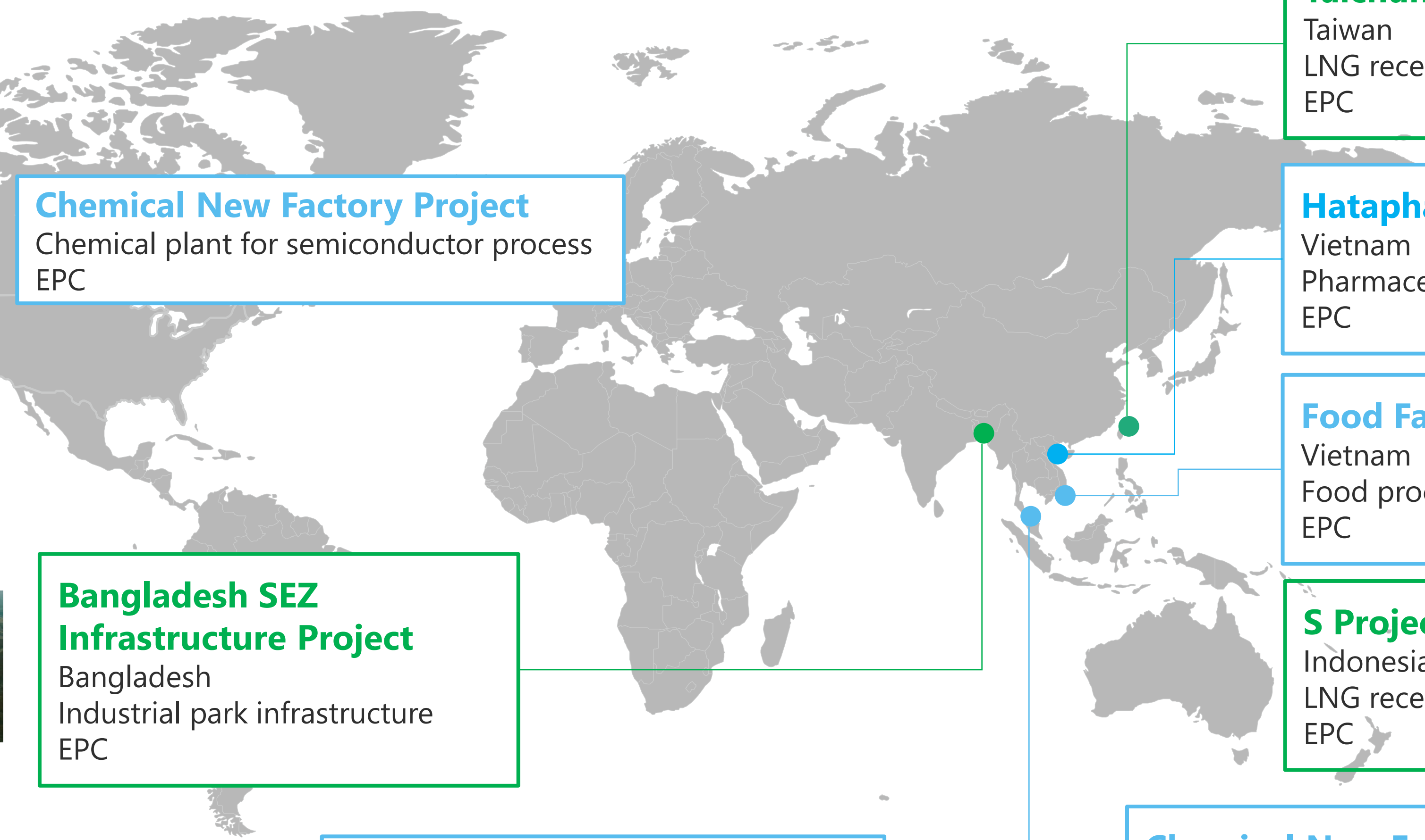
Large Projects (Petrochemicals & Others)

Last 15 Years



Life science, Industrial and Urban Infrastructure - Major EPC Achievements

- Industrial & Healthcare & Lifesciences
- Social Infrastructure



Chemical New Factory Project
Chemical plant for semiconductor process
EPC

Bangladesh SEZ Infrastructure Project
Bangladesh
Industrial park infrastructure
EPC

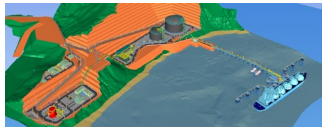
Menicon Project
Malaysia
Contact lens manufacturing plant
EPC

Taichung CPC3 Project
Taiwan
LNG receiving terminal
EPC

Hataphar Project
Vietnam
Pharmaceutical plant
EPC

Food Factory Project
Vietnam
Food processing plant
EPC

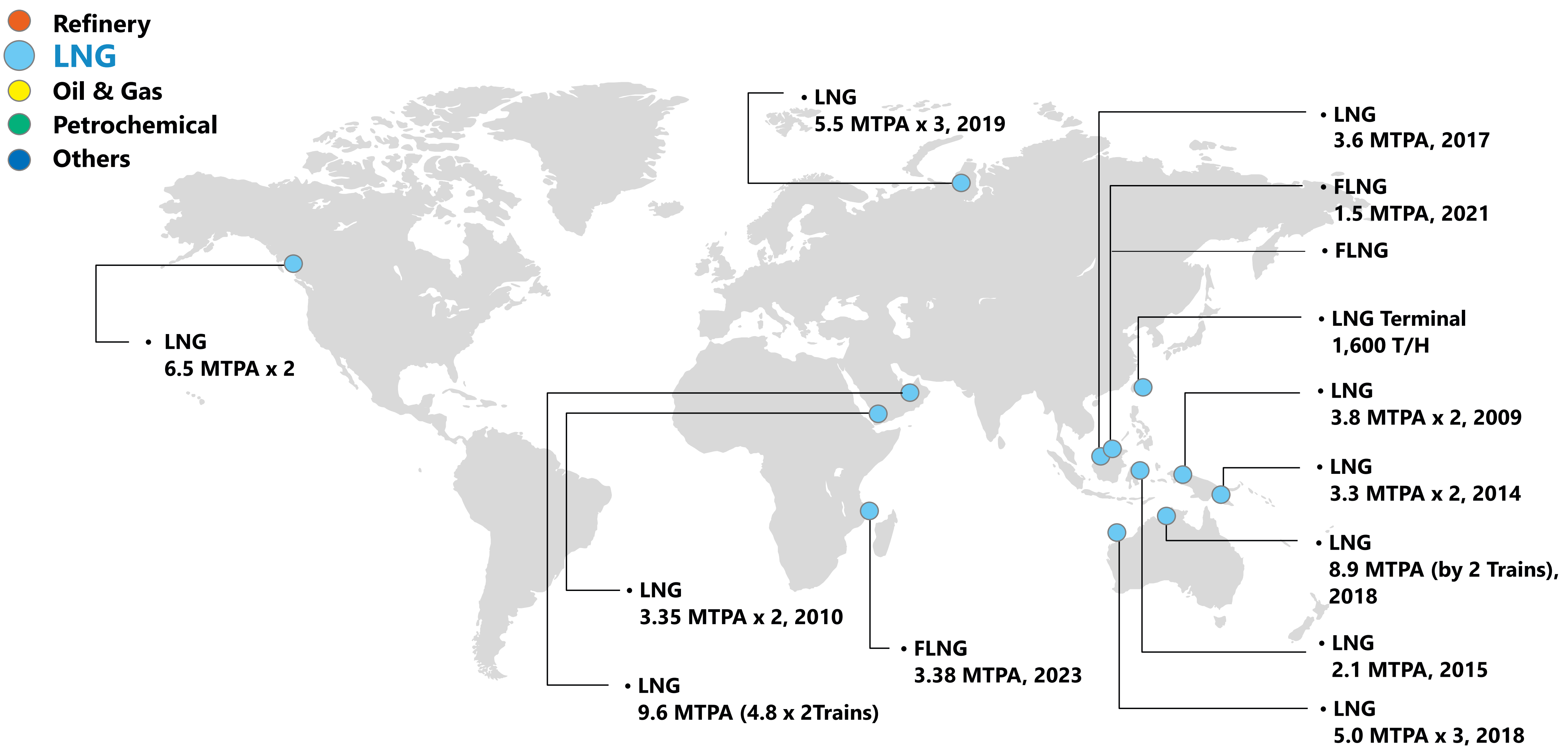
S Project
Indonesia
LNG receiving terminal
EPC



Chemical New Factory Project
Cleaning plant for semiconductor process
EPC

Large Projects (LNG)

Last 15 Years

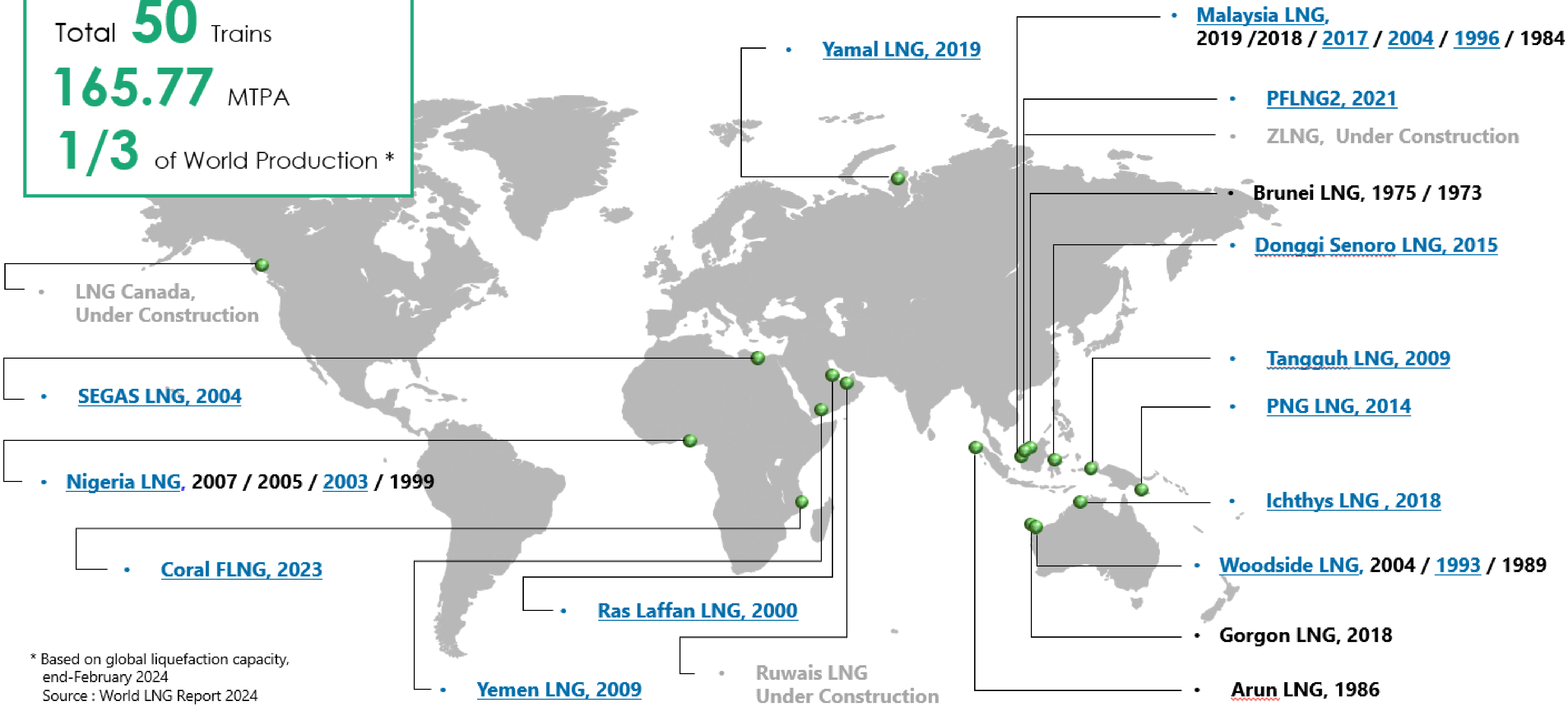


JGC's LNG Experience

Total **50** Trains

165.77 MTPA

1/3 of World Production *



* Based on global liquefaction capacity, end-February 2024
Source : World LNG Report 2024

JGC's LNG Experience

2. Complicated Module and EPC

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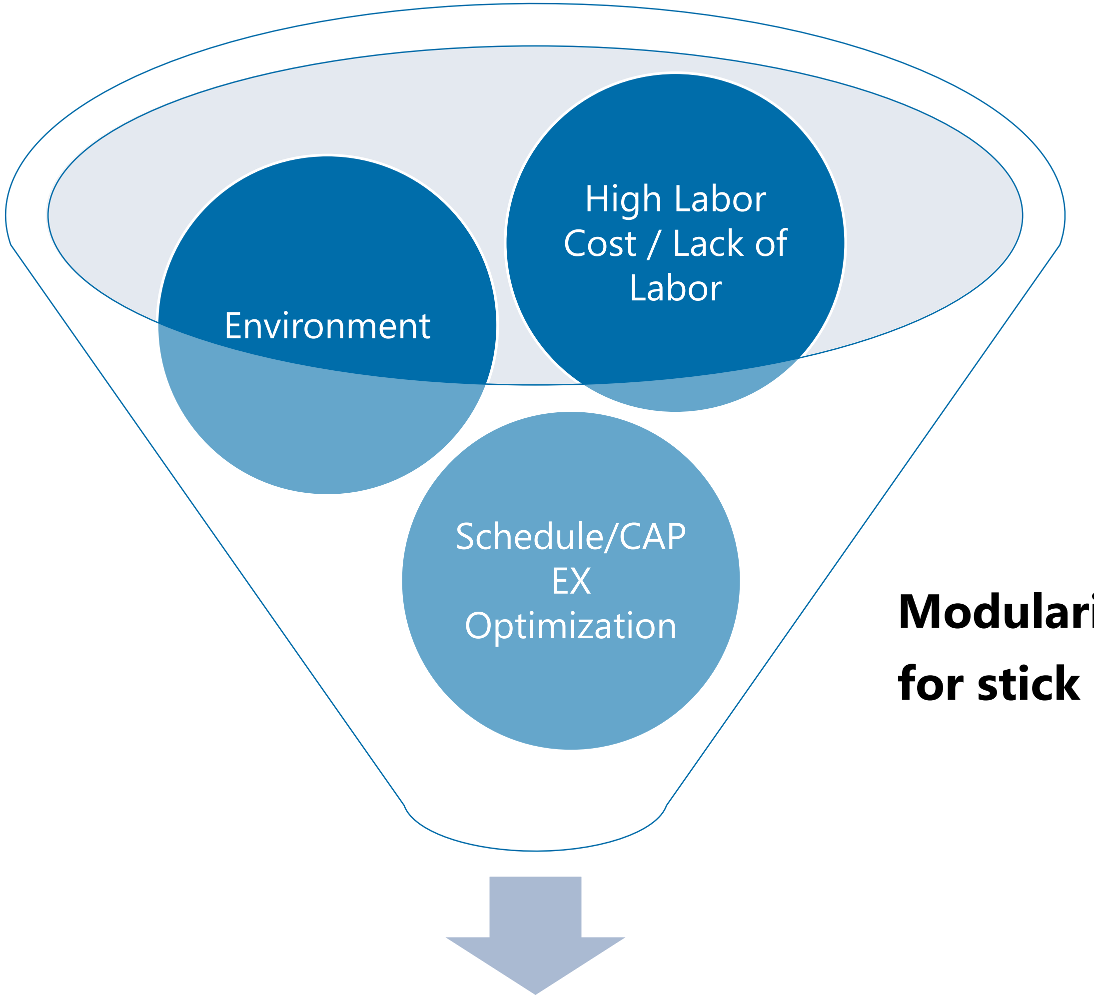
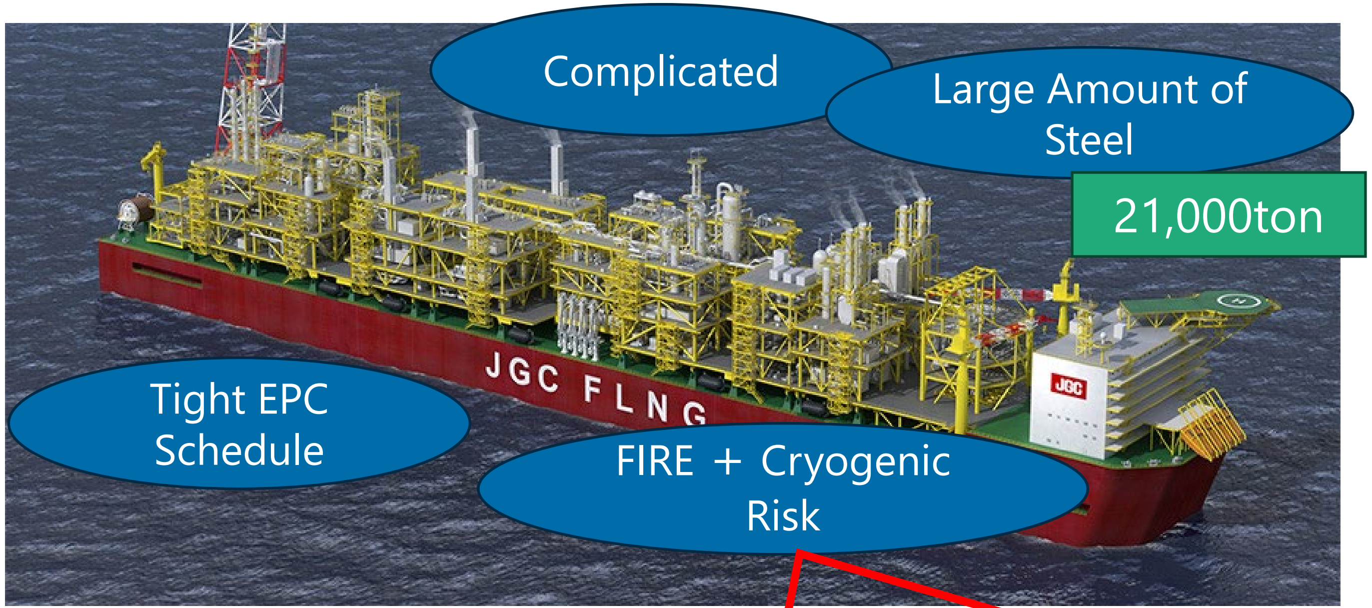
Modularization

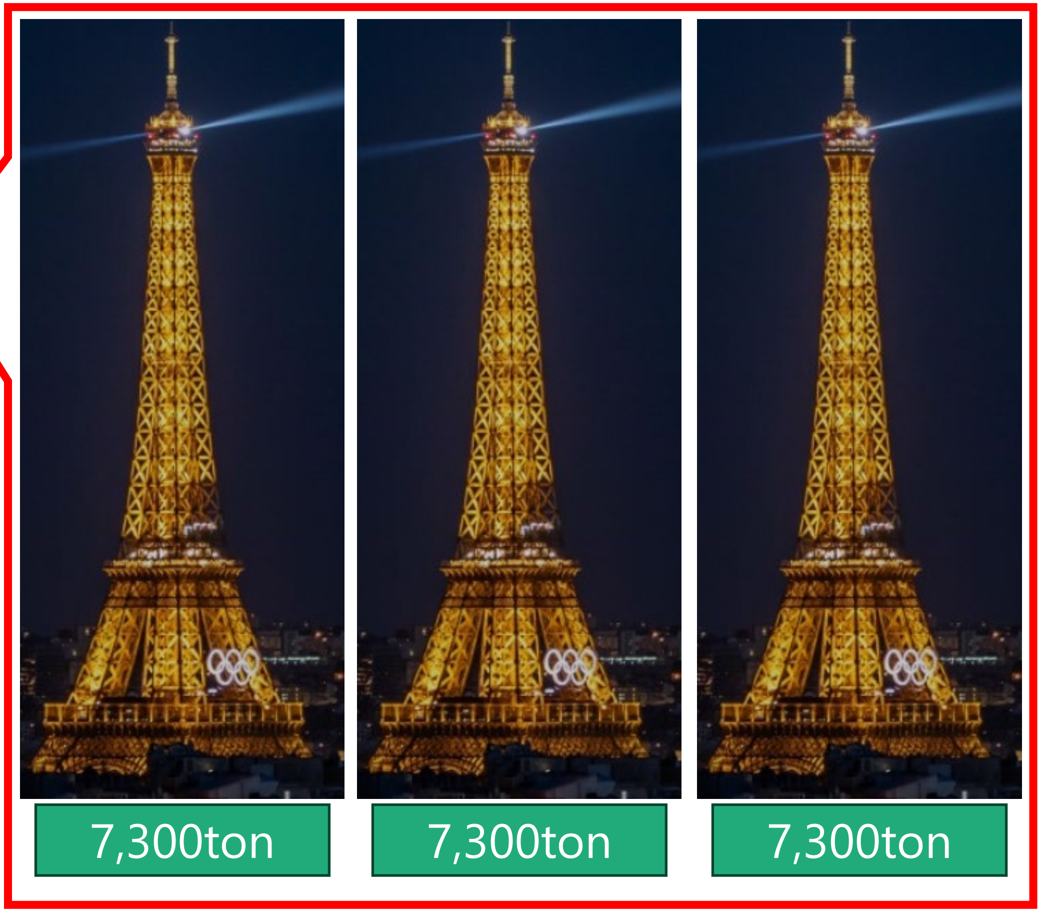


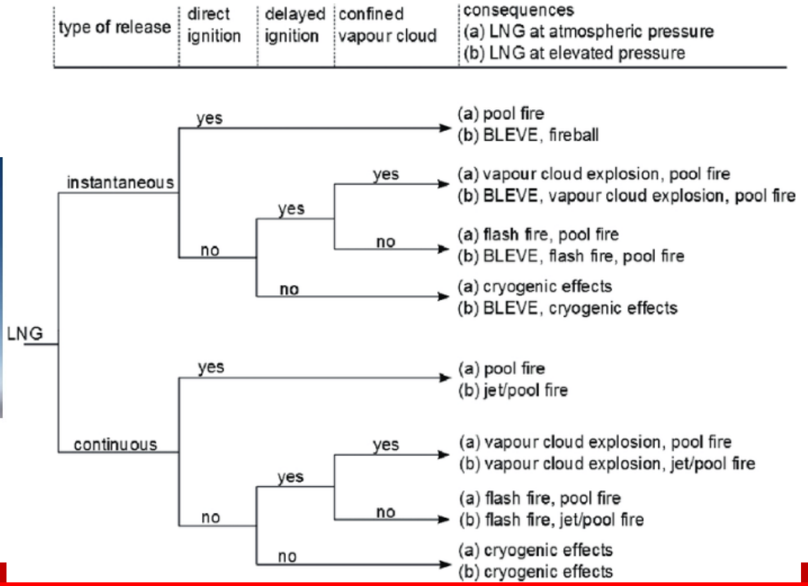
Modularization

Modularization is required since it mitigates risk for stick built construction

Characteristic of FLNG





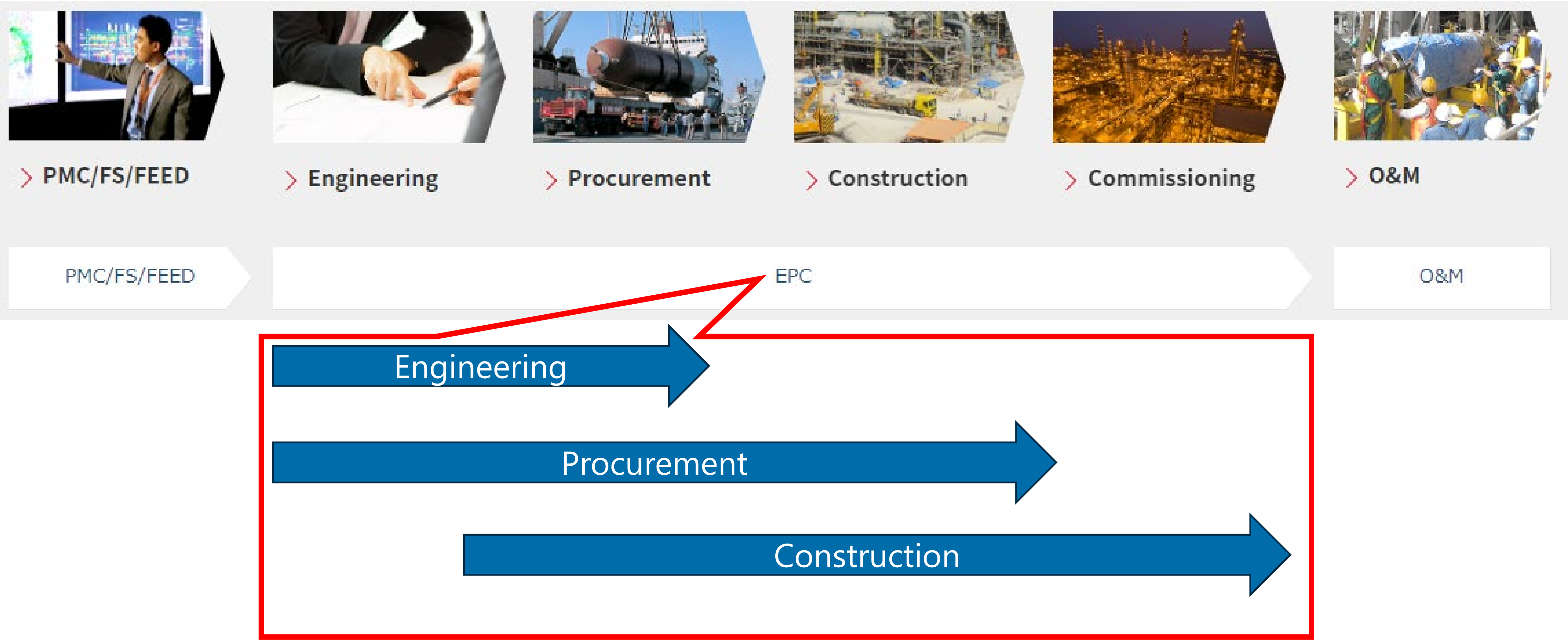


https://www.gas.or.jp/tokucho/

The OFFICIAL Eiffel Tower website: tickets, news, info... (toureiffel.paris)

EPC

- **Engineering, Procurement, and Construction**



- **Each EPC phase is overlapped to meet schedule.**

- **Preliminary design information can be input to construction work**

Typical EPC Workflow (PFP/CSP)

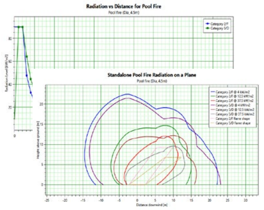
Philosophy Development and Finalization → Process and Layout Design Preliminary → Structure Design Preliminary → Fire Risk Analysis/Cryogenic Risk Analysis → Process and Layout Design Final → Structure Design Final → Fire Risk Analysis/Cryogenic Risk Analysis Refinement → Redundancy Analysis / Finalization of PFP/CSP Extent

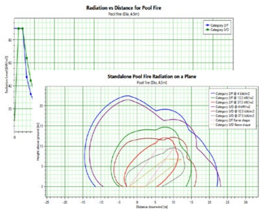
Structure Design Preliminary: Material Take Off

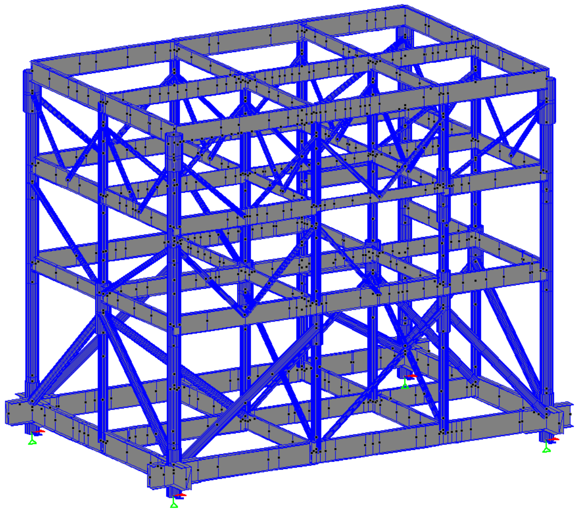
Structure Design Final: Structure Fabrication

Structure Painting Work

PFP/CSP Application







Module Structure Design

Block Paint

Integration

3. Importance of Redundancy Analysis

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PFP/CSP for EPC Contractor (and Plant Owner)

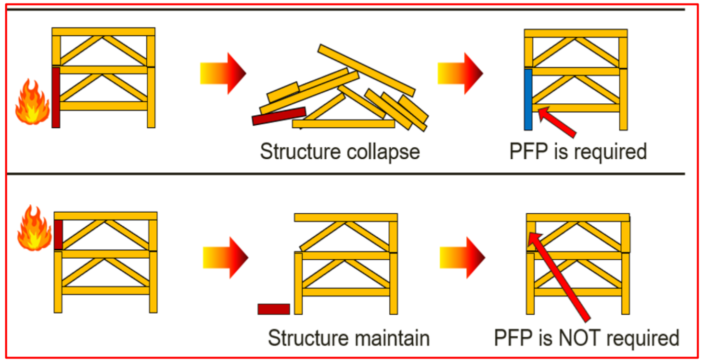
Optimization effort / Fit for Purpose of PFP/CSP is Important

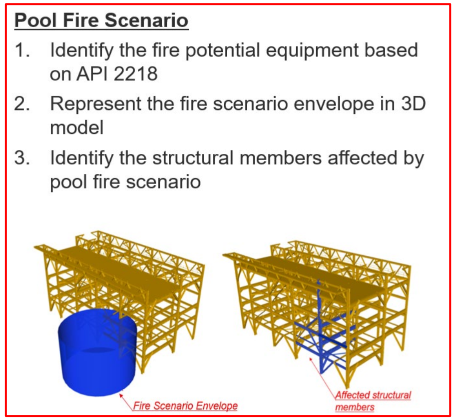
- **PFP/CSP design can have impact on project cost (CAPEX)**
  - 10% reduction of PFP/CSP can reduce cost by 1mm USD or more in large scale oil and gas facility
- **PFP/CSP is SCE (Safety Critical Element). Maintenance is required (OPEX)**
  - PFP/CSP maintenance required scaffolding, approved applicator, etc.
- **This also leads ease and safe of construction**

https://www.jgc.com/en/

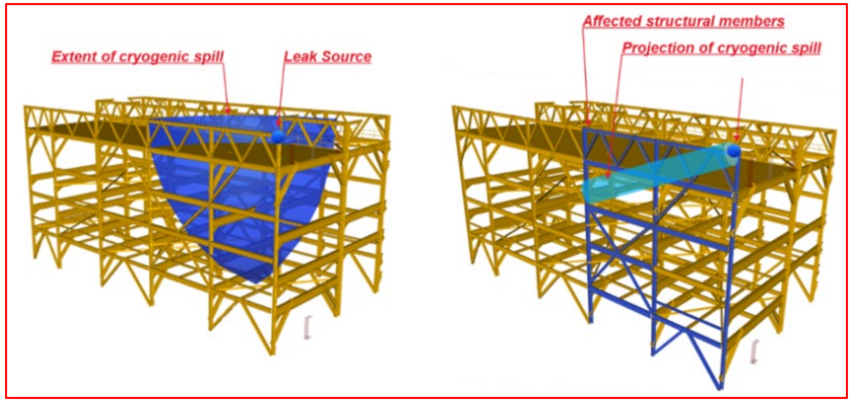
JGC's Past Research and Development

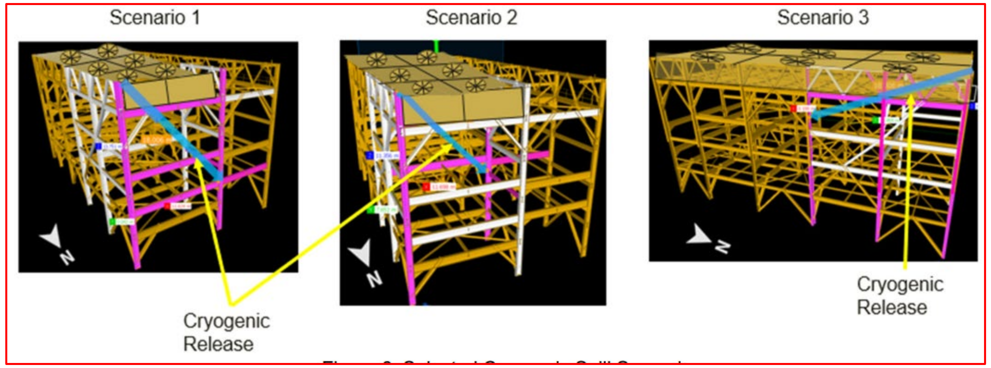
- **"Advanced Methodology of Structural Redundancy Analysis for Optimizing Passive Fire / Cryogenic Spill Protection" @ Hazards 31**

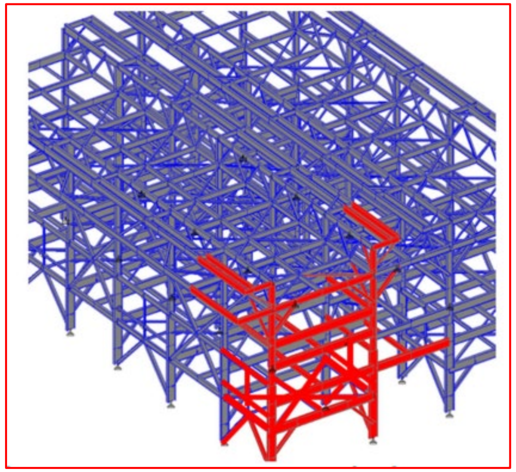




- **"Case Study of Structural Redundancy Analysis for Optimizing Cryogenic Spill Protection" @ LNG 2023**







4. Structure Design for Fire Redundancy

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4.1 Structure Design Philosophy for Fire Redundancy

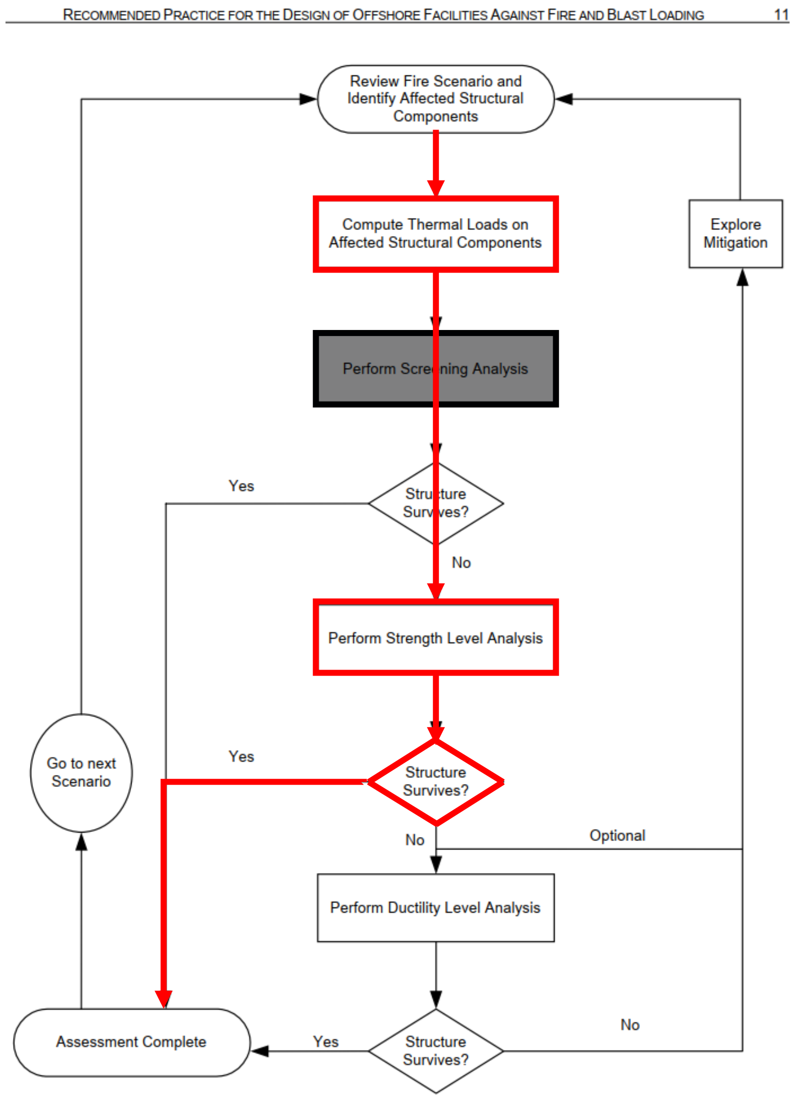
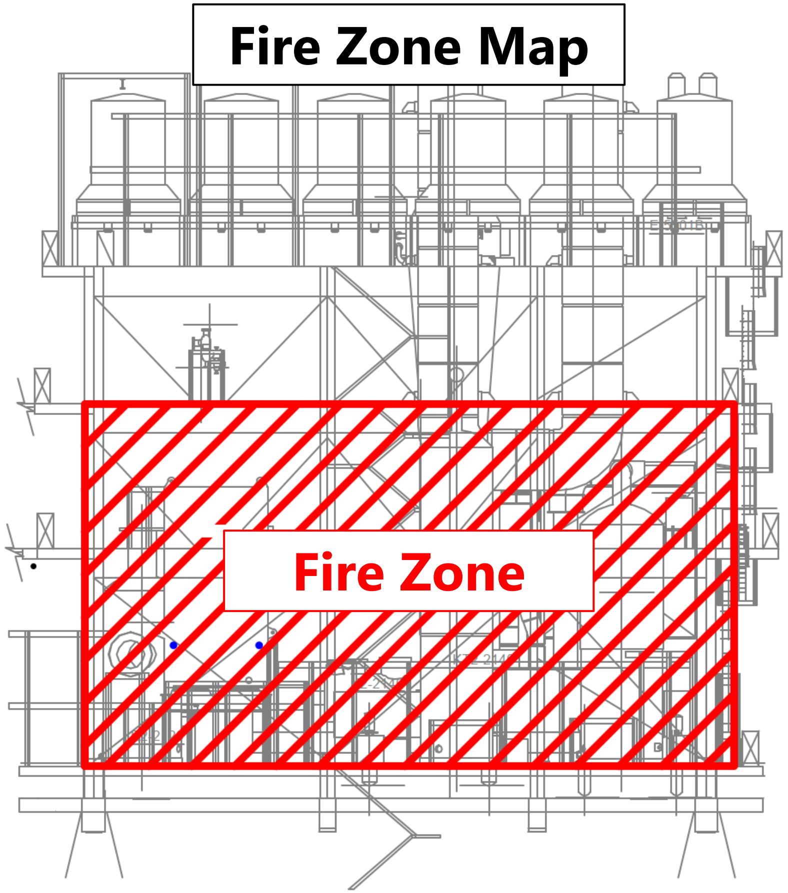


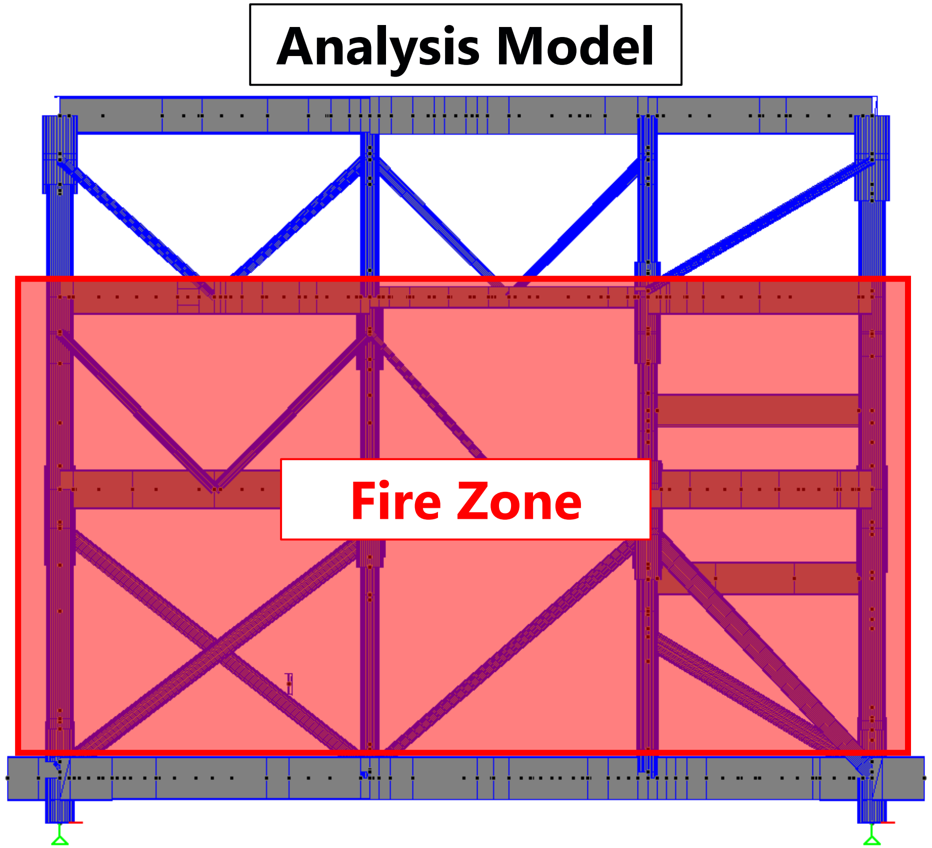
Figure 4-1—Process of Structural Assessment Against Fire

- **JGC has challenged fire redundancy analysis in EPC project**
- **Process of Structural Assessment for Fire**
  - Design flow was in accordance with API RP2FB
  - “Strength level analysis” was performed.
  - “Screening analysis” and “Ductility level analysis” were optimized.
- **Structure Performance Criteria**
  - Structure shall maintain overall integrity after fire event with frequency of 10^{-4} per years.
  - Plastic deformation and partial collapse were acceptable.
  - Performance criteria was based on the safety philosophy aligned with clients.

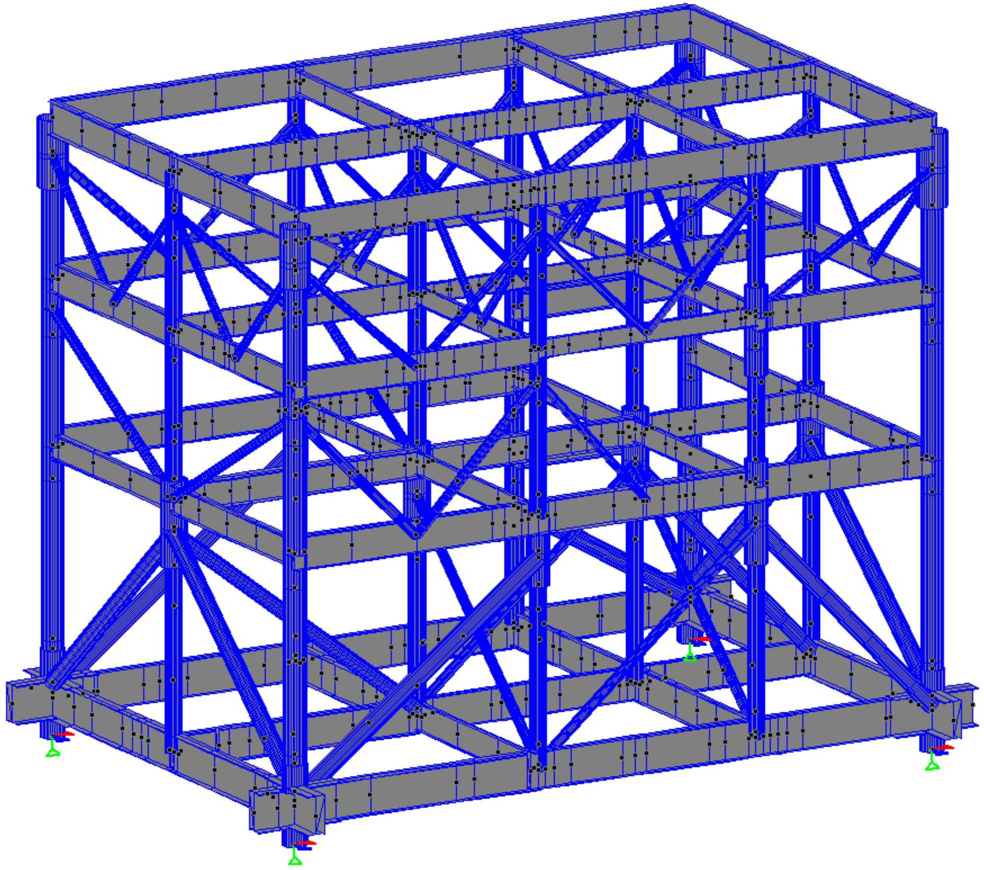
4.1 Structure Design Philosophy against Fire Redundancy

- **Fire Hazard Map**
  - Fire zone was based on "Fire Risk Analysis".
  - Jet fire would occur within fire zone.





4.2 Structure Design Setting against Fire Redundancy



Analysis Model

- **Structural Analysis Condition**

Contents	Remarks
Analysis Concept	Strength Level Analysis (API RP2FB)
Design Approach	Conventional liner elastic analysis (After fire event condition)
Software	STAAD Pro. Connect Edition
Verified Components	Primary structural elements
Acceptance Criteria	No failed member under code checking
Young’s Modulus	Varied depending on steel temperature (API RP2FB)
Yielding Stress	Varied depending on steel temperature (API RP2FB)

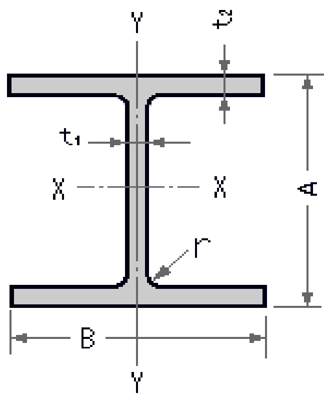
4.2 Structure Design Setting against Fire Redundancy

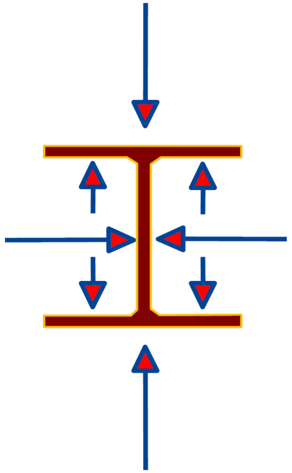
Table C.11.2-1—Young's Modulus and Yield Stress Reduction Factors for Carbon Steel at Elevated Temperature (ASTM A-36 and A-633 GR.C and D)

Steel Temperature		Young's Modulus Reduction Factor	Yield Stress Reduction Factor at Strain of			
(°C)	(°F)		0.2%	0.5%	1.5%	2.0%
20	68	1.000	1.000	1.000	1.000	1.000
100	212	0.991	0.940	0.970	1.000	1.000
200	392	0.961	0.847	0.946	1.000	1.000
300	572	0.916	0.653	0.854	1.000	1.000
400	752	0.826	0.600	0.798	0.956	0.971
500	932	0.617	0.467	0.622	0.756	0.776
600	1112	0.173	0.265	0.378	0.460	0.474
700	1292	0.130	-	0.186	0.223	0.232
800	1472	0.090	-	0.072	0.108	0.115
900	1652	0.0675	-	0.030	0.059	0.062
1000	1832	0.0450	-	0.0206	0.0394	0.0446
1100	2012	0.0225	-	0.0137	0.0263	0.0297
1200	2192	0.0000	-	0.0069	0.0131	0.0149

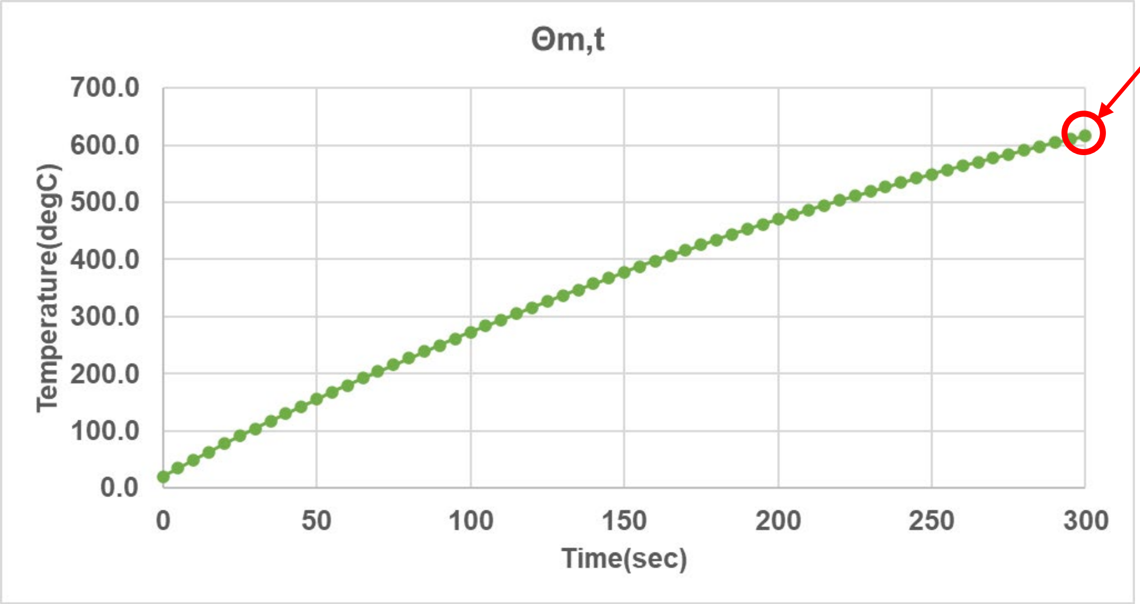
- **Young's Modulus Reduction**
  - Young's modulus reduction followed the reduction table in API RP2FB.
- **Yielding Stress Reduction**
  - Young's modulus reduction followed the reduction table in API RP2FB.
  - Strain limit was set as 1.5% as per discussion with client.
- **Load Combination**
  - Dead + 0.75Contents + Environmental (Wind + Motion)

4.2 Structure Design Setting against Fire Redundancy





- **Steel Temperature Range in Analysis**
  - Steel temperature (jet fire) was calculated for all columns, beams, braces separately.
  - Steel temperature reached after duration time was applied to structural analysis.



Steel temperature applied to analysis

4.2.5 Steel temperature development

4.2.5.1 Unprotected internal steelwork

(1) For an equivalent uniform temperature distribution in the cross-section, the increase of temperature $\Delta\theta_{a,t}$ in an unprotected steel member during a time interval Δt should be determined from:

$$\Delta\theta_{a,t} = k_{sh} \frac{A_m/V}{c_a \rho_a} \dot{h}_{net,d} \Delta t \qquad (4.25)$$

where:

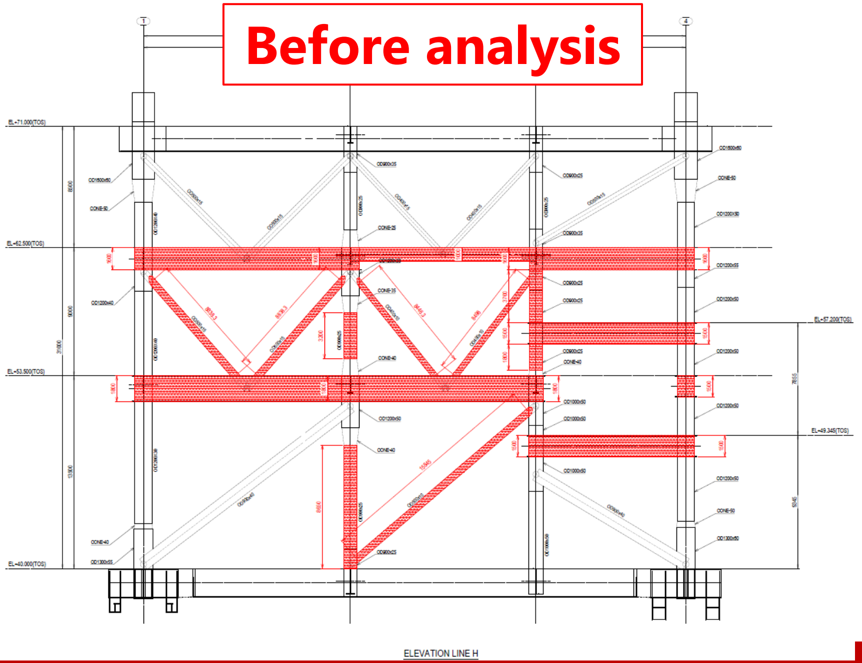
k_{sh}	is	correction factor for the shadow effect, see (2)
A_m/V	is	the section factor for unprotected steel members [1/m];
A_m	is	the surface area of the member per unit length [m²/m];
V	is	the volume of the member per unit length [m³/m];
c_a	is	the specific heat of steel, from section 3 [J/kgK];
$\dot{h}_{net,d}$	is	the design value of the net heat flux per unit area [W/m²];
Δt	is	the time interval [seconds];
ρ_a	is	the unit mass of steel, from section 3 [kg/m³].

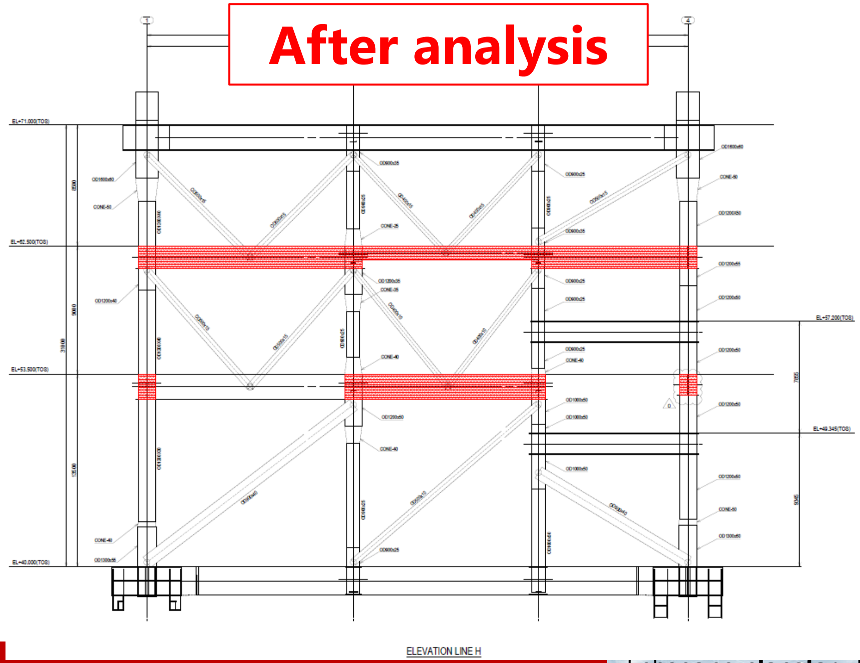
Reference: BS EN 1993-1-2:2005

4.3 Structure Design Results against Fire Redundancy

- **Fire Redundancy Analysis Results**
  - Extent area results

Structure type	PFP Extent Area Without Redundancy Analysis	PFP Extent Area With Redundancy Analysis	Extent Area Reduction Ratio
One largest structure	1,800 m2	1,100 m2	38.0%
All structure total	**6,000 m2**	**3,800 m2**	**37.0%**





5. Contractor Feedback through EPC Project

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5. Contractor Feedback through EPC Project

- **International Code and Standard**
  - Project clients are usually not so familiar with redundancy analysis. Therefore, specific prescription and recommendation in international code and standards are very helpful to make consensus with them about analysis criteria.
  - Below topics were discussed with client.
    Strain limit setting for yielding stress reduction (API RP2FB)

Steel Temperature		Young's Modulus Reduction Factor	Yield Stress Reduction Factor at Strain of			
(°C)	(°F)		0.2%	0.5%	1.5%	2.0%
20	68	1.000	1.000	1.000	1.000	1.000
100	212	0.991	0.940	0.970	1.000	1.000
200	392	0.961	0.847	0.946	1.000	1.000
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1200	2192	0.0000	-	0.0069	0.0131	0.0149

C.11.2 STRENGTH AND STIFFNESS OF STEEL

At elevated temperature, strength and stiffness of steel reduce.

Reduction of yield stress and Young's modulus may be calculated for carbon steel from the data furnished in Table C11.2-1 [23]. The values furnished are for 0.2%, 0.5%, 1.5%, and 2.0% strain.

Poisson's ratio for steel remains constant at 0.3 for steel, up to the melting point.

Loads induced by thermal expansion can be significant for highly restrained members and should be considered.

The interpretation of these data to obtain representative values of temperature effects on yield strength and Young's modulus should be performed at a strain level consistent with the design approach used:

For a design approach that does not permit some permanent set in the steel work after the fire load condition ceases, a strain of 0.2% should be used.

For a design approach that allows some permanent set in the steel work after the fire load condition ceases, higher values of strain, 0.5% to 2.0%, may be appropriate.

- 0.2% : No steel work after fire event
- 0.5% - 2.0% : With steel work after fire event

5. Contractor Feedback through EPC Project

- **International Code and Standard**
  - Below topics were discussed with client.

    Thermal properties of steel variation (thermal expansion, buckling, creep) / (API RP2FB)

C.11.1 THERMAL PROPERTIES OF STEEL

The thermal properties of steel vary with temperature. Experimental data are available for linear expansion, specific heat, density, and thermal conductivity [20,23]. Nominal thermal properties for structural steel that are valid for the range of room temperature to 600°C used to calculate fire load due to radiation, convection and conduction are given in Table C.11.1-1 [25].

Table C.11.1-1—Thermal Properties of Steel

Steel Type	Specific Heat (J/kg °C)	Thermal Conductivity (W/m °C)	Emmissivity	Coefficient of Linear Expansion (/ °C)
ASTM A36 A633 GR.C or D	520	46 - 65	0.75 - 0.90	14×10^{-6}
Stainless Steel	533	14 - 20	0.75	18×10^{-6}

The thermal expansion generates compressive loading on highly constrained members that may result in buckling, even at modest temperature. The effects of differential thermal expansion on members due to an uneven temperature profile across the member's section can generate additional bending moment on the section.

5. Contractor Feedback through EPC Project

- **Optimization in EPC Project comparing with Ideal Design Method**

There is the limitation of schedule, cost and client's requirement in EPC. Therefore, actual design method in project execution shall be optimized depending on each project.

Contents	Ideal Design	Actual Design in EPC
Goal	Minimize PFP extent area	Minimize PFP extent area However, shall meet client requirements, schedule and man hour budget
Scenario selection	Study and identify the individual fire scenario depending on actual fire event	Categorize or standardize conservative fire scenario to get client approval and save design time
Design Philosophy	International code and standard + various literatures and research, spending hour	Fully refer to international code and standard. Well-known study or research could be conducted during project phase
Structure analysis method	Perform ductility level analysis by FEA to achieve goal	Perform screening or strength level analysis by software widely used in design offices, which is realistic method to save analysis time and schedule

6. Summary

6. Summary

<Presentation Contents>

- **JGC applied fire redundancy analysis to EPC project, referring to API RP2FB.**
- **PFP extent area was totally reduced by 2,200m^2 (37% reduction).**
- **Design observation from the perspective of EPC contractor was introduced.**
  - Some discussion points in international code and standard
  - Optimization in EPC Project comparing with Ideal Design Method
- **Contractor figures out redundancy analysis with the restriction of schedule/cost and the requirement of client.**

<Next Challenge>

- **Apply CSP redundancy analysis to structure design to EPC project.**

Thank you very much

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