PRELUDE FLNG
A STORY OF INNOVATION

- Prelude FLNG Project Overview
- Managing Innovations in a MegaProject
  - Side-by-side Offloading
  - Turret & Mooring
  - Water Intake Risers

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Reserves: Our use of the term “reserves” in this presentation means SEC proved oil and gas reserves.

Resources: Our use of the term “resources” in this presentation includes quantities of oil and gas not yet classified as SEC proved oil and gas reserves. Resources are consistent with the Society of Petroleum Engineers 2P and 2C definitions.

Organic: Our use of the term Organic includes SEC proved oil and gas reserves excluding changes resulting from acquisitions, divestments and year-average pricing impact.

Resources plays: Our use of the term “resources plays” refers to tight, shale and coal bed methane oil and gas acreage.

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PRELUDE FLOATING LNG

- Facilities for gas production, liquefaction, storage of LNG, LPG and condensate & direct offloading to market – all on FLNG
- Designed to be permanently connected and permanently manned
- Designed to survive 10,000 year environmental conditions, including tropical cyclones
- FLNG Facility is 488m long, 74m wide – largest vessel ever

LNG : 3.6 mtpa
LPG : 0.4 mtpa
Condensate: 1.3 mtpa
MAJOR PROJECT MILESTONES IN 2017:
SAILAWAY FROM SAMSUNG (END JUNE) & ARRIVAL IN AUSTRALIA (END JULY)
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Technology Development and Project Delivery are two distinct activities.

**Project Delivery**
- **Identify & Assess**: Assess opportunity
- **Concept Select**: Select development option
- **Define (FEED)**: Front end engineering
- **Execute**: Design, Construction, Installation

**Technology Development**
- **Discover**: “proof of concept”
- **Develop**: Mature components
- **Demonstrate**: Scaling, piloting, field trials
- **Deploy**: QA/QC, FAT

- It is always preferable to develop and demonstrate a new Technology prior to implementation in a major Project.
- PRELUDE FLNG characterised by innovation (gamechanging) & large scale (largest floating vessel). Hence it is stretching the boundaries.
MANAGING INNOVATIONS IN A MEGA-PROJECT

- Need to get it right first time; build in redundancy (belts & braces, e.g. load path thru chain and rubber hose in RHA).
- Limit new innovations in a Mega-Project. When new innovations are needed, recognise this early on and focus on it.
- Recognise that technology maturation does not end at “proof of concept”. Plan for further maturation & testing during FEED & Execute Phases.

**Offloading (2004-2015).** Assign responsibility for technology sign-off to TA1 & TA2 (Parallel process to project delivery). Engineering Manager maintains project delivery role.

- Technology step outs in existing concepts are harder to recognise. Treat as new technology.

“Technology step out”
Helical strakes on risers (installation load step out)
**PRELUDE FLNG: SIDE-BY-SIDE OFFLOADING LNG & LPG**

- Offloading of LNG & LPG will be carried out in side-by-side arrangement in open sea for 1st time
- Operation: LNG Carrier approach, berthing, offloading, departure
- FLNG is provided with thrusters to facilitate birthing and optimize heading during offloading

- Challenge recognised ~ 2004. Several JIPs: Motion of 2 floating bodies in proximity; sloshing in LNGC tanks
- Bridge simulations to develop procedures & train personnel.
- S-by-s feasibility is project specific; depends on env. conditions & vessel characteristics. Confirm feasibility during FEED & EXECUTE
- Dedicated Offloading Arms: Finalize development in EXECUTE

**OFFLOADING CRITERIA**

- Wind speed
- Wave height
- Line loads
- Fender loads
- **LNG Carrier Roll**
- Offloading Arm X, Y, Z
- Vessel clearance
- Tug operability
Heading of the FLNG:

- Often governed by wind and current direction

- For certain periods of the year, wind and current dictate FLNG heading and swell arrives at 90°, resulting in roll of the LNGC

- Offloading downtime governed by LNGC Roll

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Prelude FLNG offloading operability evaluated by analysing motion of 2 floating bodies (s-b-s) using local operating conditions (e.g. for 40 years).

- A 3-hr sea state is denoted as **Uptime** when all acceptance criteria (e.g. LNGC roll) are satisfied. If 10 successive sea states are **Uptime** then offloading operation (30 hrs) can be performed.

- Estimate % operability for the offloading operation in each month & each year.

- Conclusion that offloading operability is significantly influenced by LNGC roll, especially in July-September.

Thruster assistance in July-September improves Offloading operability significantly.

Requirements for offloading arms (X, Y, Z displacements) and accelerations defined.
NEW CRYOGENIC OFFLOADING ARMS

CONVENTIONAL LOADING ARM
- Used for Jetty-to-carrier offloading
- High stresses on LNG-carrier manifold

NEW CONCEPT DEVELOPED BY SHELL & FMC
- Lower stresses on carrier manifold
- Simplified operation & maintenance

¼ Size Model manufactured & tested under extreme combinations of:
(i) Displacements: $X_{rel}$, $Y_{rel}$, $Z_{rel}$;
(ii) Loads on LNG-Carrier manifold;
(iii) Connecting phase accelerations & loads.
FULL SCALE TESTING OF 1ST OFFLOADING ARM - 2014

Prelude Offloading Arm undergoing Factory Acceptance Testing (FAT); testing of emergency disconnection under cryogenic conditions with liquid Nitrogen.
EFFECT OF LNG SLOSHING ON LNGC ROLL MOTION & ON OPERABILITY

Prelude FLNG operability analyses based initially on ballasted LNGC. Recognised that more severe situations may occur during filling conditions. Problem rather complex (motion of 2 vessels s-b-s further complicated by sloshing)

Testing carried out by UWA/Shell/Shanghai examined sloshing and intermediate filling conditions

- Ballasted Case gives most severe response in beam seas
- 25% full gives most severe response in quartering seas
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TURRET STRUCTURE

- Largest Turret ever built – designed to satisfy 10,000 yr conditions
- Several technology step outs

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TURRET WEATHERVANING BEARING SYSTEM

- Axial bogies: Carry vertical loads on turret including mooring line loads: ~proprietary, standard size ~ existing
- Radial wheels: Resist horizontal loads due to vessel motions
- Lower pads: designed to come into contact only in extreme & survival conditions.
  - They limit horizontal loads on radial wheels and reduce bending moment acting on the bogies
- Turret-hull interface loads depend crucially on gap at lower pads. Nominal gap=30mm. Tolerance 10mm. Turret rotated in hull taking tolerance measurements to ensure that tolerances are met at all locations
Mooring system among largest ever made; Chain diameter = 175mm, Strength = 2500T, Line length ≈ 1500m.

Technology step outs in: (i) identifying critical 10,000 yr conditions for each system, (ii) low friction bushings, (iii) Fatigue of chain under Out-of-Plane bending, hawser size, interlink stiffness.

Low friction bushings, qualified to higher loads, approved by DnV and have been manufactured.

Pile size & installation in calcareous soils is a technology step out: challenge to control freefall & reach target penetration: Clump weight tool developed and implemented.
FLNG MOORING & PILES

- All piles successfully installed in 2016 reaching target penetration, mooring lines prelaid in 2016
- Mooring lines picked up and connected to FLNG in August 2017 – PRELUDE is declared “storm safe”
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WATER INTAKE RISERS

- New concept to deliver 50,000 m³/h of cooling water
- Incentive to go deeper: 150m below sea level
- Sparing philosophy: Allow for 1 spare riser
- Retractable for maintenance & inspection
- 25 years of service life
- Concept development started 2004

Avoid collision with moorings & risers

Typical water temperature profile in NW Australia

- Temperature (°C)
- 6-10 °C
**WATER INTAKE RISER – CONCEPT SELECTION**

**Individual risers**
- Easy change-out
  - Interferes with marine activity
  - Requires protection balcony
  - Large footprint on deck (piping)

**Rubber**
- Flexible – can accommodate vessel motion
  - Unknown failure modes
  - Difficult life time prediction

**Riser Bundle**
- Protected from boat impact
  - Small footprint
    - Dedicated crane to retrieve riser

**Steel**
- Extensive experience
- Weight just right
  - Rubber only at hull interface
WATER INTAKE RISER CONCEPT

8 @42" WI risers supported around a 30" structural riser

3 riser spacers to avoid collision & ensure bundle behaviour

Helical strakes on 4 corner risers only

RISER HANGER ASSEMBLY
Chain to carry axial load
Rubber to eliminate bending
Low friction bearings

RISER/HULL INTERFACE
Riser Response

- Top rubber connection is very effective; risers behave as moment-free at top
- Max stresses arise from bending under 2\textsuperscript{nd} mode at period = 7sec

Extreme Response

- Analyse riser under many extreme combinations of waves, winds, currents to identify critical cases for design
- Stresses under 100-yr and 10,000 yr conditions acceptable everywhere including steel sections & rubber & chain
- Redundancy:
  - If chain fails, rubber can carry riser weight
  - If rubber fails, chain can carry riser weight

Bending Moments in the riser

SHAPE

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**WATER INTAKE RISER - FATIGUE DESIGN**

- Fatigue life governed by local hot spot stresses at welds
- For each sea state in wave scatter diagram, estimate nominal stress ranges using global dynamic analyses, accounting for vessel motion and riser response

**Critical Locations**

- Girth Weld
- Pipe Wall
- Merlin Connector

Local Stress range distribution

\[
\sigma_{\text{hotspot}} = \sigma_{\text{pipewall}} \cdot SCF_{\text{Geometric}} \cdot SCF_{\text{Mismatch}}
\]

- Girth Weld: Double-sided and dressed flush
- S-N Curve validated using fatigue testing
- Fatigue life targets achieved for all locations

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Potential for two types of Riser Vibrations

(i) Vibration caused by internal flow in the riser  (ii) Vibration caused by external currents (VIV)
Potential for vibration due to entry of water at high speed into a free hanging riser

Topic of Guido Kuiper's PhD Thesis

After Guido's PhD investigation

Theory

Unstable behaviour
for $U_f >$ critical speed, $U_c$

Experiments

If $U_f > U_c$ we observe small amplitude oscillations (die & re-start)

$U_c = 5$ m/sec

Prelude max speed 2.8 m/sec

Induced stresses are negligible

No concern about vibrations due to internal flow
VIV characteristics

- Vortices shed alternately at Shedding frequency
- If Riser Natural frequency \( \approx \) Shedding Frequency of Vortices, then lock-in
- Amplitude \( \approx 1 \times \text{diameter} \)

What will happen in a bundle of 9 closely spaced risers?
SCENARIO 1: VIV of Bundle as a unit; (displacements ~ 5D)

SCENARIO 2: VIV of individual risers; smaller displacements (displacements ~ 1D)
SCENARIO 3:
Vortex synchronisation on 3 risers induces VIV of entire Bundle (displacement < 1D)

SUPPRESSION OPTION: Install strakes on 4 corner risers only (VIV ???)

VIV Testing of Scenario 3 and SUPPRESSION OPTION
WATER INTAKE RISERS – EXECUTE PHASE

De-risking of new technology - ensure new components perform as intended

- Helical strake tests to qualify for installation (tech. step-out)
- Verify that riser alignment & thicknesses are within tolerance
- Full scale sections of rubber hose tested in tension & torsion
  - Adequate capacity & stiffness in Tension
  - Measure torsion stiffness & torsion fatigue for use in design

WIR De-risking
Review 2016
FLNG is a Game-changer for remote offshore gas.

As far a possible PRELUDE uses proven & tested systems brought together in innovative ways – However, some new concepts:

- **Offloading**: 1st side-by-side offloading of LNG & LPG; extensive simulations and testing to establish operability. New cryogenic Offloading Arm developed & qualified.

- **Turret & Mooring**: biggest ever turret, biggest bearing loads on chainstoppers, bushing qualification, large diameter piles

- **WI Risers**: Largest ever in terms of throughput; new concept, new components, new phenomena

Recognise need for de-risking of new technology through Design & Construction to ensure full-size systems perform as intended – allow time & $ - need to get is right 1st time

In a Mega-Project you deliver value over 25 years so make it last !!