Closeout Evaluation

Pengerang Cogeneration Plant Project

Prepared for PETRONAS

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REVISED FINAL

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This IPA report summarises the performance of PETRONAS's Pengerang Cogeneration Plant (PCP) Project. We compared the performance of this project with the performance of similar projects in Industry and with PETRONAS's average performance using IPA's Project Evaluation System (PES®).[1]. Based on this analysis, past IPA research, and input from the project team, we provide lessons learned that can be used to improve future project performance.

IPA previously conducted pacesetter (PET-2207-PAC), prospective (PET-2403-PRO), and construction readiness (PET-2603-EXE) evaluations of the PCP Project.

Project team members supplied the information for this analysis in meetings on 25 and 26 July 2018, at the PCP site office in Pengerang, Malaysia. Project team members present at these meetings included Aesrol Azizie Othman (HSE Manager), Ahmad Sabri Ahmad Shukri (Project Engineer), Amirul Ariffin (Project Benchmarking), M Fauzi Bahari (QA/QC Manager), M Zulkarnain Muhamad (Engineering/Commissioning Manager), Mohd Faizul Mat Isa (Project Control Executive) ,Mohd Rasdan B Abd Rahim (Lead Civil & Structural Engineer), Nal-Azizi Nawawi (Head of Project Control & Services), Nguyen Chi Cuong (Project Benchmarking), Reza Rosdee Othman (Procurement Executive), Shahrizan Abd Manaf (Construction Engineer), Shaiful Ridzuan B Abd Ghani (Project Services Manager), Syed Jaffar B Syed Ahmad (Head of Project Execution), and Wan Azirul Azreen (QA/QC Engineer). Ben van Deventer and Pei Hsing Seow represented IPA. Although these project team members provided information, the interpretation and analysis are IPA's and do not necessarily reflect the views of those interviewed. For more information, contact Ben van Deventer of IPA at +61 499 057 657 or bvandeventer@ipaglobal.com.

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[1] PES is a registered trademark of IPA.

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PCP Project Closeout Dashboard

Key Message for Project System

- By most measures, the PCP project was a success: it delivered a functional facility in time for its main user, the RAPID Project, at low cost and with good safety
  - The project was very low cost despite its long schedule, much better than the average PETRONAS or industry performance
  - The only project outcome gap was that COGEN Unit 1 was not able to deliver power to the Peninsula Grid by the date committed as per the Power Purchase Agreement (PPA), which was 1 June 2017
- Gaps in project definition led to slip in execution, but with *Good* TDI, the project team were able to minimise the slip for COD 1 and deliver COD 2, 3, and 4 early

Key Project Metrics

Met Objectives

Business Objectives:		Met	**Technical Objectives:**		Met

Competitiveness / Predictability

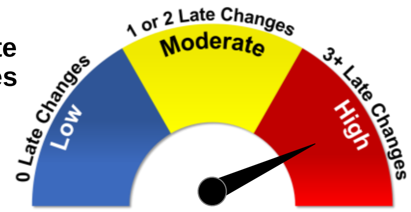
Competitiveness			Predictability		
Safety:	0.18 RIR	Better	**Cost Deviation:**	-8%	On Budget
Cost Index:	0.84	Low	**Schedule Deviation:**	29%	Late
Execution Duration Index:	1.23	Slow	**Construction Schedule Deviation:**	38%	Late

Discipline / Project Practices

Project Control Index

FEL Index

Major Late Changes



Team Development Index

Important Project Events/Issues

- The PCP Project faced many typical megaproject issues, including managing multiple stakeholders and first-to-region issues, such as a lack of basic infrastructure and services, which had an influence on its schedule
- Although the PCP Project had industry-average schedule targets at FID, the ill-defined interface[2] with RAPID[3] led to issues that resulted in a nearly 30 percent schedule slip; these issues first became apparent in detailed engineering and carried over into construction

[2] *Interface* in this instance refers to all relevant interactions, not limited to physical tie-in points.
[3] Refinery and Petrochemical Integrated Development (RAPID) Complex

- Delays in construction occurred because the steam pipe welding effort was underestimated, in addition to quality issues in the supply of structural steel and heavy rains floating a section of 2-meter diameter cooling-water pipe out of its trench
  - The planned construction duration was aggressive relative to Industry, and with slip highlighted as a risk by IPA at the Prospective evaluation

Lessons Learned and Recommendations

System Level

- Enforce company project control standards regardless of the contracting strategy
- Authorising projects without complete basic data damages project outcomes

Project Level

- Good safety outcomes can be achieved with disciplined owner-lead safety practices
- Engineering slip[4] is a leading indicator of problems in construction
- No contracting type transfers business risk to the contractor[5]
- Strong team integration helps ensure projects begin execution with solid foundations

[4] Slip in engineering was primarily due to several late changes from RAPID.
[5] The study by Ed Merrow, Chris Valleau, and Neal Banks, *Contracting for Engineering and Construction*, IBC 2015, IPA, March 2015, found that liquidated damages do not prevent slip but are strongly associated with lower operability.

PCP Project Metrics Summary

Project Outcomes

Metric	Estimate[6]	Actual	Industry Average[7]	PETRONAS Average
Safety (Incident Rate[8])				
DART		0.05	0.17	0.02
Recordable		0.18	0.39	0.02
Contingency	4 percent	-4 percent	-4 percent	Not Applicable
Cost Index	0.92	0.84	1.00	1.19
Cost Deviation	Not Applicable	-8 percent	0 percent	-15 percent
FEL Duration (Index)	38.0 months (1.80)	38.0 months (1.80)	21 months (1.00)	(1.19)
Execution Duration (Index)	35.7 months (0.95)	46.3 months (1.23)	38 months (1.00)	(0.90)
Schedule Deviation	Not Applicable	29 percent	19 percent	1 percent
Engineering Duration (Index)	15.0 months (0.78)	16.9 months (0.88)	19 months (1.00)	(0.99)
Construction Duration (Index)	23.8 months (0.84)	32.9 months (1.17)	28 months (1.00)	(1.04)
Start-Up Duration (Index)	19.8 months (2.83)	2.7 months (0.38)	7.0 months (1.00)	(1.63)
Cycle Time (Index)	90.6 months (1.38)	85.5 months (1.30)	66 months (1.00)	(1.24)

Project Drivers

Metric	Project	Industry Average	PETRONAS Average
BEAM Use	Not Used	15 percent	0 percent
Team Development Index	*Good*	*Fair*	*Fair*
FEL Index	*Fair* (6.75)	*Fair* (6.00)	*Poor* (6.95)

Project Execution Discipline

Metric	Project	Industry Average	PETRONAS Average
Project Control Index	*Fair*	*Fair*	*Good*
Major Late Changes	3	1.71	1.20
Project Manager Turnover	Yes	42 percent of projects	80 percent of projects

[6] Note that the estimate cost and schedule are based on the project targets as of FID, not the mid-execution re-baselined targets.
[7] Because of rounding, indices may not calculate exactly.
[8] DART (days away, restrictions, and transfers) and recordable incident rates are per 200,000 field labour hours.

Project Background

The Pengerang Cogeneration Plant (PCP) is within the Refinery and Petrochemical Integrated Development (RAPID) Complex in the Pengerang district, state of Johor, Malaysia. PCP is a gas-fired cogeneration plant with a capacity of 1,250 tonnes per hour (tph) of high pressure (HP) process steam and 1,220 MW of power to off-takers, together with the associated infrastructure and facilities.

Business Objectives:	• Meet the RAPID Complex's requirements for a reliable and continuous supply of steam and power as well as the export of power to the Peninsula Grid by the contracted COD 1 date of 1 June 2017 • After superior safety, the PCP project's priorities were: 1) Schedule, 2) Cost, and 3) Capacity
Project Objectives:	• Design and construct a cogeneration facility that can: – Reliably supply the RAPID Complex with 620 MW of power and 1,250 tph of steam – Supply up to 600 MW of power to the Peninsula Grid
Scope & Technology:	• To meet the reliability objective, the nameplate capacity is 1,965 MW (at ISO conditions) – Based on using four (N+1) Siemens SGT5-8000H GTGs (400 MW ISO each) and two STGs (115 MW and 250 MW). • The total installed steam production capacity is 3,388 tph – However, the declared capacity of the plant at its battery limits is 1,700 tph, limited by the steam header
Development & Execution Strategy:	• The PETRONAS project team and a cogeneration specialist consultant completed front-end engineering design (FEED) and developed the invitation to bid (ITB) packages • PCP Project scope was executed as a lump-sum turnkey (LSTK) (also called an engineering, procurement, construction, and commissioning [EPCC] contract) – The Siemens AG-led consortium was awarded the contract in April 2014

Project Timeline

FEL 2	
July 2011	• FEL 2 began • RAPID's requirements were not frozen, but the power and steam requirements were estimated at 480 MW and 2,000 tph, respectively • The owner, PETRONAS Gas & Power Business Unit (GPBU), requested the Project Management and Delivery (PMD) team to conduct pre-feasibility studies to select a scope optimised for RAPID's estimated energy demand
August 2011	• The pre-feasibility study indicated that the total generated power can be as high as 2,000 MW with 2,000 tph of steam generation through a Cogeneration (Cogen) Plant concept – GPBU intended to use the balance for power export to Peninsula Grid • Endorsement of the proposal to export power to the Peninsula Grid is granted by the PETRONAS Executive Committee (EXCO)
October 2011	• The PMD project team receives endorsement from the Infrastructure & Utilities Project Steering Committee to undertake FEED for the PCP Project with a technical partner that is a specialist in cogeneration simulation and grid system studies
January 2012	• Following a series of presentations to the Malaysian Energy Commission and MyPower, PETRONAS submitted the PCP plan of development to the Malaysia Energy Commission
March 2012	• End of FEL 2 and the beginning of FEL 3 • The PCP Project receives authorisation from the PETRONAS EXCO to proceed with in-house led FEED • Project is planned to be executed under an EPCC contract, with oversight by a PETRONAS lead project management team (PMT), in conjunction with an external project management partner

FEL 3	
March 2012	• PMD assumed the overall leadership and project management team role for FEED • VY Consult appointed the technical consultant responsible for the overall FEED deliverables
April 2012	• As RAPID's FEED progressed concurrent to the PCP Project's, the steam demand was revised from 2,000 tph to 1,342 tph and power to 620 MW • Following a meeting with the Planning and Implementation Committee for Electricity Supply and Tariffs (JPPPET), PETRONAS commits to supplying at least 400MW of power to the Peninsula Grid
May 2012	• Following the submission of the PCP development plans, Conditional Approval for the development of the Pengerang cogeneration plant by KeTTHA (Ministry of Energy, Green Technology, and Water)
November 2012	• EPCC contractor prequalification evaluation ends with 15 bidders invited to tender • Due to potential conflicts of interest, the FEED technical consultant was not allowed to bid for EPCC contract or the PMT external party partnership

December 2012

- FEED for the EPCC ITB preparation were completed by the technical consultant
  - Estimated ISBL costs were US$1,620 million with a target completion by February 2017

May 2013

- ITB packages issued to 15 bidders that passed the prequalification evaluation
  - Each was required to submit a bid for the base case of a natural gas fired cogeneration plant with a nominal capacity of 1480 tph high pressure steam and 1220 MW of power together with associated infrastructure and utilities.
  - Each bidder was also required to submit an alternative design that met the base case requirements *and* delivered further cost, schedule, and operating costs benefits

January 2014

- Delay in site preparation works necessitated a plot location change; the new plot is now located north-west of the original plot; it was of equivalent size and dimensions.
- Bid phase extended by a month due to the plot change; the relocation required new fire, blast, and noise reviews, necessitating a layout redesign
- Target completion date was updated with commercial operating date (COD) 1 in June 2017 to meet supply agreement with Tenaga Nasional Berhad (TNB), and the start-up of remaining units staggered until COD 4 in February 2019

March 2014

- Bid evaluation completed with the Siemens AG-lead consortium selected as the preferred bidder based on the PCP asset life cycle cost
- With Siemens AG's engineering team located in Germany, it was planned that the PMT would be partly located in Germany and budget allocated accordingly

April 2014

- Following an economic review, RAPID was approved with some packages cut, changing the project's power and steam profile
- FID: PCP is included in the list of packages approved for execution with an estimated ISBL cost of US$960.6 million, based on the preferred bidder's submission
- EPCC and PMT external party partnership contract award recommendations were approved as part of the PCP FID package

May 2014

- EPCC contract awarded to the Siemens AG-lead consortium and the PMT external party partnership to Mott MacDonald

Execution

June 2014

- Notice to proceed issued to EPCC contractor
- Detailed schedule submitted by Siemens, with plan to meet COD 1 a month early to provide contingency

July 2014

- RAPID's steam off take changed from high pressure (HP) steam to very high-pressure steam (HHP) steam, constituting the first major late change and delaying the start of detailed engineering
- At RAPID's request to optimise that facility's layout, the tie-in points for steam, demineralised water, treated water, fire water, condensate and effluents were relocated from the south to the west side of the PCP
  - With a cost effect of US$5 million, this constituted the second major late change

December 2014

- Siemens instructed to hold off steam package engineering due to potential reversal of RAPID's change to HHP extraction
- Began piling as planned for the heat recovery steam generator
- Plans to locate part of the PMT to Germany were cancelled, resulting in a significant underrun of estimated project management costs

January 2015	• RAPID confirmed the third major late change by reversing from HHP steam to HP steam and confirmed revised steam parameters • Steam package engineering resumes
February 2015	• Siemens submitted notice of schedule delay due to steam changes
June 2015	• Installation of structural steel delayed by quality issues (incorrect positioning of fastening penetrations) • Delays made worse by lack of local fabrication services
August 2015	• Construction began with the first foundations • Contractor noted that productivity was much lower than expected due to site location
December 2015	• Engineering progress reached 95 percent, marking the end of detailed engineering, 3.4 months later than planned
January 2016	• Double shifts began to mitigate the effect of critical resource underestimation (error in estimating labour hours for steam pipe welding) • Heavy rains floated a section of 2-meter diameter cooling-water pipe out of its trench • All construction schedule contingency (float) consumed
September 2016	• Project had a lost time injury when a worker fell from height while erecting scaffold on the cooling tower • In immediate response to this incident, the PETRONAS project team instituted a complete reform of the safety on site, beginning with the appointment of a large on-site presence of owner safety supervisors and scaffolding inspectors. – The increase in on-site presence was matched by the EPCC contractor. – In lieu of the penalty imposable as per the EPCC contract, Siemens invested ~RM 1 MM in a *Practical Safety Training Centre*
January-April 2017	• Realising that the Commercial Operation Date (COD) 1 date would not be met, the project team began working on an alternative construction and commissioning strategy to minimise slip • Informal meetings held with TNB to discuss open-cycle operation of the first cogeneration unit • Project director replaced in a planned turnover driven by a companywide restructure
May 2017	• PETRONAS issued a letter to TNB that COD 1 would be delayed, with COD 1 (open cycle) to be delivered by 21 October 2017, and closed cycle by 28 February 2018
January 2018	• Second project director turnover, which was unplanned in this instance
May 2018	• Construction completion marked by the first fire of the fourth cogeneration unit

Start-Up

October 2017	• COD 1 (Open Cycle) achieved as per updated construction and commissioning plan following many failed starts; Siemens' base tune was based on their recent successful install in Egypt; corrections to this tune resulted in successful firing • With part of the plant now operating, additional safety risk was introduced – This risk was mitigated by physically sectioning off the operating part of the plant, and workers were briefed on simultaneous operations requirements
January 2018	• With the commissioning of the steam turbine generators, COD 1 (Closed Cycle) was achieved as per updated construction and commissioning plan
April 2018	• After a flashback on the second turbine caused by an incorrectly installed pressure sensing line, COD 2 was achieved using the modified tune from the first cogeneration unit • Steam blowing to RAPID begins
July 2018	• COD 3:100 percent grid code test completed; however, commercial operation was not yet declared
August 2018	• COD 4: 100 percent grid code test completed 5 months ahead of the planned schedule, but commercial operation was not yet declared • As the plant was now ready to be fully operational, this marks the end of start-up and the end of the project cycle
September 2018	• Forecast COD 3 with the declaration of commercial operation of the third cogeneration unit
October 2018	• Forecast COD 4 with the declaration of commercial operation of the fourth cogeneration unit

Engineering slip is a leading indicator of problems in construction

Driven by multiple late changes from RAPID, the PCP Project's detailed engineering slip significantly disrupted construction. Research has shown engineering slip to be a key leading indicator of problems during construction and field cost growth. PETRONAS teams should be vigilant for signs of slip in the engineering schedule and should evaluate ahead of time how construction may be affected as well as potential responses.

Competitive Analysis of Project Outcomes

Basis of Comparison—Analytic Methodology

The analysis presented in this report is based on statistical models and comparisons that draw on the IPA PES Database.

Statistical Models

Using industry data, IPA developed a set of multi-variate regression models to benchmark major project outcomes (cost and schedule). The benchmarks and distributions generated by the models account for the fact that a project outcome has multiple drivers. Controlling for these drivers simultaneously allows us to measure the effect of each variable on that outcome. Our analytic techniques also include data normalisation methods that allow us to make valid comparisons across different time periods (e.g., constant dollars) and for different regions of the world (i.e., location adjustments).

This evaluation uses the following statistical models:[9]

- Contingency Allowance Model
- Cogeneration Cost Capacity Model
- FEL Duration Model
- Detailed Engineering Duration Model
- Construction Duration Model
- Engineering and Construction (Execution) Duration Model

[9] The models used in this evaluation are described in the Cost and Schedule sections of this report.

Comparison Dataset

IPA's research has identified inherent project characteristics that influence performance (e.g., project size, location, technology, technical complexity, and scope). Based on these findings, we extract project subset(s) from the IPA PES Database with similar characteristics to serve as a basis of comparison for the project being analysed.

For the PCP Project cost analysis, we used IPA's Cogeneration Cost Capacity Model. The Cogeneration Cost Capacity Model generates an industry cost benchmark for a cogeneration plant's inside battery limits (ISBL) scope based on the power output, steam to power ratio, presence of a steam turbine generator, and number of feedstock types, among other characteristics. The model comprises 39 major projects executed by more than 25 multinationals across the world in the refining, chemicals, mining, consumer products, and other sectors. To produce the benchmark, the model was executed excluding any projects installing less than 100 MW of power. This dataset of 39 major cogeneration projects was also used to provide the cost breakdown analysis.

To validate the schedule benchmarks, we considered comparable greenfield projects installing a large amount of pre-engineered equipment. As the PCP is connected to the national grid, its start-up duration is benchmarked against power generation projects. For this reason, a third comparison dataset was selected for power generation projects of similar cost to the PCP Project.

The Cogeneration Cost Capacity Model's definition of ISBL scope for analysis purposes is shown for reference in the table below.

IPA Cogeneration Model Scope

Scope Included in Model	Scope Excluded From Model
• Gas turbine generators (GTGs)	• Pumps
• Heat recovery steam generators (HRSGs)	• Tanks
• Supplemental firing/duct burner for HRSG	• Cooling tower
• Steam turbine generators	• Feed water heaters
• Condenser (connected with the steam turbine)	• Condensate treatment plant and ancillaries
• Inlet air chilling/heating system	• Wastewater treatment system
• Feed gas compressor	• Bridge cranes
• Selective catalytic reduction/emission control	• Station/instrument air compressor
• Feed water pump	• Reciprocating engine generator set(s)
• Distributed control system	• General plant instrumentation
• Generator step-up transformers	• Medium voltage equipment
	• Low voltage equipment
	• Substation
	• Any auxiliary/spare equipment

The PCP Project's ISBL scope key characteristics and those of IPA's Cogeneration Cost Capacity Model are summarised in the table below.

Key Project Characteristic	Project	IPA Cogeneration Model Dataset *(n = 39)*
Cost *(millions of US$)*	811[10]	197 *(13 to 839)*
Location	Pengerang, Johor, Malaysia	59 percent North America 31 percent Europe 10 percent Middle East and Asia
Net Power (ISO Rating) Output[11] (MW)	1,965	220 *(4 to 1,000)*
Number of GTGs	4	54 percent single GTG 28 percent two GTGs 18 percent three or more GTGs
Number of STGs	2	64 percent no STG 33 percent single STG 3 percent two STGs
Sector	Refining	46 percent refining 44 percent chemicals 10 percent others, including mining, pulp and paper and consumer products
Contracting	LS EPCC	67 percent LS EPC 21 percent reimbursable 12 percent mixed
Project Type	New unit	
Construction Methodology	Modular	53 percent modular
Technology	Off-the-shelf	80 percent off-the-shelf 13 percent new integrations only 7 percent minor or substantially new

The PCP Project's ISBL scope key characteristics and those the schedule comparison datasets are summarised in the table below.

Key Project Characteristic	Project	Schedule Comparison Dataset	
		Planning and Execution *(n = 11)*	**Start-Up *(n = 5)***
Cost *(millions of US$)*	811[12]	721 *(361 to 956)*	723 *(488 to 1326)*
Location	Pengerang, Johor, Malaysia	27% North America 18% Asia Pacific 10% South America 45% Europe, Middle East, and Africa	20% South America 80% Europe, Middle East, and Africa
Project Type	New Unit		
Scope	Cogeneration Plant	Pre-engineered equipment installations	Power plants
Technology	Off-the-shelf	82 percent off-the-shelf	80 percent off-the-shelf

[10] Cost in U.S. dollars for total cogeneration plant's ISBL scope.
[11] Total net ISO power output from the GTGs and STGs combined.
[12] Cost in U.S. dollars for total cogeneration plant's ISBL scope.

Safety

Project Safety			
Metric[13]	**Project**	**Industry Average**	**PETRONAS Average**
Total Field Hours	17,611,598	Not Applicable	Not Applicable
DART Incident Rate	0.05	0.17	0.02
Recordable Incident Rate	0.18	0.39	0.02

The PCP Project had 16 recordable injuries, 4 of which were DART incidents, in 17,611,598 field hours. The PCP Project's recordable incident rate is therefore 0.18 per 200,000 field hours, which is better than Industry for large projects but higher than the PETRONAS average. The DART rate is 0.05, which is better than Industry and comparable with the PETRONAS average.

IPA research shows that the owner-company safety culture and operations experience are transferred to capital projects, and that the owner organisation has the greatest influence on project safety. The key to excellent construction safety lies in the attitude and values of the individual workers, which influence the decisions that they make on a task-by-task basis. Financial incentives to the contracting company are nearly always too far removed from the individual workers to influence their decisions. The table that follows shows the team's use of the safety Best Practices identified by IPA.

Safety Best Practices		
Practice	**Status**	
***Best Practical* FEL**	***No***	• The project had *Fair* FEL at authorisation
Assign a safety manager/ specialist to the project	***Yes***	• The team included a dedicated owner safety specialist, and, following the LTI, increases the safety supervisors
Use pre-task planning before every task	***Yes***	• Standard in PETRONAS's work process
Recognition rewards to individuals for safety	***Yes***	• Individuals were recognised, and rewards were given for good safety practices
Reward workers for identifying hazards	***Yes***	• Workers were incentivised by recognition awards to correct unsafe conditions • Using the HERO card system, the team focused on more than just safety incidents: it examined the hazards and potential incidents to change behaviours
Give immediate feedback on safety suggestions	***Yes***	• This practice was considered fundamental to success
Apply specific disciplinary actions (temporary leave, dock pay, change position, etc.)	***Yes***	
Incorporate safety into Constructability Reviews	***Yes***	• The project's HSE manager participated in Constructability Reviews

[13] DART (days away, restrictions, and transfers) and recordable incident rates are per 200,000 field labour hours.

Good safety outcomes can be achieved with disciplined owner-lead safety practices

Precipitated by the lost time incident, the PCP Project team developed a strong owner-led safety culture that used most safety Best Practices. The project's safety was better than Industry, despite the significant growth in construction labour, subcontractor turnovers, schedule pressure, and other challenges. Furthermore, IPA's research has found that safety is positively influenced by initiatives, such as the HERO Card system used by the PCP Project, that reward safe behaviour, rather than incentives that reward good outcomes. Contract incentives aimed at rewarding safety outcomes may lead to underreporting of safety incidents.

Cost

Project Cost (millions of US$)			
Cost Element	**Actual Cost**	**Cost Estimate**	**Deviation**[14]
Project Definition	11.35	11.35	0 percent
Detailed Engineering	52.47	46.71	12 percent
Project Management	53.48	77.33	-31 percent
Equipment	478.78	480.83	-0.4 percent
Bulk Materials	72.04	72.15	-0.2 percent
Construction Management	12.50	12.50	0 percent
Construction Labour	121.31	115.24	5 percent
Other Construction	8.77	8.77	0 percent
Contingency		34.05	Not applicable
Total Engineering and Construction Costs	**810.69**	**858.92**	**-8 percent**
Escalation		0.00	Not applicable
Special	83.61	85.66	-2 percent
Start-Up	16.00	16.02	0 percent
Total Project Costs	**910.30**	**960.60**	**-5 percent**

Cost Analysis Considerations

IPA's database stores cost values normalised to a constant location, time, and currency (U.S. Gulf Coast [USGC], in January 2003 U.S. dollars). To perform this normalisation, we remove escalation from estimates, convert nominal currency to U.S. dollars, apply a factor to control for location-based wage and productivity differences from the USGC, and then de-escalate to January 2003. Estimates are de-escalated from the estimate date while actual costs are de-escalated based on an expenditure profile established from the project's schedule.

The PCP Project cost analysis considers only the ISBL. The estimated project costs are based on the ISBL costs that were submitted as part of the EPCC bid, in combination with PETRONAS' project planning costs and estimated project management costs. When comparing actual and estimates, IPA normally de-escalates actual costs to the date of the estimate and considers only the estimate without escalation. However, because the PCP Project estimate had escalation embedded in it, actual costs are not de-escalated and are instead compared as spent.

Due to the lump-sum turnkey (LSTK) contract, detailed actual costs are not available to the owner's team, only the cost of changes for which change orders or notices were issued. The actual costs reported are estimated based on a combination of the estimated ISBL costs, reflective of the contract sums, and the allocation of the costs of changes to the relevant cost categories.[15] There may be some cross-contamination of costs between the categories; the PCP Project's breakdown may not be reliable.

[14] Cost deviation is reported as a percent of the cost estimate.
[15] The PCP Project team allocated these costs in consultation with IPA.

Contingency

One area of concern in a company's project system is assigning reliable contingency allowances in project cost estimates. Contingency that reflects project risks allows a better understanding of the likely project costs.

IPA's statistical model, called the Contingency Allowance Model (CAM), provides an industry benchmark of the contingency required to achieve various confidence levels of an overrun or underrun. In other words, we have modelled the difference between the base estimate—the estimated cost without contingency, escalation, special, and start-up costs—and the actual cost. Note that this is not the amount of contingency *included* in the estimate; it is the contingency that was used, and it is negative when a project spends less than its base estimate.

Contingency			
	Contingency in the Estimate	**Contingency Used**	**Industry Average Contingency Use** ***(50 percent range)***
Contingency	4 percent	-4 percent	-4 percent *(-10 to 2 percent)*

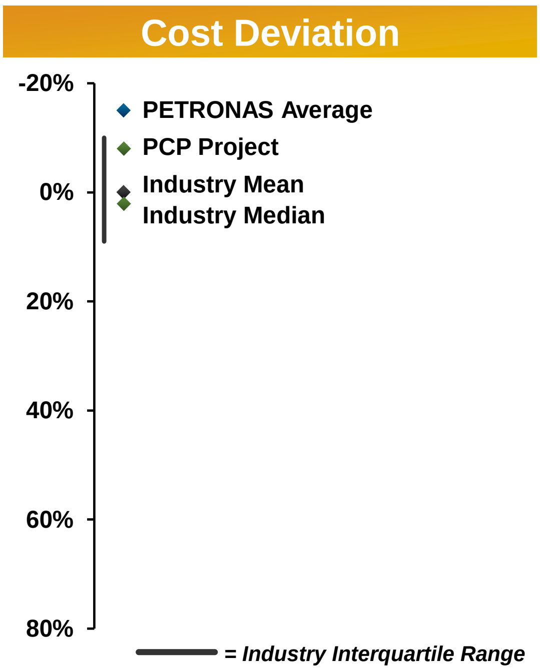
The PCP Project estimate included 4 percent contingency relative to its base estimate. The contingency allocation was based on business guidance, not on project risk measures. Based on the relative amount of equipment in the estimate, FEL, and other project characteristics, Industry has historically used (i.e., spent) an average of -4 percent contingency for the design and construction of facilities like the PCP Project. The negative contingency benchmark indicates base estimate underrun. One large contributor to the low contingency benchmark is the high equipment component in the project's cost estimate. Equipment cost is the cost category that experiences the least cost growth, and as such, projects that have a high equipment component typically require minimal contingency. The project used -4 percent contingency, which is in line with the industry average.

Cost Deviation

Cost deviation is measured as the difference between the project's authorised and actual cost. In other words, how accurately did the project team forecast the actual project costs?

The PCP Project underran its ISBL cost estimate by 8 percent; the project's cost deviation was in the expected range of Industry, and more predictable than a typical PETRONAS project.

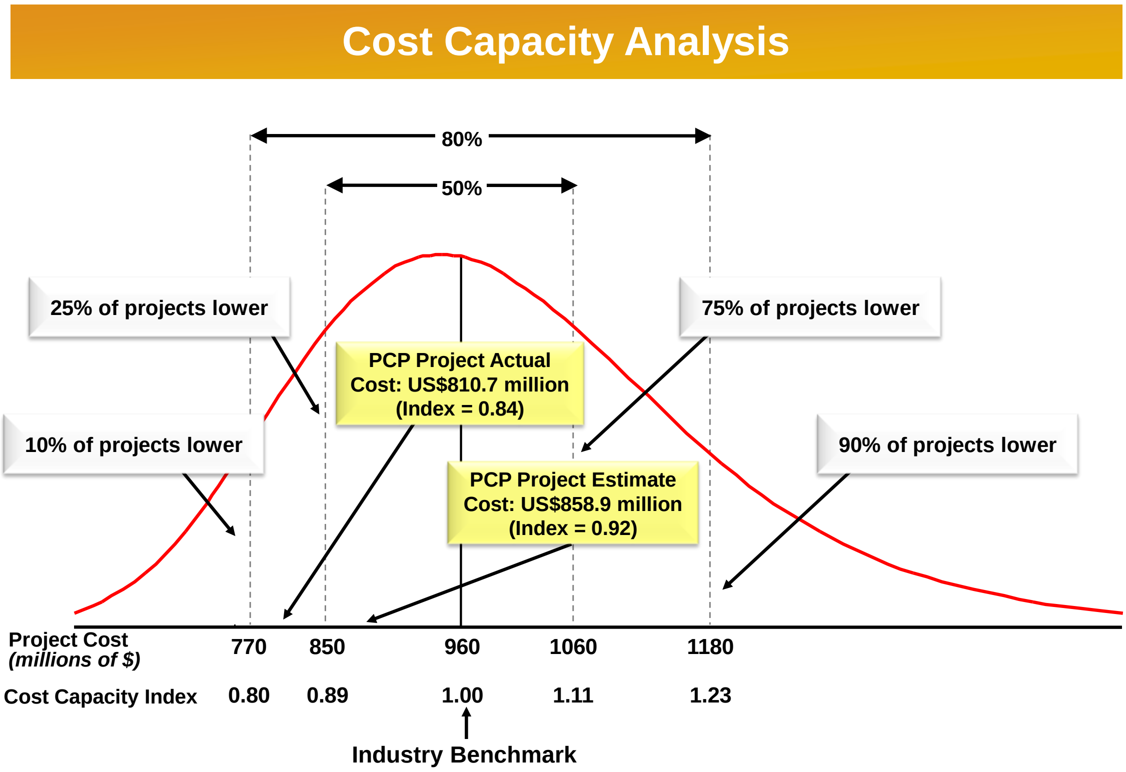
Although the project had additional costs associated with late scope and design changes, the largest contributor to the cost deviation was the underrun of project management costs, principally due to the cancellation of the overseas relocation of the PMT.



Cogeneration Cost Capacity Analysis

IPA's cost capacity analysis[16] evaluates what Industry would spend, on average, to develop a given functionality given the design capacity and operating conditions (i.e., how much is spent versus others to produce a given amount of product).

Using IPA's Cogeneration Cost Capacity Model, we benchmarked the estimated and actual ISBL costs for a cogeneration plant with a total ISO-rated power output of 1,965 MW, and then compared that cost with the PCP Project's ISBL cost. IPA's Cogeneration Cost Capacity Model generates an industry average cost benchmark based on the electrical power output and the number of feedstocks, among other characteristics.



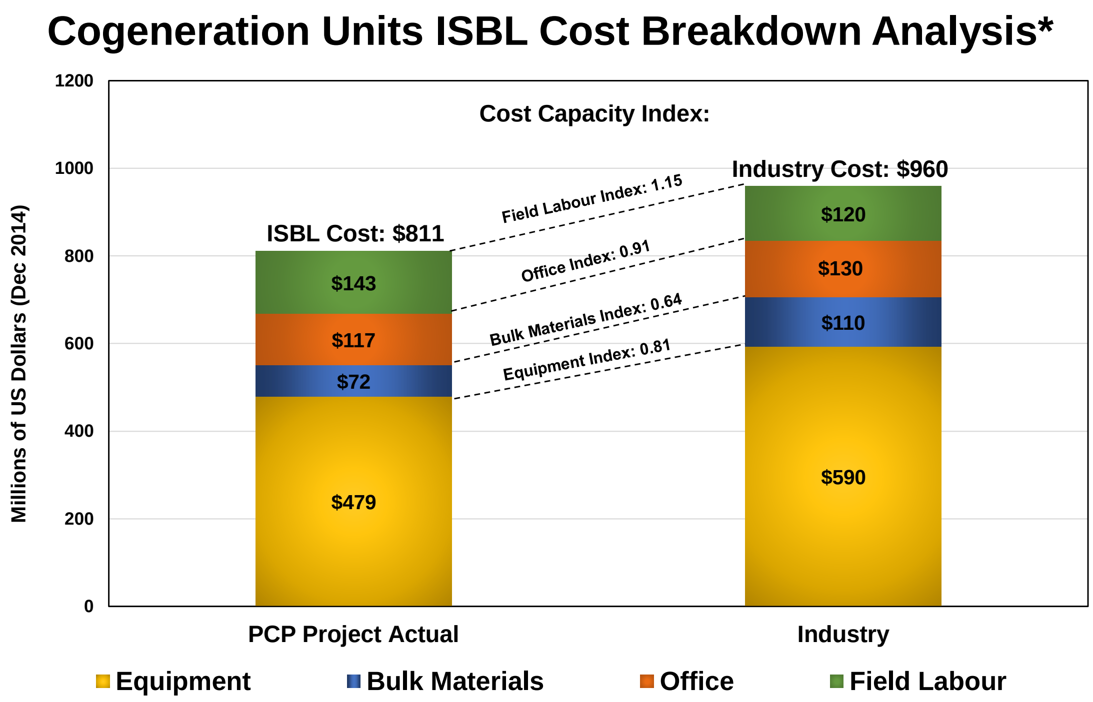
As shown above, the project's estimated ISBL cost of US$858.9 million was 8 percent lower than the industry average of US$960 million for a similar cogeneration unit (similar power and single fuel feed), resulting in an estimate Cost Capacity Index (CCI) of 0.92. The actual cost was US$810.7 million, resulting in an actual CCI of 0.84. Given that there was no change in the design, the change in the CCI between estimate and actual is in line with the estimate underrun.

[16] IPA uses the term cost *capacity* analysis, but it is really a cost *functionality* analysis because the model considers other factors besides capacity.

Cost Breakdown Analysis

To complement our cost analyses and provide a better understanding of the difference between the project and industry costs, we provide cost breakdown analyses for the PCP Project's ISBL cost based on the cost comparison dataset and its cost capacity benchmarks. The costs are reported in millions of 2018 U.S. dollars in a Peninsular Malaysia location and the estimate includes the previously discussed contingency allocations. The estimated and actual project values outside the interquartile range of Industry, either on the low or high end, are in bold and underlined.

Cost Category (millions of US$)	Estimate (with Contingency Allocation)	Actual	Industry Average *(50 percent range)*
Project Definition	<u>**11.35**</u>	<u>**11.35**</u>	24 *(20 to 31)*
Detailed Engineering	50.91	52.47	64 *(48 to 79)*
Project Management	<u>**84.28**</u>	<u>**53.48**</u>	41 *(24 to 53)*
Equipment	<u>**480.83**</u>	<u>**478.78**</u>	593 *(516 to 672)*
Bulk Materials	72.15	72.04	113 *(67 to 143)*
Construction Management	14.64	12.50	15 *(7 to 18)*
Construction Labour + Other Construction	<u>**144.77**</u>	<u>**130.08**</u>	107 *(78 to 125)*



* Costs may not add up and indices may not calculate exactly because of rounding

As displayed in the table and figure above, the cost breakdown analysis for the cogeneration plant's ISBL cost shows that, except for construction labour plus other construction and project management, actual costs are lower than Industry. Given the labour requirement underestimate, we would expect actual field labour costs to be higher than Industry; however, the contractor absorbed this cost and this cost category underran its estimate. As noted earlier, due to the LSTK nature of the contract, there might have been some cross-contamination of costs between the categories; hence, the PCP Project's breakdown may not be reliable. For example, it is possible that some bulk material costs were included in the field labour costs.

Schedule

Project Schedule						
Phase	**Planned Start**	**Planned Finish**	**Planned Duration (months)**	**Actual Start**	**Actual Finish**	**Actual Duration (months)**
Project Definition	1 Jul 11	31 Aug 14	38.0	1 Jul 11	31 Aug 14	38.0
FEL 2	1 Jul 11	1 Mar 12	8.0	1 Jul 11	1 Mar 12	8.0
FEL 3	1 Mar 12	31 Aug 14	30.0	1 Mar 12	31 Aug 14	30.0
Authorisation	15 Jan 14	3 Apr 14	2.6	15 Jan 14	3 Apr 14	2.6
Detailed Engineering	1 Jun 14	31 Aug 15	15.0	16 Jul 14	13 Dec 15	16.9
Procurement	30 Jun 14	31 Jul 16	25.0	14 Aug 14	20 Oct 16	26.2
Construction	1 Jun 15	24 May 17	23.8	27 Aug 15	25 May 18	32.9
Start-Up	10 Mar 17	16-Jan-19	22.2	8 Aug 17	15 Aug 18	12.2
COD 1		1 Jun 17			21 Oct 17	
COD 2		16 May 18			10 Apr 18	
COD 3		1 Dec 18			23 Sep 18	
COD 4		1 Feb 19			21 Oct 18	
Execution	1 Jun 14	24 May 17	35.7	16 Jul 14	25 May 18	46.3
Cycle Time	1 Jul 11	16-Jan-19	90.5	1 Jul 11	15 Aug 18	85.5

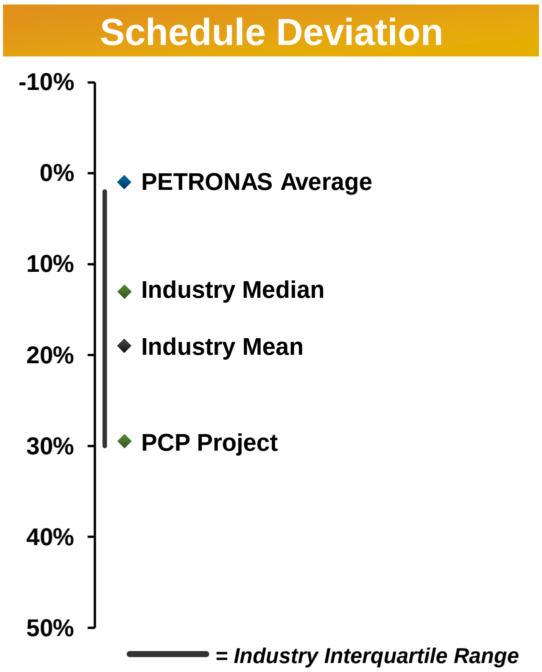
Schedule Analysis Considerations

Like the cost analysis, the schedule analysis in this report is based on models that use the IPA PES Database. We used the datasets described in the Basis of Comparison section to validate the schedule models and to benchmark the project’s start-up duration. The start-up duration used in this analysis is different from the duration provided by the project team, as IPA only considers the time between mechanical completion and steady state operation of the final unit. The completion of the grid code acceptance test of the fourth cogeneration unit has been taken as the end of start-up as this is when the plant is deemed to be for ready for steady-state operation.

Schedule Deviation

Schedule deviation is the difference between the project's authorised and actual execution (engineering and construction) durations. In other words, how accurately did the project team forecast the actual project schedule?

The PCP Project slipped its planned execution schedule by 29 percent, which is more than the PETRONAS average execution schedule slip of close to zero. The industry average schedule slip for large projects is 19 percent;[17] the PCP Project's schedule slip is at the upper limit of the Industry interquartile range.

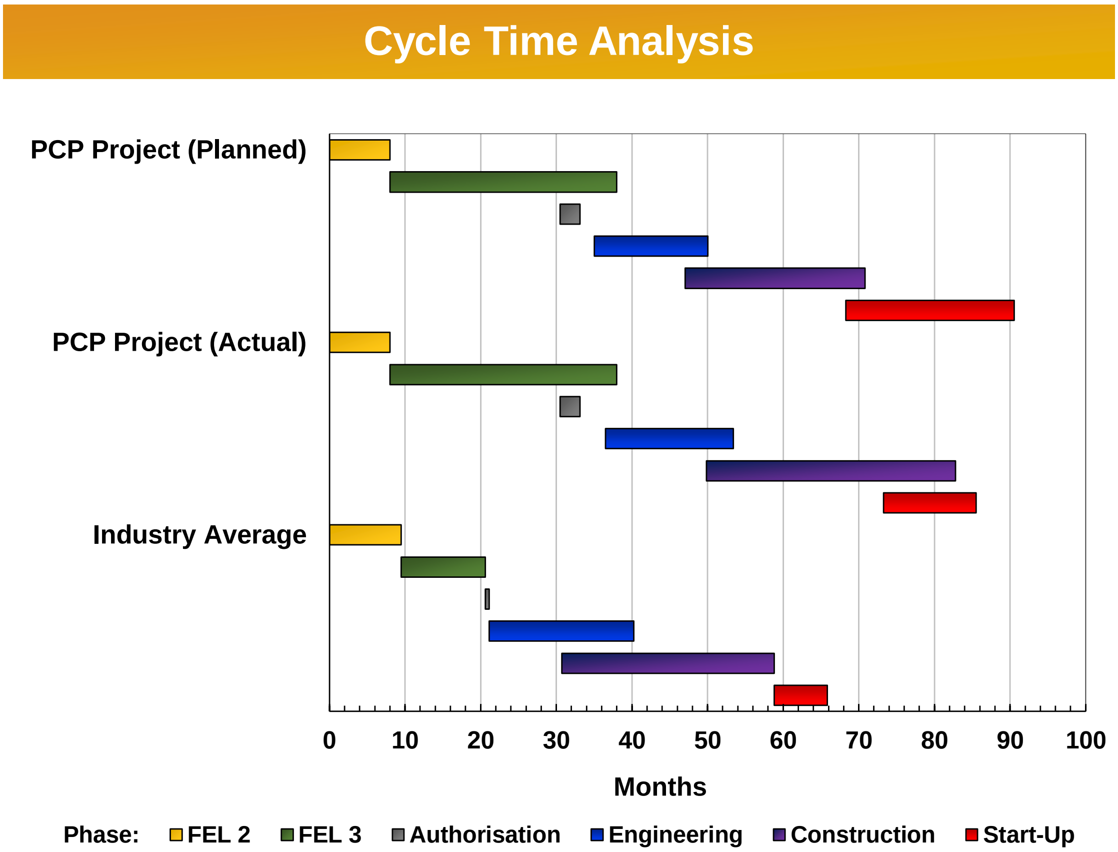


The schedule deviation was driven by delays in engineering and construction. Engineering started 1.5 months later than planned and was 1.9 months longer than planned. The delays in engineering translated into construction delays. Construction started 2.9 months later than planned and took 9.1 months longer than the aggressive planned duration.

The delays in engineering were primarily driven by changes from RAPID, with further delays in construction driven by underestimated labour requirements, quality issues in the supply of structural steel, and heavy rains causing a feedwater pipe to float out of its trench.

[17] The industry average schedule slip is higher than the median because it includes several projects with large slips.

Cycle Time



As shown above, the PCP Project's actual cycle time of 85.5 months is 30 percent longer than the industry average cycle time of 64 months, resulting in a Cycle Time Duration Index of 1.30. Although PETRONAS projects tend to have long cycle times relative to Industry, the cycle time performance of the PCP Project is slower than the PETRONAS average of 1.24. The PCP Project's long cycle time is primarily due to long FEL, followed by long execution. The slow execution phase was composed of fast engineering and slow construction, with smaller than industry average overlap between the two phases.

Schedule Effectiveness

A project's schedule durations can significantly affect its competitiveness. IPA uses a suite of robust schedule models to determine industry benchmarks. IPA's schedule models produce industry average durations for the following project phases: project definition (FEL), detailed engineering, construction, and execution (the start of detailed engineering through mechanical completion).

Schedule Effectiveness

Phase	Planned Duration *(Index)*	Actual Duration *(Index)*	Industry Average[18] *(50 percent range)*	PETRONAS Average Index
FEL	38.0 months *(1.80)*	38.0 months *(1.80)*	21 months *(16 to 28 months)*	1.19
Det. Engineering	15.0 months *(0.78)*	16.9 months *(0.88)*	19 months *(15 to 24 months)*	0.99
Construction	23.8 months *(0.84)*	32.9 months *(1.17)*	28 months *(23 to 34 months)*	1.04
Execution	35.7 months *(0.95)*	46.3 months *(1.23)*	38 months *(33 to 44 months)*	0.90
Start-Up[19]	19.8 months *(2.83)*	2.7 months *(0.38)*	7.0 months *(1.3 to 13.6 months)*	1.63
Cycle Time	90.6 months *(1.38)*	85.5 months *(1.30)*	66 months *(55 to 78 months)*	1.24

The project's FEL duration of 38.0 months is significantly longer than the industry average of 21 months, resulting in an FEL Duration Index of 1.80. The project's FEL duration is inconsistent with PETRONAS's average performance relative to Industry for large projects. PETRONAS's average FEL Duration Index is 1.19 (or 19 percent longer than Industry). The PCP Project's FEL duration was long due to an extended bidding process and multiple changes in RAPID's requirements. The multiple changes during the PCP Project's FEL were a result of concurrent FEED with the RAPID Project. As PETRONAS is a national oil company, its projects typically have a long bidding process to meet governmental requirements.

The project's target detailed engineering duration was 15.0 months, which was 22 percent faster than the industry average of 19 months for similar projects. The engineering target was fast and at the lower limit of the industry interquartile range. Although engineering slipped by 1.9 months for an actual engineering duration of 16.9 months, it was still 12 percent faster than the industry average.

The planned construction duration of 23.8 months was 16 percent shorter than the industry average of 28 months for a target Construction Duration Index of 0.84. PETRONAS's average construction duration schedules are comparable to Industry. With 38 percent slip, the PCP Project's actual construction duration of 32.9 months is considerably longer than planned and much slower than Industry. As discussed in the project timeline, in addition to engineering slip, construction was delayed by an underestimation of critical resource requirements, in addition to quality issues in the supply of structural steel, and heavy rains causing a feedwater pipe to float out of its trench.

The target execution duration of 35.7 months was comparable with the industry average of 38 months and marginally slower than PETRONAS's average performance (Execution Duration Index of 0.90). Execution slipped by 10.6 months, or 29 percent of the target duration, due to engineering and construction slip. The actual execution duration of 46.3 months is 23 percent longer than Industry and outside the normal range. The engineering and construction overlap of 3.5 months is 8 percent of the actual execution schedule and in line with the plan but much lower that the industry average of 25 percent. This indicates that the project team were aware of their construction readiness, with construction not started until the relevant engineering had been sufficiently completed.

[18] Because of rounding, indices may not calculate exactly.
[19] IPA defines the start-up duration as the time from mechanical completion to the time when steady-state, routine operation of the facility occurs, regardless of whether nameplate capacity has been obtained.

To match RAPID's planned demand profile, the PCP Project's planned start-up duration was much longer than Industry. However, despite the slip in execution the project was able to recover schedule progress in start-up. As of the time of the interview, the expectations were for an early finish, with an actual start-up duration that is both considerably shorter than planned and 62 percent faster than industry average.

No contracting type transfers business risk to the contractor

IPA studies have found that liquidated damages do not prevent slip but are strongly associated with lower operability.[20] The team's contracting approach largely helped to minimise cost growth, but the use of an LSTK contract did not control the schedule risks. Although the contractor bore some of the burden associated with the project (e.g., the costs associated with the underestimated welding labour), any operating losses associated with schedule slip are born most heavily by the facility owner.

Developing a feasible schedule requires knowing critical resources regardless of contract type, quantifying their associated risks, and integrating appropriate contingencies (both cost and schedule) into the project execution plan.

[20] Ed Merrow, Chris Valleau, and Neal Banks, *Contracting for Engineering and Construction*, IBC 2015, IPA, March 2015.

Analysis of Project Drivers

Except for the PCI, the drivers of the PCP Project are the same at closeout as at the prospective evaluation. The PCP Project team were not able to achieve their planned project control practices and so the planned PCI rating was not reached.

Team Development

Team development provides the building blocks for a successful project. Having the right functional influence on the project team enables meaningful FEL deliverables, reduces changes, and results in better projects. IPA measures team development using the Team Development Index (TDI). The TDI comprises the following factors: *Project Objectives, Team Integration, Roles and Responsibilities, Risk Understanding, and Project Implementation Process*.

PCP Project TDI

Industry TDI: *Fair*
PETRONAS TDI: *Fair*

Project Objectives

Project teams must understand the business objectives and how the business wants the objectives traded against each other. Clear business objectives enable the project team and business to fully engage and find, shape, and develop the right scope. This TDI factor measures whether the specific project objectives have been developed and translated from the business objectives and if they have been communicated to and are understood by all project team members.

Clear Objectives	Clear	• Specific project objectives were developed • Objectives were clearly communicated to and understood by team members

The best available tool for improving clarity and gaining alignment of business and project objectives is the Business and Engineering Alignment Meeting (BEAM). BEAM is a facilitated process—usually a workshop—proven to be an effective practice for bringing together business and project teams to form a common understanding of the business needs and the project system's response to those needs. For optimal results, BEAM must be completed at the end of FEL 1, or as one of the very first activities in FEL 2. In addition, all stakeholders must be represented by people with the ability to make decisions for their area, and all issues raised during the workshop must be resolved and closed during the session. BEAM documentation is essential and must be distributed to the project team as soon as possible after the session so that it can be used to guide FEL 2 work.

Business and Engineering Alignment Meeting	
BEAM Used?	No

Although a Classes of Facility Quality was used, the PCP Project team did not use a BEAM process. BEAM was not mandated by PETRONAS.

Team Integration

Team integration measures whether all functions that can influence the project are represented on the project team and whether the team is adequately staffed. Functional representatives must be active participants on the team. Representatives must have the authority to make decisions for the function they represent and provide functional input to the project team.

Team Integration	Integrated	• All functions that could influence project outcomes were adequately represented on team

Roles and Responsibilities

This TDI factor measures whether roles for team members were defined, responsibilities identified, expectations established, and tasks outlined and assigned. This factor also examines whether these responsibilities and tasks were agreed to and the team was aligned.

Roles & Responsibilities	Defined and Unambiguous	• Roles, responsibilities, and expectations were clearly defined • Responsibilities and tasks were agreed on • Project team was aligned

Risk Understanding

This TDI factor assesses whether risks were identified and mitigation plans formed.

Risk Understanding	Assessed and Understood	• A risk assessment plan outlining risk reviews was developed for each project phase • Technical, project, and operational risk assessments were done before each gate and approved by technical quality assurance representatives

Project Implementation Process

This TDI factor measures whether a common work process is in place for developing and executing the project. It also considers whether this process is used on similar company projects and whether the project team understands this process.

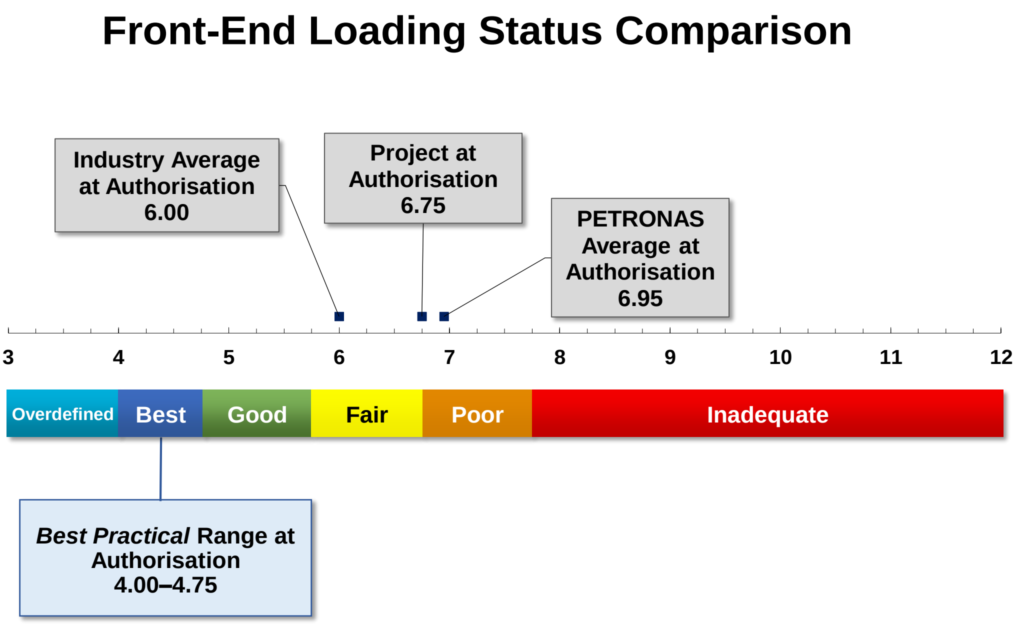
Project Implementation Process	Followed	• PETRONAS has a common work process in place for developing and executing projects • This process was followed by the PCP Project and was understood by the project team

Strong team integration helps ensure projects begin execution with solid foundations

Despite the challenges in execution, the project met the business need and delivered the project close to budget with a solid safety performance. The project enjoyed good operations support and input, including strong business support. All key functions had clear, able, and consistent representation on the team, including strong operations representation throughout execution. Having an operations representative—with authority to make decisions on behalf of the operations organisation—involved in project planning allowed the team to improve the sequence of activities on site.

Front-End Loading

Front-End Loading (FEL) is the process by which an organisation translates its opportunities into capital projects. The objective of FEL is to develop a detailed understanding of the project scope that meets business objectives. FEL proceeds until the right project is selected and is not finished until a full design-basis package has been completed. The FEL Index reflects the status of three equally weighted factors: site-specific items, project engineering, and project execution planning. The first factor for site-specific items has four equally weighted sub-factors: plot plans and unit configurations, soils and hydrology work, environmental regulatory requirements, and health and safety requirements.



As reported in the prospective evaluation, the PCP Project had *Fair* FEL, but at the high end, so essentially the same as PETRONAS's average of *Poor* for large projects. However, this lags the industry average and *Best Practical*. The plot plans were in development, not finalised; comprehensive geotechnical surveys were planned during early execution; preliminary HAZOP reviews had been done, and environmental permitting compliance requirements were known, and permits had been granted. The project harboured some residual risk by not completing fully detailed HAZOP reviews and geotechnical investigations on the cogeneration plant scope prior to authorisation.

Engineering definition for the scope was *Limited Study*, which lags *Best Practical*. The basis of design was finalised, and the steam and power requirements were known. Process flow diagrams and P&IDs had been developed, but major equipment specifications were being developed. The key gap with the engineering definition was the factored cost estimate. A basis of estimate had not been developed at authorization, and the cost estimate had not been subjected to risk and range analyses. The project execution plan for the total project was *Preliminary*, which lags *Best Practical*, mainly due to gaps in the project schedule. The execution schedule developed by the project team at FID was based on critical-path methodology but not yet resource-loaded.

Other Practices

Metric	Project	Industry Average	PETRONAS Average
Value Engineering	Not Used	22 percent	0 percent
Constructability Reviews	Used	65 percent	40 percent

For several years, IPA measured 10 Value Improving Practices (VIPs) that tend to improve the value of capital projects in the process industries. Continued research has shown that some VIPs are more influential than others, and that none are as important to project outcomes as the more fundamental practices of team development, FEL, and project controls.

We, therefore, now measure only the most leveraging practices from among the VIPs: Value Engineering and Constructability Reviews. These practices need to follow a consistent process, with documentation and usually facilitation. In addition, for maximum benefit, these practices should be coupled with optimal project definition and applied to the project at the right time.

Value Engineering is the examination of what is needed to meet the business objectives of a project and the elimination of non-value-adding investment. In FEL 2, this practice is sometimes called *Process Simplification*. Value Engineering (in FEL 2 or FEL 3) is a structured, rigorous process to search for opportunities to eliminate or combine process steps, equipment, piping, valves, and/or other supporting process material.

Value Engineering was not used.

Constructability Reviews are systematic examinations of the design, plans, and sequencing as they affect construction efficiency. They can be used from FEL 2 through early execution.

Constructability Reviews were used, in FEL 2 and FEL 3; they were updated in execution.

Analysis of Project Execution Discipline

Project Controls

IPA research shows that projects with strong project cost and schedule control practices have more predictable and effective costs and schedules. IPA research identified two categories of project controls that have significant effects on project outcomes: estimating for control and control during execution. The Project Control Index (PCI) quantifies the strength of the practices used for estimating for control along with the practices for project control during execution.

Project Control Index

PCP Project PCI

Planned PCI at Authorisation: *Good*
Industry: *Fair*
PETRONAS: *Good*

Estimating for Control

Estimate quantitatively validated by in-house estimating specialist:	• The ITB estimate was factored, and therefore without sufficient detail for a quantitative validation • The estimate was reviewed by PETRONAS and the FEED contractor but was not quantitatively validated using a PETRONAS database

Control During Execution

Physical progressing methods used:	• Physical progress was sometimes used • Detailed physical progress was planned on all disciplines – Lack of master deliverables list prevented the project team from effectively monitoring engineering progress
Progress report frequency and detail:	• Progress was reported as planned on a monthly discipline level
Owner project control specialist assigned to the project starting in FEL:	• PETRONAS' project team performed project control via an integrated project controls system – Including a PETRONAS project control specialist resources from FEL to project completion

Although the PCP Project planned for *Good* project controls, in line with the normal discipline of PETRONAS's large projects, the actual PCI was *Fair*. The project was not able to meet its planned project control discipline because the contractors did not fully understand PETRONAS's expectations.

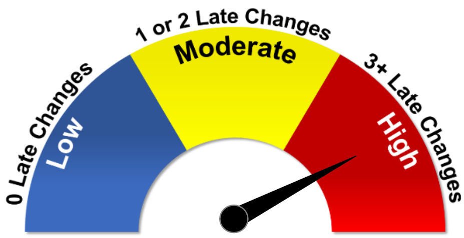
Enforce company project control standards regardless of the contracting strategy

PETRONAS's expectations for project reporting and controls were not clearly outlined prior to contract award, resulting in frustrations and inefficiencies for both owner and contractor. Although the differences were reconciled during execution, they could have been avoided by better communication of expectations in the ITB packages.

Major Late Changes

Research shows that late changes—design or scope—have greater effects on projects than typically estimated at the time of the change. Each major late change adds an average of 2.5 percent to the total installed cost, more than twice the estimated cost, and 3 percent to the execution schedule. A primary reason for well-defined projects that do not achieve commensurate results is late changes.

Late Changes Summary



Project: ***3 Major Late Changes***
PETRONAS Average: ***1.20 Major Late Changes***
Industry Average: ***1.71 Major Late Changes***

Major Change	Timing	Source	Schedule Effect	Cost Effect (US$ millions)
Change of steam specification from HP to HHP	Detailed Engineering	Business	2 months	4.6
Reversal of change of steam specification from HP to HHP	Detailed Engineering	Business	1 month	1.5
Relocation of RAPID tie-in points	Detailed Engineering	Business	1 month	5.0
Total Cost Effect (absolute value)				11.1
Total Schedule Effect			4 months	

The PCP Project had three major late changes, which contributed to the project's poor schedule predictability. Early in detailed engineering, the removal of process units from the RAPID Project scope drove a change in the scope of the PCP project, with the steam generation changed from HP steam to HHP steam. At the same time, this change in the RAPID Project scope drove a second major change for the PCP Project, requiring the redesign and relocation of multiple tie-in points connecting the two facilities. Further changes in RAPID's ISBL design drove a third major late change as the original scope change was reversed after 5 months of detailed engineering. All the major late changes experienced by the PCP Project were driven by the business, as flow-on effects from undefined basic data from RAPID's ISBL scope.

IPA research identified a set of Best Practices that enable a project team to avoid late changes when used effectively. As shown in the table that follows, the team used some, but not all, of these practices. In particular, the project did not have *Best Practical* FEL at authorisation or *Optimal* FEL at the end of FEL 2.

Practices to Avoid Late Changes	
Practice	**Achieved/ Not Achieved**
***Good* or *Best Practical* FEL at authorisation**	***Not Achieved***
Integrated team	***Achieved***
Clear and documented business objectives	***Achieved***
Clear trade-offs between cost, schedule, and operability	***Achieved***
Roles and responsibilities aligned	***Achieved***
Risk matrix	***Achieved***
PHA done on near-complete P&IDs before authorisation	***Achieved***
Definitive investigation of raw materials properties	***Achieved***
Early completion of the site review	***Not Achieved***
PFDs complete going into FEL 3	***Not Achieved***
BEAM use	***Not Achieved***
Strong project controls	***Not Achieved***

Authorising projects without complete basic data damages project outcomes

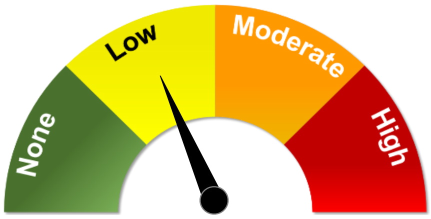
At authorisation, the PCP facility design was based on estimated steam and power requirements from RAPID. These basic data are fundamental to the design of the facility and had the potential to greatly influence the ability of both the PCP Project and the RAPID Project to meet their business objectives.

One defining feature of a complex project is that there are multiple interfaces to consider, each with the potential to affect the project. These are the project's stakeholders. The project team is often unable to directly manage these stakeholders; however, this does not preclude their potential effect from being understood and planned for. The PCP Project relied on its interface with RAPID for both feed and output, with each having a large effect on the facility design. Projects such as the PCP must make every effort to influence their stakeholders to ensure that interfaces are well defined as early as possible.

Key Team Member Turnover

The turnover of key team members (the project manager, lead engineer, or construction manager) has detrimental effects on project performance and predictability. The table below summarises the PCP Project and IPA's recently developed Key Team Member Turnover Metric.

Key Team Member Turnover

Team Member	**Turnover**	**Industry Average**	
Project Manager	Turnover	42 percent of projects	• The project had two project director turnovers • The first turnover was in the middle of construction and was planned, due to a companywide restructure • The second turnover was at the end of construction and was not planned
Lead Engineer	No Turnover	22 percent of projects	
Construction Manager	No Turnover	31 percent of projects	
Key Team Member Turnover	 **PCP Project Key Team Turnover**		**Industry:** ***Low***

IPA has historically reported only project manager turnover; however, recent IPA research found that turnover of the lead engineer or construction manager can be equally (or more) detrimental to project performance. In addition, turnover in multiple key team member positions is more detrimental than in a single position. Based on these findings, IPA now provides the Key Team Member Turnover rating to more accurately quantify the magnitude of project key team member turnover.

Although the project had one planned and one unplanned turnover of its project director, in both instances, the incumbent person was part of the core project team, minimising the disruption to the project and maintaining some continuity.

Although our Key Team Member Turnover metric is for project manager, lead engineer, and construction manager turnover, the turnover of business and operations representatives may also be detrimental to the project, especially if the turnover induces or enables changes to scope or design.

Conclusions, Lessons Learned, and Recommendations

Conclusions

Key Project Metrics

Met Objectives

Business Objectives:		Met	**Technical Objectives:**		Met

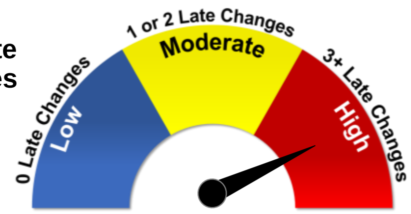
Competitiveness			*Predictability*		
Safety:	**0.18 RIR**	Better	**Cost Deviation:**	**-8%**	On Budget
Cost Index:	**0.84**	Low	**Schedule Deviation:**	**29%**	Late
Execution Duration Index:	**1.28**	Slow	**Construction Schedule Deviation:**	**38%**	Late

Discipline	*Project Practices*

Project Control Index

FEL Index

Major Late Changes



Team Development Index

The schedule-constrained but capital cost-focused PCP Project met most of its objectives: it delivered the scope with better than Industry safety, finished on budget, meets its full supply agreement into the national grid although with some slip, and is able to meet RAPID's electrical power and steam needs. Although the project's planned execution duration was average versus Industry, execution slipped by 29 percent against its target due to engineering and construction delays. The target cost was met, with minimal deviation, and was 16 percent cheaper than Industry.

The PCP Project was authorised for execution with *Fair* FEL, although similar to the PETRONAS average for large projects at authorisation. There were notable gaps in the Engineering Status and Project Execution Planning, driven by ill-defined basic data of the interfacing RAPID facility. With a lack of solid basic data, the project had major changes during detailed engineering. Team development was *Good*, which helped the project team in recover progress during execution. Although the planned PCI met Best Practice, the team was not able to implement the planned project control practices in execution because PETRONAS's expectations were not clear to the contractor.

Detailed Lessons Learned and Recommendations

System Level

1. ***Enforce company project control standards regardless of the contracting strategy***
   PETRONAS's expectations for project reporting and controls were not clearly outlined prior to contract award, resulting in frustrations and inefficiencies for both owner and contractor. Although the differences were reconciled during execution, they could have been avoided by better communication of expectations in the ITB packages.

2. ***Authorising projects without complete basic data damages project outcomes***
   At authorisation, the PCP facility design was based on estimated steam and power requirements from RAPID. These basic data are fundamental to the design of the facility and had the potential to greatly influence the ability of both the PCP Project and the RAPID Project to meet their business objectives.

   One defining feature of a complex project is that there are multiple interfaces to consider, each with the potential to affect the project. These are the project's stakeholders. The project team is often unable to directly manage these stakeholders; however, this does not preclude their potential effect from being understood and planned for. The PCP Project relied on its interface with RAPID for both feed and output, with each having a large effect on the facility design. Projects such as the PCP must make every effort to influence their stakeholders to ensure that interfaces are well defined as early as possible.

Project Level

1. ***Good safety outcomes can be achieved with disciplined owner-lead safety practices***
   Precipitated by the lost time incident, the PCP Project team developed a strong owner-led safety culture that used most safety Best Practices. The project's safety was better than Industry, despite the significant growth in construction labour, subcontractor turnovers, schedule pressure, and other challenges. Furthermore, IPA's research has found that safety is positively influenced by initiatives, such as the HERO Card system used by the PCP Project, that reward safe behaviour, rather than incentives that reward good outcomes. Contract incentives aimed at rewarding safety outcomes may lead to underreporting of safety incidents

2. ***Engineering slip is a leading indicator of problems in construction***
   Driven by multiple late changes from RAPID, the PCP Project's detailed engineering slip significantly disrupted construction. Research has shown engineering slip to be a key leading indicator of problems during construction and field cost growth PETRONAS teams should be vigilant for signs of slip in the engineering schedule and should evaluate ahead of time how construction may be affected as well as potential responses.

3. ***No contracting type transfers business risk to the contractor***
   IPA studies have found that liquidated damages do not prevent slip but are strongly associated with lower operability.[21] The team's contracting approach largely helped to minimise cost growth, but the use of an LSTK contract did not control the schedule risks. Although the contractor bore some of the burden associated with the project (e.g., the costs associated with the underestimated welding labour), any operating losses associated with schedule slip are born most heavily by the facility owner.

[21] Ed Merrow, Chris Valleau, and Neal Banks, *Contracting for Engineering and Construction*, IBC 2015, IPA, March 2015.

Developing a feasible schedule requires knowing critical resources regardless of contract type, quantifying their associated risks, and integrating appropriate contingencies (both cost and schedule) into the project execution plan.

4. ***Strong team integration helps ensure projects begin execution with solid foundations***

Despite the challenges in execution, the project met the business need and delivered the project close to budget with a solid safety performance. The project enjoyed good operations support and input, including strong business support. All key functions had clear, able, and consistent representation on the team, including strong operations representation throughout execution. Having an operations representative—with authority to make decisions on behalf of the operations organisation—involved in project planning allowed the team to improve the sequence of activities on site.