



Co-creation between pipeline operator and machinery OEM in the development of a modern gas turbine.

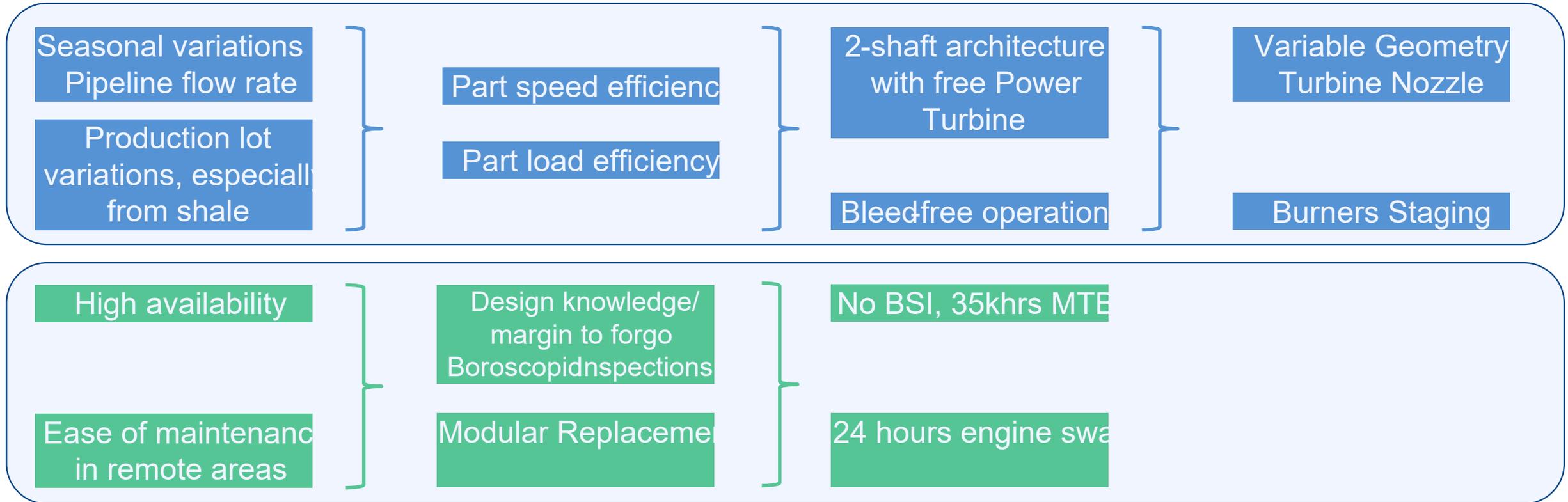
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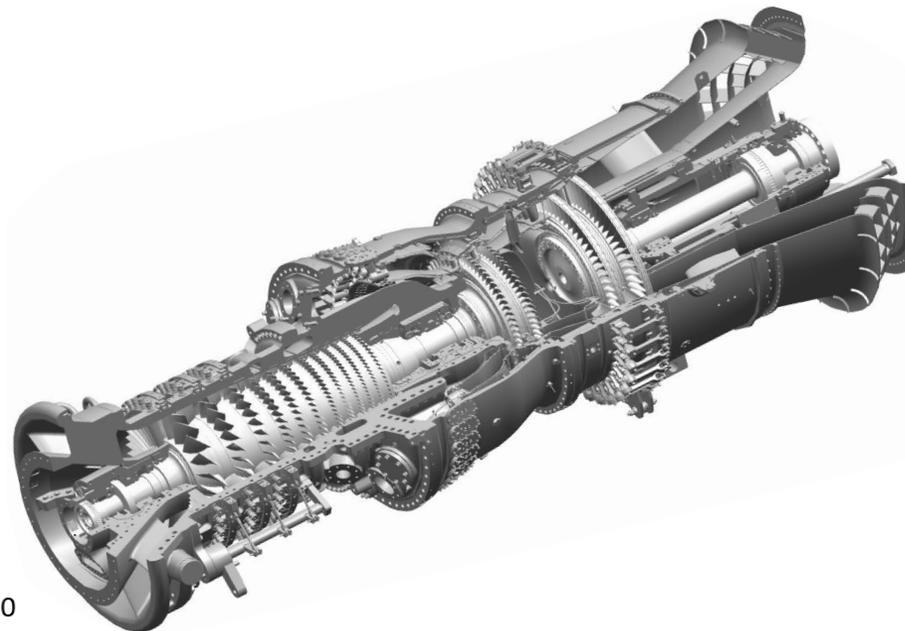
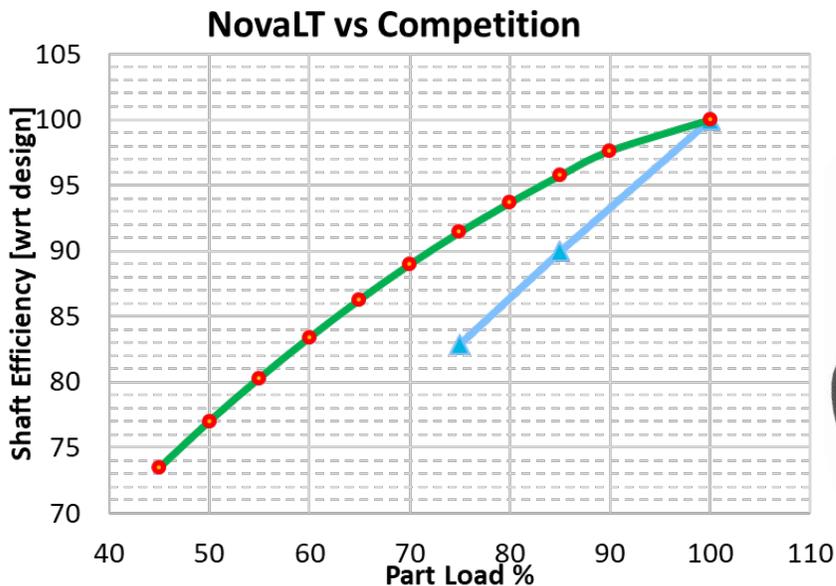


The requirements of a typical Pipeline Customer were translated into mechanical features





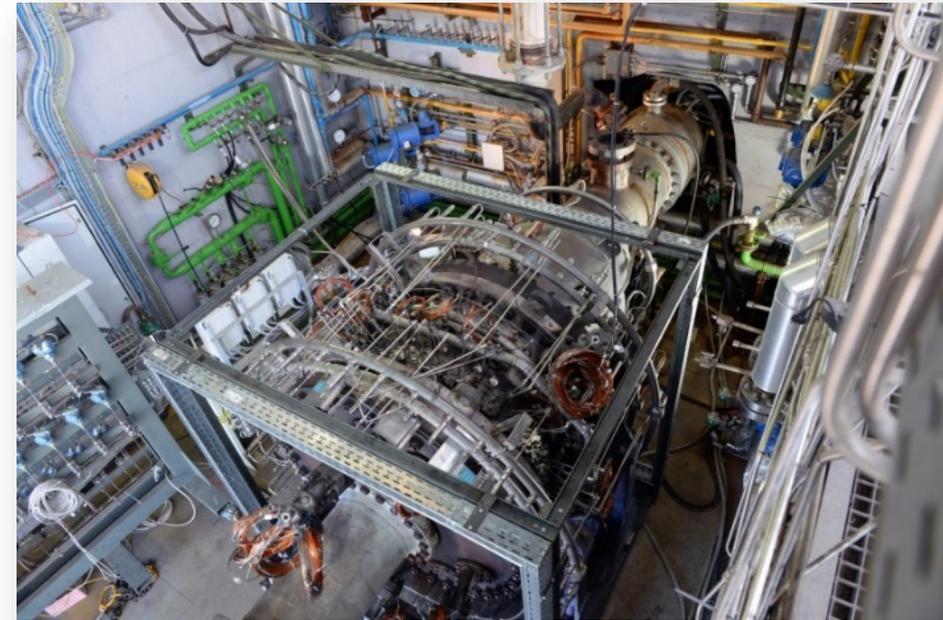
| Application | Power | Efficiency | Speed | Emissions with natural gas | MTBM | Exhaust flow | Exhaust temp. |
|------------------|----------|---------------------|-------------------------------|----------------------------|-------------------------|--------------|---------------|
| Mechanical drive | 17.5 MW | 37.6% (@shaft) | 7800 rpm (@ load shaft) | 15 ppm NOx | 35 khr GG 70 khr LPT | 54.6 kg/sec | 494 deg C |
| Generator drive | 16.8 MWe | 36.1% (@ generator) | 1500 rpm or 1800 rpm (geared) | 25ppm CO | | | |



- The combination of NGV, low bleed (from 7 stage) and staging allows for unbeatable part load efficiency
- 88% of rated efficiency at 70% load
- Maintenance concept: modular replacement
- 15 ppm NOx 50%100% load
- 25ppm NOx 15%50% load



- Initial single cup test to screen between burner concepts
- Full Annulus Rig test (FAR) at Safta (Italy) for full geometry validation (~500 hours). Flame holding test performed.
- Extreme ambient temperature assessment
- Fuel composition sensitivity performed



The NovaLT16 underwent a complete testing program, beginning with the combustion system



First two produced engines in 2015 for:

- A new and clean engine, to measure performance and to establish control strategies (50 hours, 50 cycles)
- A fully instrumented and packaged engine to assess: aeromechanics, rotordynamics, thermal behavior, transients, thermodynamic mapping, power gen operation (500 hours, 250 cycles)



These tests delivered a full functional and mechanical validation



- The second produced engine was refurbished and put in continuous power gen operation (Endurance Test), at Florence site
- Electricity was sold to the Grid Provider, following an maximum revenue operating profile (20% load during nights, 50% load during weekends, 100% during working days)
- 6400 hours were accrued and certified by a Third Party Inspector (Poyry)
- Final tear down showed no issues



After Functional operation, also Reliability became the focus of the validation

NovaLT fleet leader in TC Energy's site, Canada

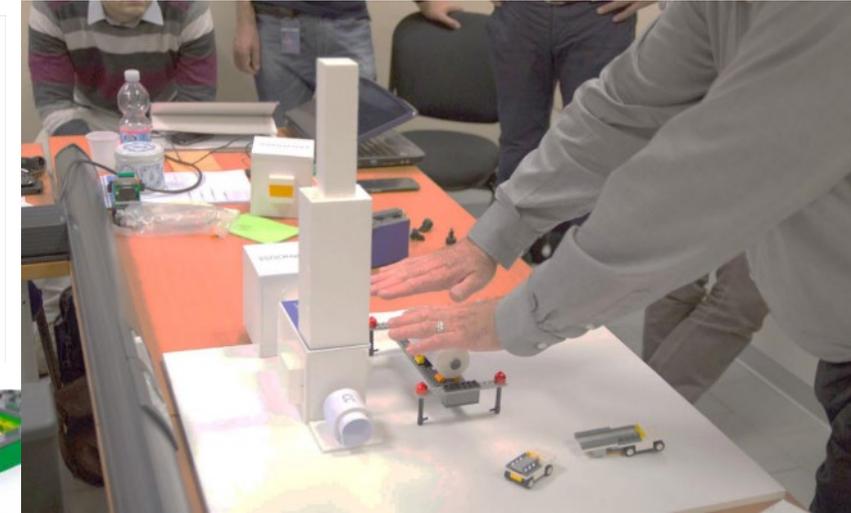
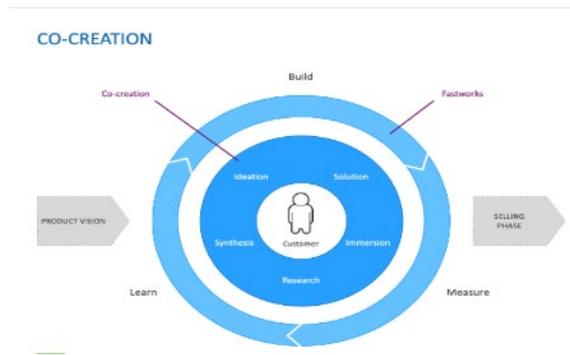
A successful story of co-creation and FastWorks

Target to lower life -cycle costs and improve maintainability

- Co-creation is part of FastWorks product development approach
- Process steered by third party firm Frog Design

Methodology

- Site visit at TC Energy premises
- Face-to-face interviews of Customers' experts in maintenance, dispatching, fleet and environment
- Collaboration workshops
- Informal idea-sharing (LEGO® bricks) on various package options





- TCPL unit was commissioned at Alces site in Nov 2017
- The unit has been running ever since, in mechanical drive service, withstanding ambient temperatures down to -41°C (record low in Jan 2019)
- Remote diagnostic available

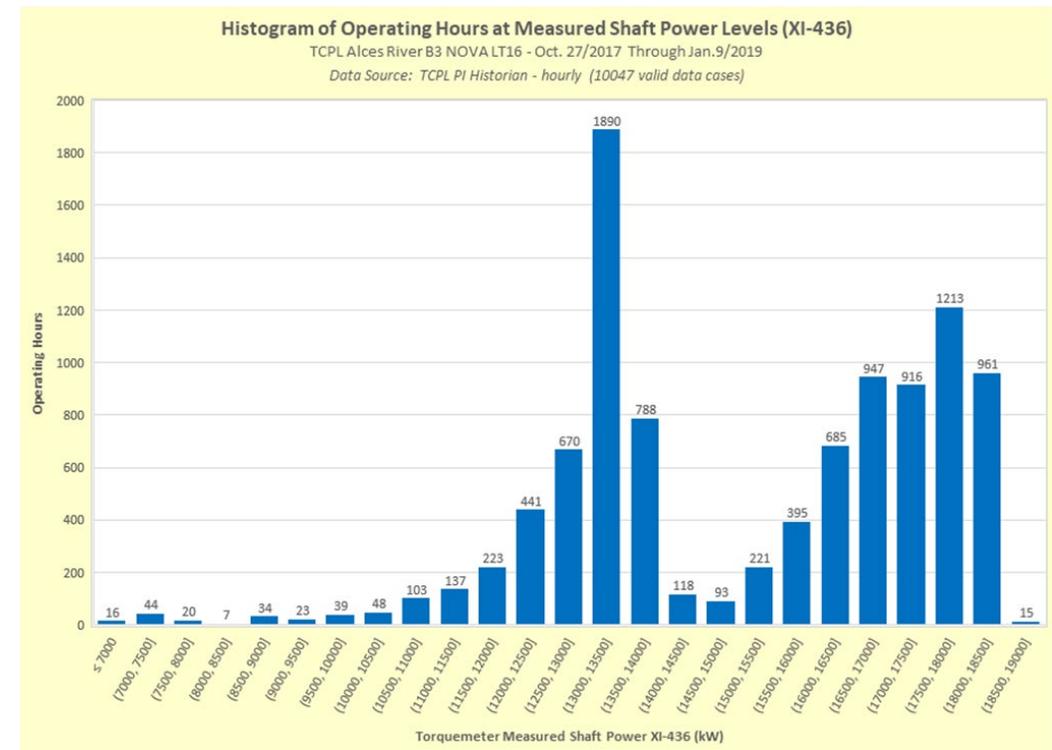
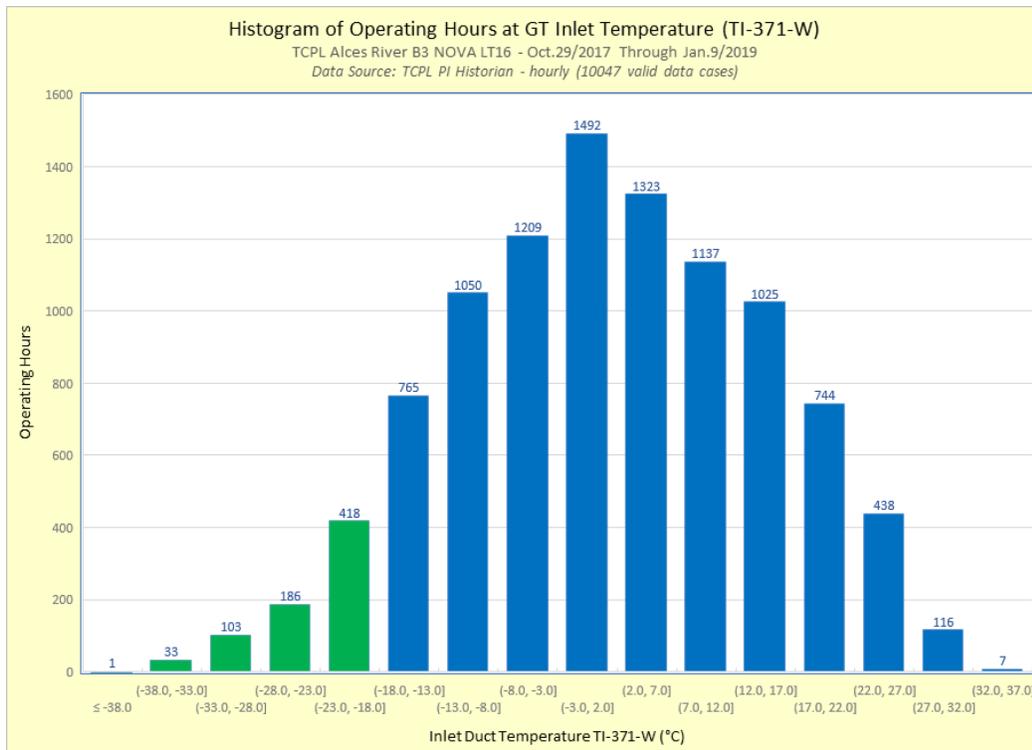


More than 11000 hours accrued

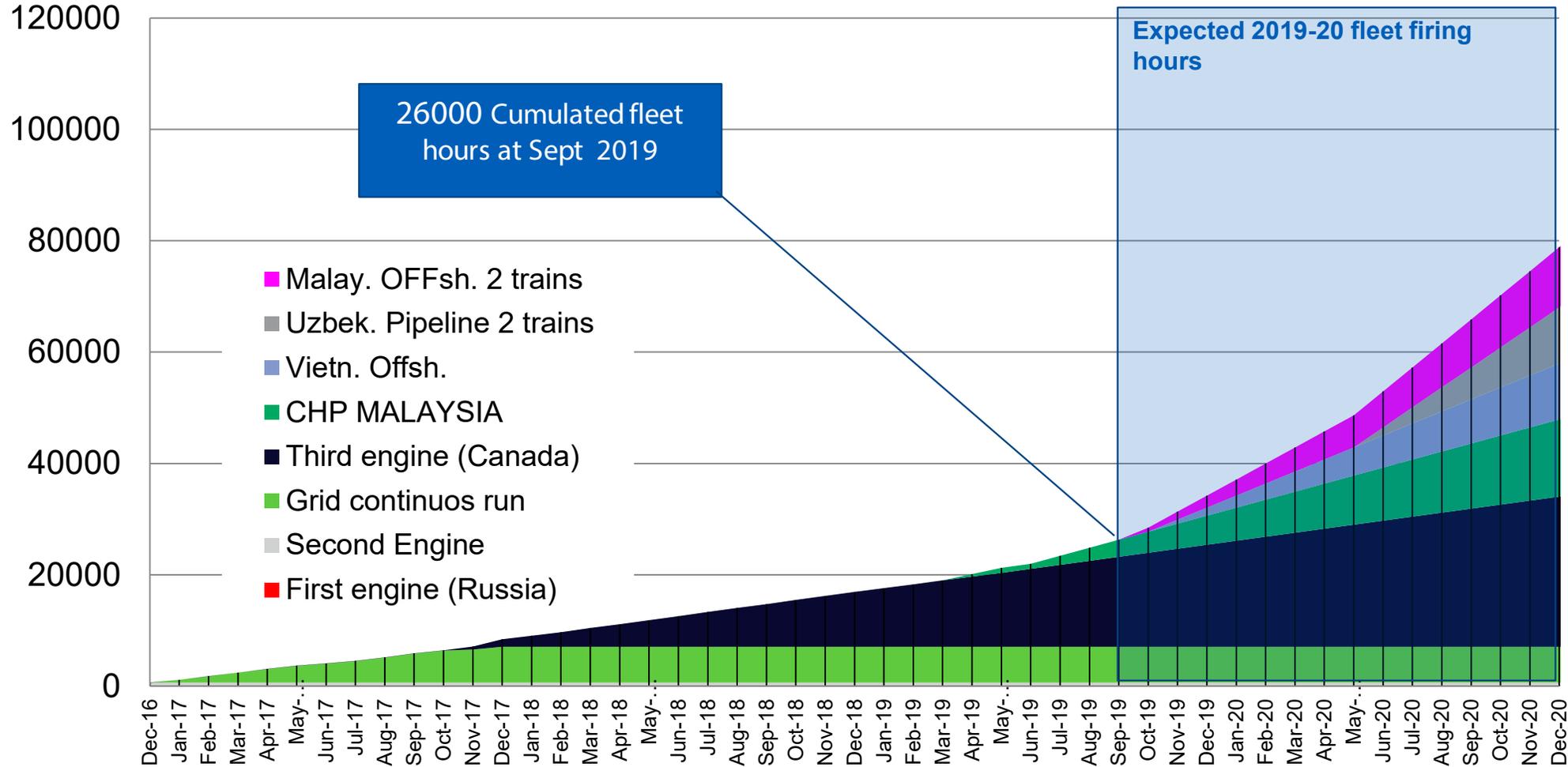




- ~50% of the time at below 0°C ambient temperature
- Bimodal distribution of power (measured with torque meter), showing significant part load operation
- Utilized power turbine speed range: 75-105%



NovaLT16 fleet firing hours @ Sept 2019



26000 Cumulated fleet hours at Sept 2019

Expected 2019-20 fleet firing hours

- Malay. OFFsh. 2 trains
- Uzbek. Pipeline 2 trains
- Vietn. Offsh.
- CHP MALAYSIA
- Third engine (Canada)
- Grid continuous run
- Second Engine
- First engine (Russia)

15 units produced, Cumulated 26,000 commercial hours, fleet leader @ 17000 hours,

Thank you

