IceCube Upgrade NSF Re-Baseline Review
April 26-28, 2022

Terry Benson
1.2 Implementation – Drilling Plenary

Brief Bio

Charge Question M1

Terry Benson – UW Physical Sciences Lab (PSL)

- PSL Instrumentation Manager, mechanical engineer
- IceCube Upgrade Drill Systems Engineer
- Nearly 20 years hot water drill experience – joined IceCube EHWD team in 2003
- Drilling shift lead in the field
- 9 trips to South Pole for hot water drilling projects

PSL Team:
EHWD experience from IceCube Gen1 has become concentrated at PSL, and joined by a younger generation of skilled, enthusiastic engineers that are firmly engaged in Upgrade.

1.2 Implementation - Drilling

Charge Question ST1

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Charge Question ST1

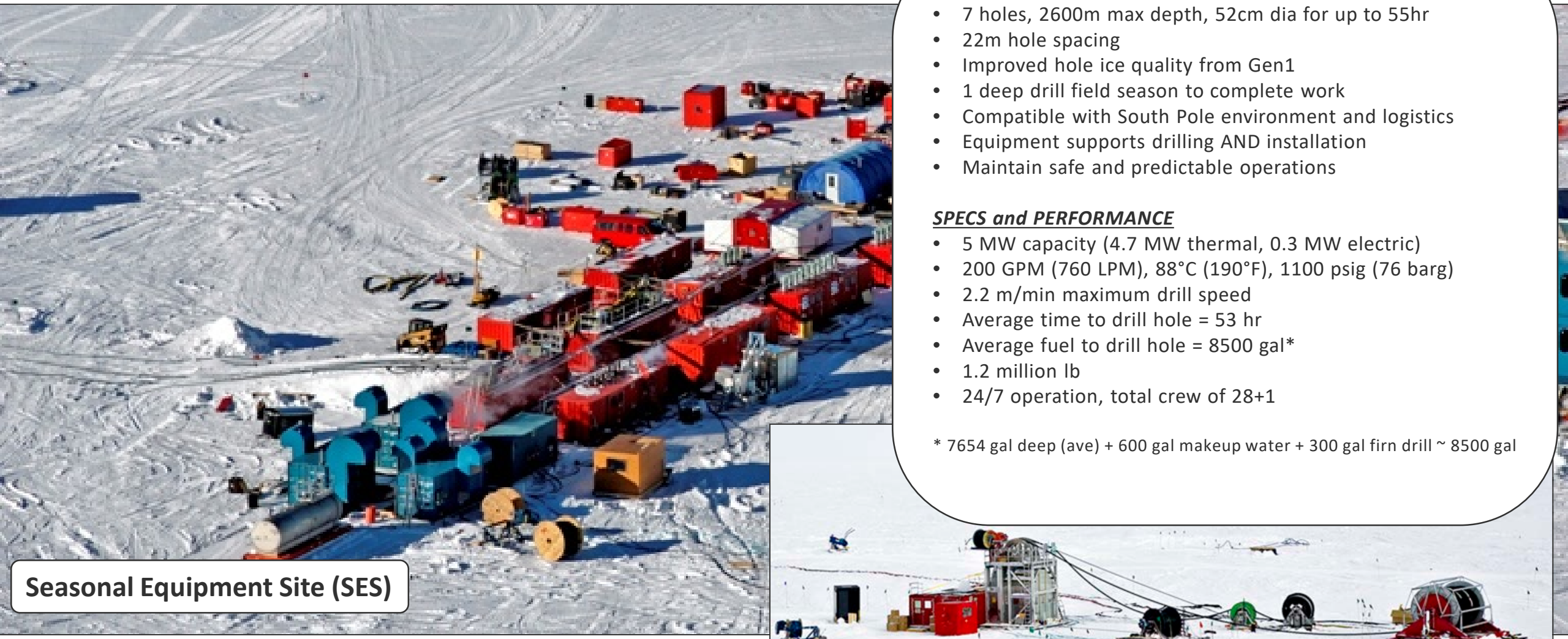
REQUIREMENTS

- 7 holes, 2600m max depth, 52cm dia for up to 55hr
- 22m hole spacing
- Improved hole ice quality from Gen1
- 1 deep drill field season to complete work
- Compatible with South Pole environment and logistics
- Equipment supports drilling AND installation
- Maintain safe and predictable operations

SPECS and PERFORMANCE

- 5 MW capacity (4.7 MW thermal, 0.3 MW electric)
- 200 GPM (760 LPM), 88°C (190°F), 1100 psig (76 barg)
- 2.2 m/min maximum drill speed
- Average time to drill hole = 53 hr
- Average fuel to drill hole = 8500 gal*
- 1.2 million lb
- 24/7 operation, total crew of 28+1

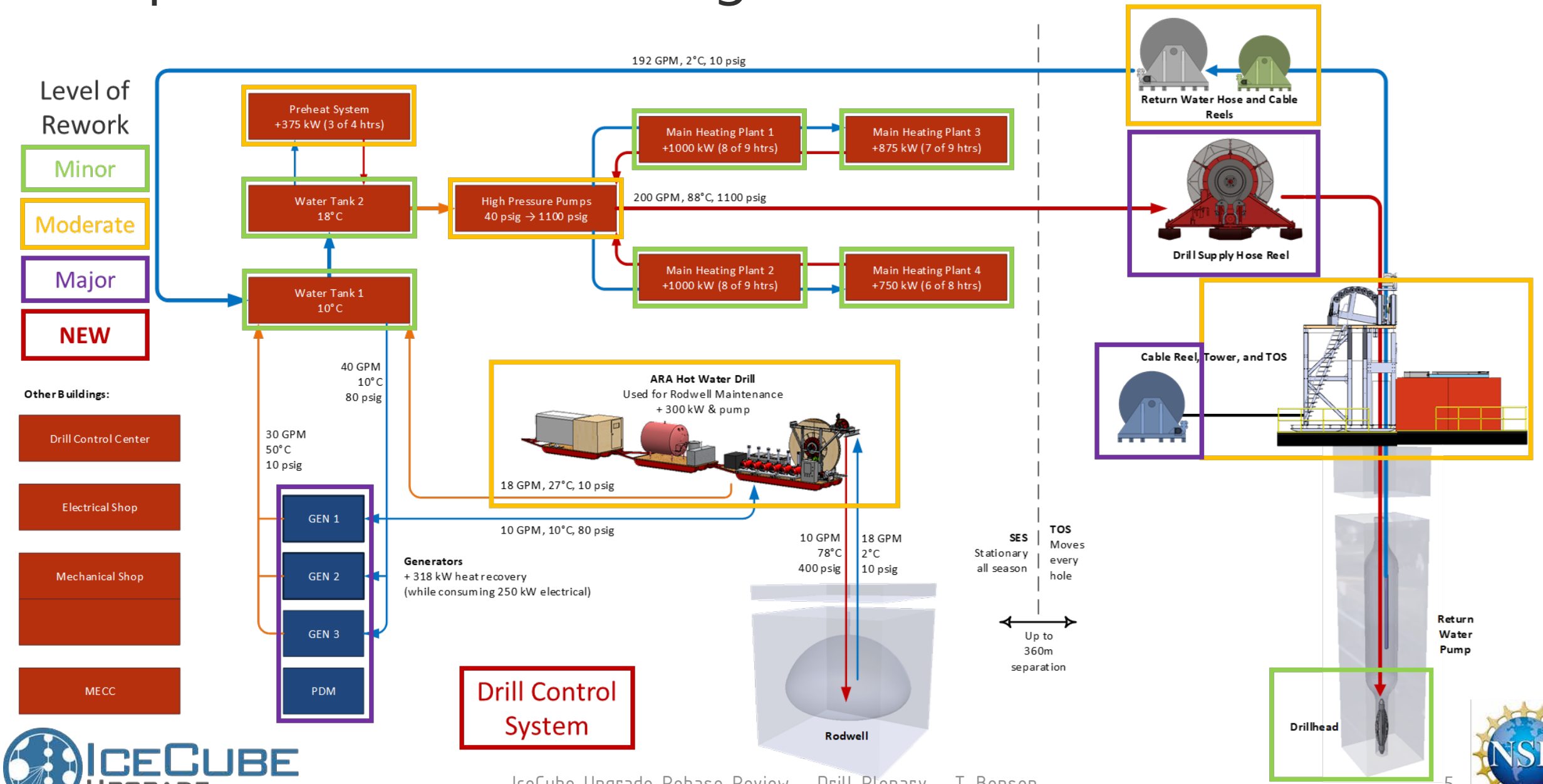
* 7654 gal deep (ave) + 600 gal makeup water + 300 gal firn drill ~ 8500 gal



Seasonal Equipment Site (SES)

1.2 Implementation - Drilling

Charge Question ST1



Overall Deliverable

Charge Question ST1, M1

- 7 Holes successfully and safely drilled and instrumented

WBS	Name	Description
1.2.1	Management and Systems Engineering	Implementation/drill/install management, systems engineering, safety, travel, logistics
1.2.2	Thermal Plant	Water heating systems, fuel system
1.2.3	Tower Operations Site	Drill tower operations and equipment, reels, drillheads, hose and cables
1.2.4	Control System	Control system hardware and software, e-stop system
1.2.5	Power Generation and Distribution	Generators and power distribution
1.2.6	Water Handling Systems	Tanks, pumps, filtration, plumbing, hoses, Rodwell system
1.2.7	Support Equipment	Ancillary equipment, shops, inventory, tools, PSL testbed
1.2.8	Drill Field Seasons	All effort and travel related to on-ice drilling activities
1.2.9	Installation – Off Ice	Installation hardware, instrumentation, and procedures
1.2.10	Installation – On Ice	Everything related to on-ice installation activities

Interfaces

Charge Question ST5

- Hole Requirements
  - Type
  - Depth
  - Lifetime (hole diameter)
- Installation
  - Equipment – drilling and installation uses the same equipment
  - Technique and process
  - Resources – driller/installer
- Logistics and USAP Support
  - Cargo movement and timing
  - Population
  - On-Ice support and coordination
  - Fuel

Current Technical Status and Work to Go

Charge Question ST1

- Current Status
  - 18/19 Recon and 19/20 Eval/Retro seasons complete
  - This gave us a solid understanding of technical scope to achieve deliverables
  - Most of the equipment and cargo is now back in Antarctica
  - PY4 (off-ice): Wrapping up remaining major mechanical upgrades, working on control system hardware
- Replanning and Rebaseline
  - Significant effort during past 2 years on replanning and reacting
  - NSF/AIL support plans provided early 2022 put us on solid planning ground
  - Complete bottoms-up rebaseline based on these new constraints results in much better plan than just 5 months ago

ICU Drill Field Seasons – High Level

TODAY

	PY1 18/19	PY2 19/20	PY3 20/21	PY4 21/22	PY5 22/23	PY6 23/24	PY7 24/25	PY8 25/26
Original Baseline	Recon	Eval & Retro	Upgrades	Integrate & Test	Drill			
PY4 Re-Baseline	Recon	Eval & Retro	X	X	X	Upgrades	Integrate & Test	Drill

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- Work to Go (PY5-8)
  - Control system hardware and software
  - Drilling procedures development and training
  - Recruitment of seasonal drillers
  - Field Season 1 (FS1): Upgrade by subsystem, build up Seasonal Equipment Site (SES)
  - Field Season 2 (FS2): Firn drill, install core controls, integrate all, full-system wet test
  - Field Season 3 (FS3): Drill and install 7 holes

L2 Milestones

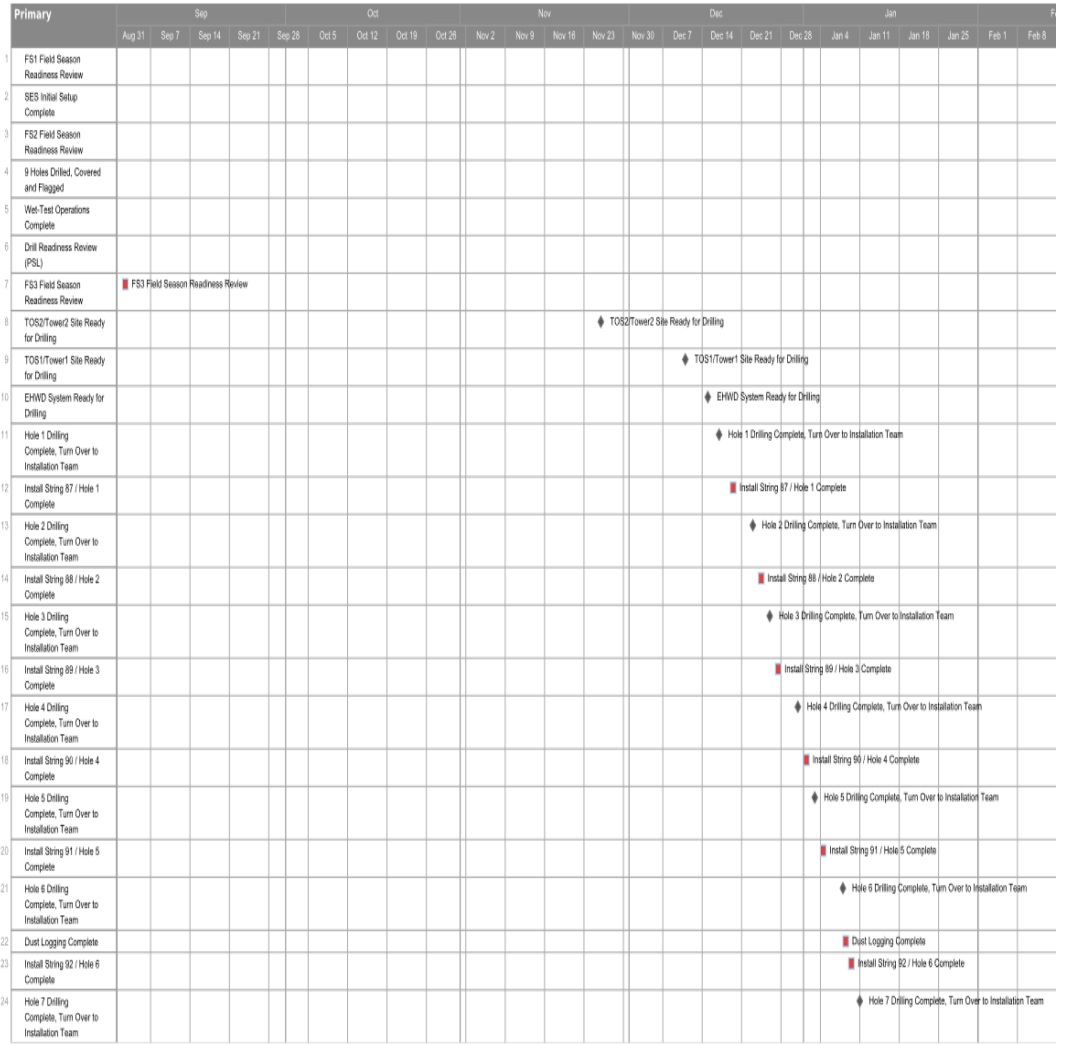
Charge Question ST2

1.2 has:

- 4 L1 milestones
- 30 L2 milestones
- 296 Internal milestones

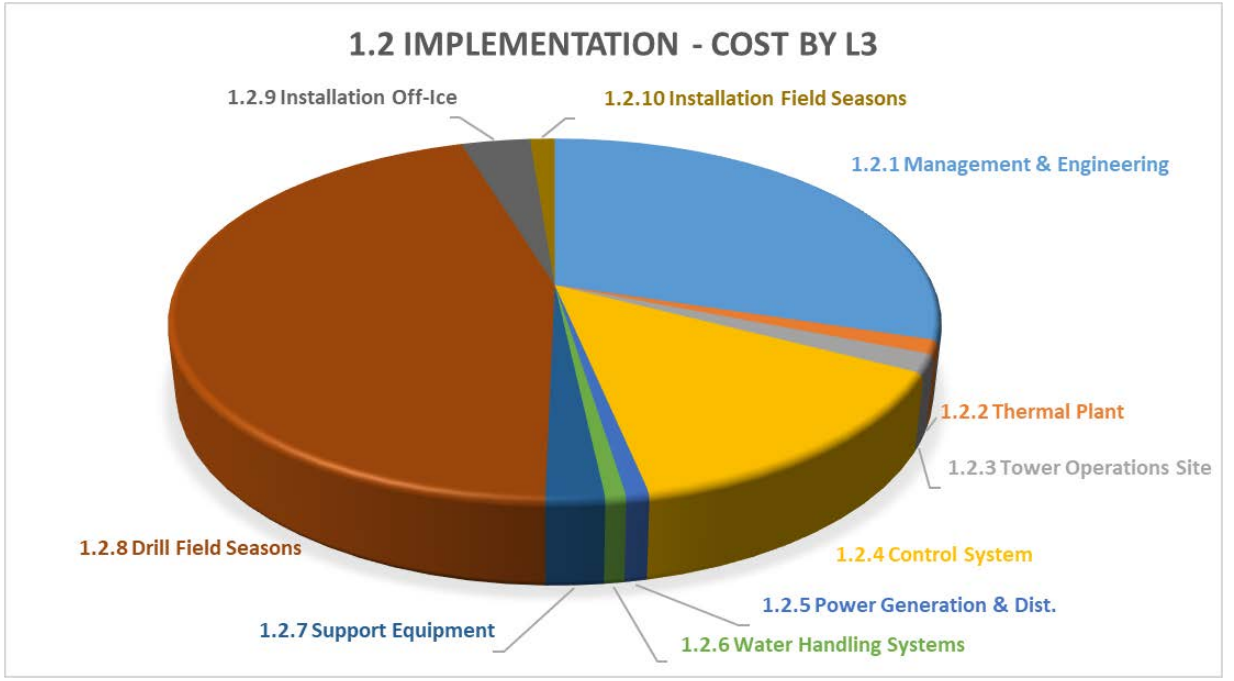
L2 Milestone SUMMARY

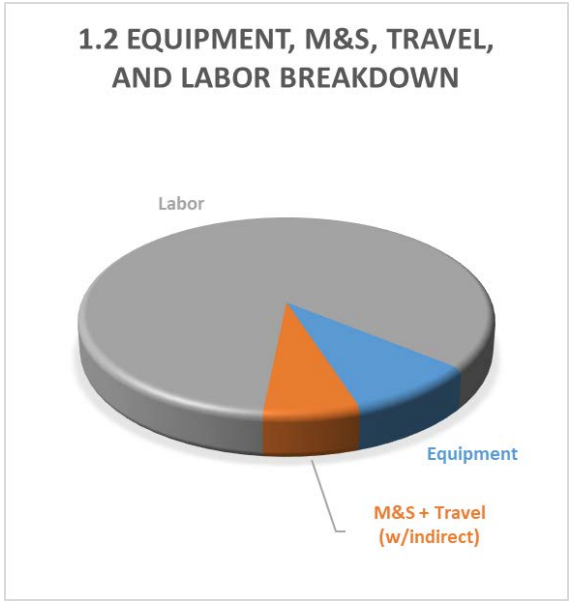
Sep 2023/24/25	Field Season Readiness Reviews
Jan 10, 2024	SES Initial Setup Complete (FS1)
Jan 6, 2025	9 Firn Holes Drilled (FS2)
Jan 22, 2025	Wet Test Operations Complete (FS2)
Jul 1, 2025	Drill Readiness Review
Nov 26, 2025	TOS2 Ready for Drilling (FS3)
Dec 11, 2025	TOS1 Ready for Drilling (FS3)
Dec 15, 2025	EHWD System Ready for Drilling (FS3)
Dec 2025 – Jan 2026	Drill/Install Completion Milestones, Holes 1-7 (FS3)
Jan 13, 2026	Drilling and Installation Complete (FS3)
Apr 2026	Final Drill/Install Completion Reports

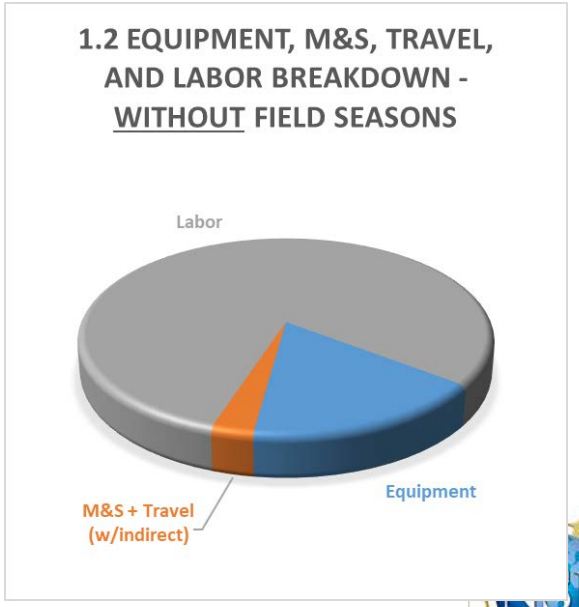


Cost and Main Cost Drivers

WBS	Name	PY5-PY8 Budget (Costs to Go)
1.2.1	Management and Systems Engineering	$2,359,319
1.2.2	Thermal Plant	$95,123
1.2.3	Tower Operations Site	$128,644
1.2.4	Control System	$1,110,838
1.2.5	Power Generation and Distribution	$64,401
1.2.6	Water Handling Systems	$57,615
1.2.7	Support Equipment	$163,036
1.2.8	Drill Field Seasons	$3,555,137
1.2.9	Installation – Off Ice	$273,576
1.2.10	Installation – On Ice	$98,922
	TOTAL	**$7,906,611**







Risks

In the Risk Register, 1.2 (Drill) has:

(6x) OFF-ice risks
- Control system development
- Loss of expertise
- Novel string install

(21x) ON-ice risks
- Serious injury/incident for each FS
- (1x) consolidated drill season-killer
- Talent acquisition for seasonal drillers
- Some logistics risks
- Many equipment failure risks that result in ~ 1-2 week delay or similar

1.2 (Drill) off-ice risks (snippet)

Charge Question ST3

		Risk Identification and Tracking	Post-Mitigated Risk Evaluation						
			Probability and Impacts				Exposure		
Risk ID	Associated WBS	Risk Description	Risk Probability	Impact on schedule	Impact on cost	Impact on technical performance	Schedule Risk Score	Cost Risk Score	Technical Performance Risk Score
		1.2 Northern Risks							
TECH1	1.2.4	Unable to complete controls system work on-schedule due to cargo front-loading and/or staffing limitations.	Low	Low	Moderate	Low	Low	Moderate	Low
TECH2	1.2.4	Unable to make critical controls hardware procurements (motor drives, DGH's servers, sensors, etc) on-schedule due to vendor shortages and transportation delays.	Moderate	Moderate	Moderate	Low	Moderate	Moderate	Moderate
TECH3	1.2.4	Delay in development of user interfaces, control algorithms, and hands-on integration and test activities due to Test Bed limitations.	Moderate	Low	Moderate	Low	Moderate	Moderate	Moderate
TECH4	1.2	Loss of key drilling expertise/personnel	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
TECH5	1.2	Novel string installation - Final down-hole cable design requires the development of new equipment and processes for installation (i.e. New rope reel with coordinated load sharing)	Moderate	Moderate	Moderate	Low	Moderate	Moderate	Moderate

1.2 (Drill) on-ice risks (snippet)

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ORG4	1.2	Serious FS3 injury or incident occurance halts on-ice activities until full accident investigation	Very Low	Very High	Very High	Low	Moderate	Moderate	Low
ORG5	1.2	Serious FS2 season injury or incident occurance halts on-ice activities until full accident investigation is completed	Very Low	Very High	Very High	Low	Moderate	Moderate	Low
ORG6	1.2	**Serious FS1 season injury or incident** occurance halts on-ice activities	Very Low	Low	High	Low	Low	Low	Low

Response to Previous Reviews

Charge Question L1

Nov 2021 Logistics Review

LR8	Include recording accelerometer in sample packaging for first available South Pole Traverse to get a sense of the potential for shock and vibration damage during shipment using the traverse.	Terry Benson	In progress
LR9	Activities planned for the same construction season should be prioritized before the start of the season to ensure resources are applied to the most critical activities should delays begin to be experienced.	Dar Gibson, Ian McEwen	Closed
LR10	Drilling activities in the schedule should be broken down into smaller duration activities to allow for better visibility of the entire drilling process and to allow planned efficiency when staff are expected to move from one hole to the next.	Dar Gibson, Terry Benson	Closed
LR11	Drilling activities should include some buffer time to allow for inefficiencies experienced at shift changes and mid-day breaks.	Dar Gibson, Terry Benson	Closed

Conclusion

- A complete bottoms-up budget, schedule, and risk has been completed for remaining 1.2 scope
- 3 more field seasons are required and have been carefully planned, the off-ice effort is driven by the field season tasking
- Scope of drill repairs and upgrades is understood, and on-track to deliver a successful 25/26 drilling season