Subsea
Technical Challenges in a Tough Environment

Tom MacDougall

Artificial Lift Group Sustaining Manager
Singapore Product Center

Agenda

Setting the Stage

- Energy Supply & Demand

Subsea

- Market & Environment
- Key Challenges
- System Integration
- Next Generation Systems
- Intervention Alternatives

Reliability

- Survivability
- Accelerated Life Testing
- Robust Design

Setting the Stage: Energy Supply & Demand

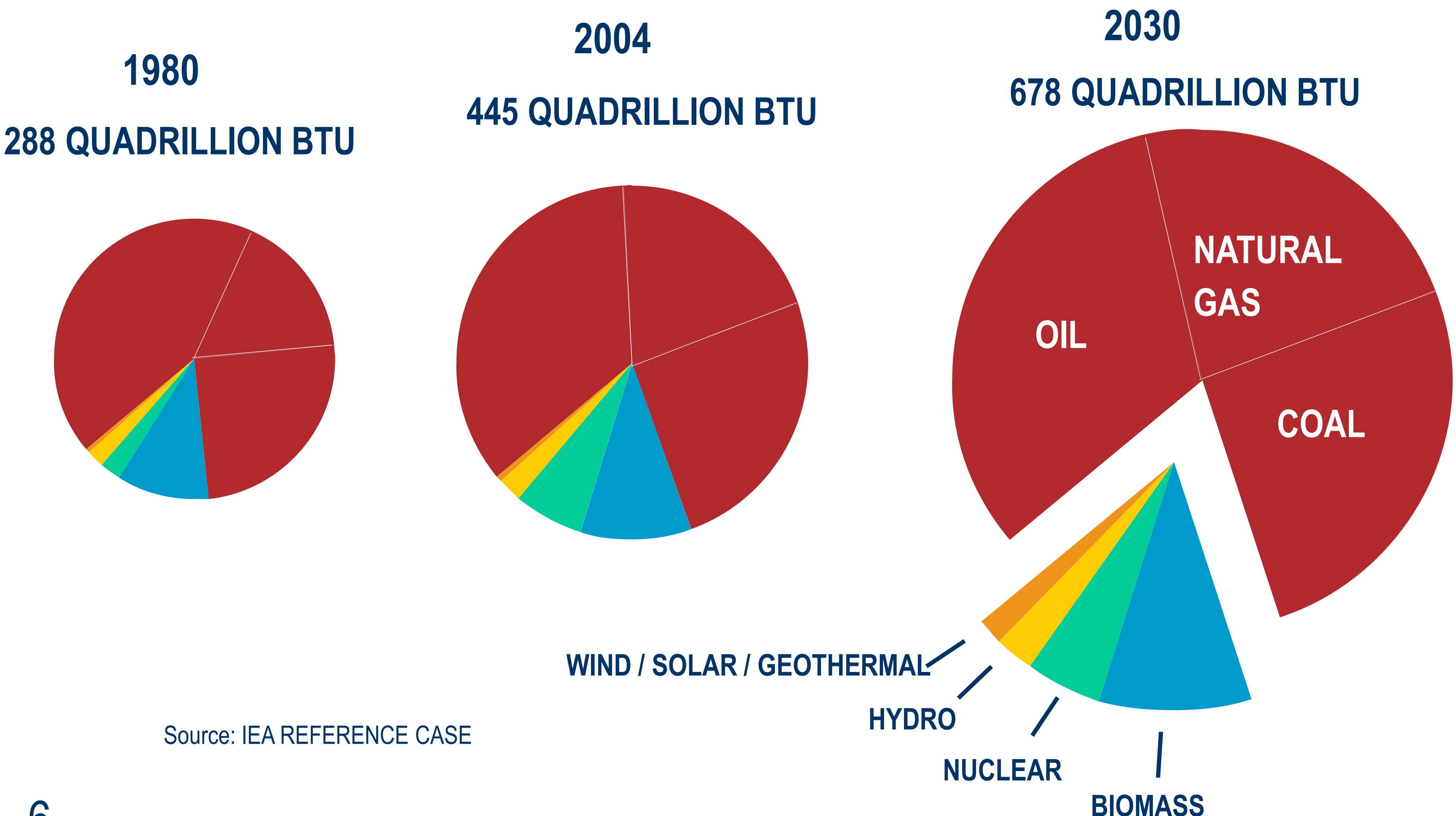
The world consumes over 400 Quadrillion Btu/Year

400,000,000,000,000,000 Btu/yr !!!!!

(~380,000,000,000,000,000 kJ/yr)

….and this is anticipated to grow by 50 to 60% by 2030

Projected Energy Sources
Fossil Fuels are indispensable



Source: IEA REFERENCE CASE

Will the World "Run Out" of Oil?

Is the world running out of energy resources?

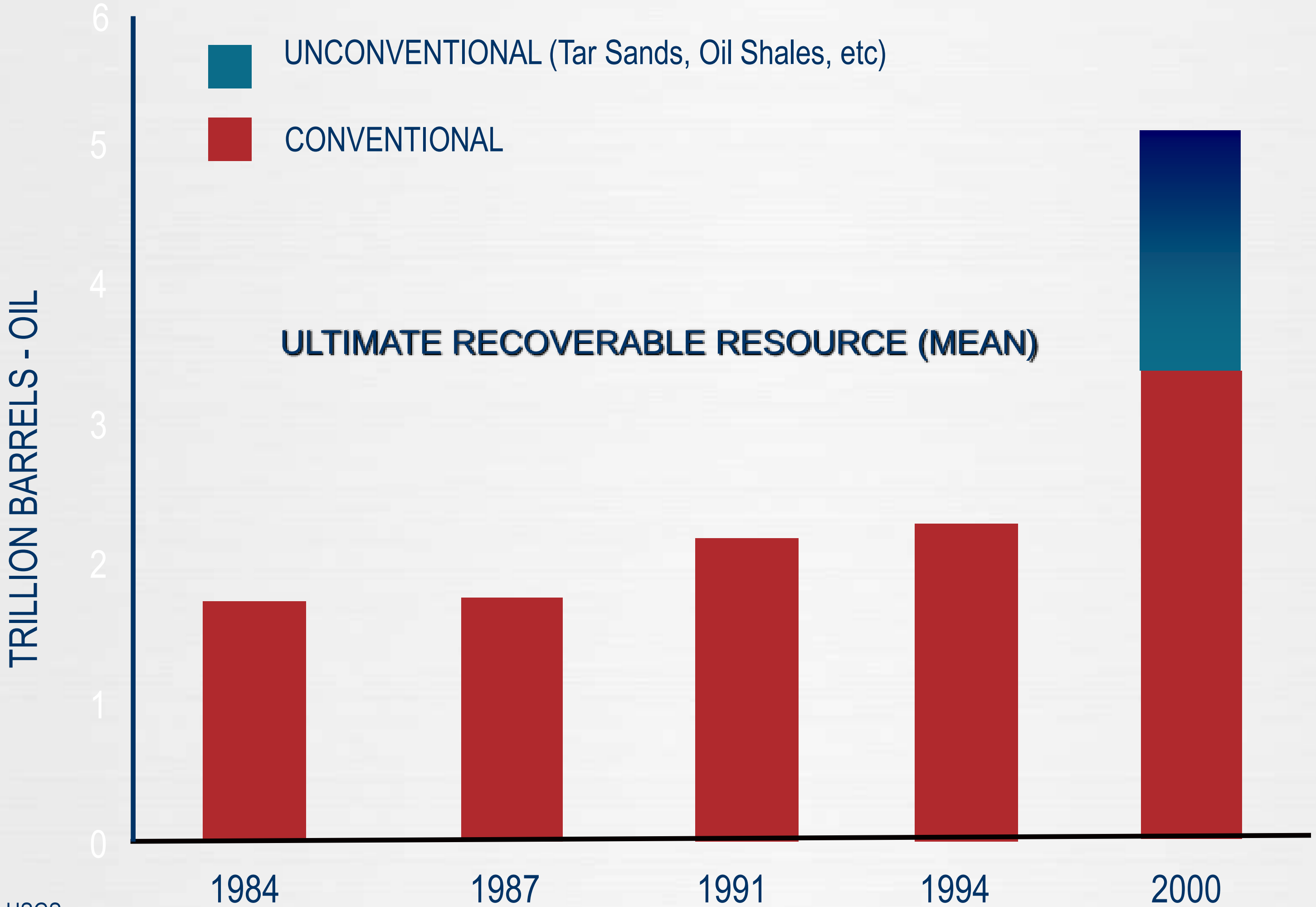
NO!!!

We have used ~ 1 trillion BBL of Oil To date

We have identified >5 trillion BBL recoverable reserves

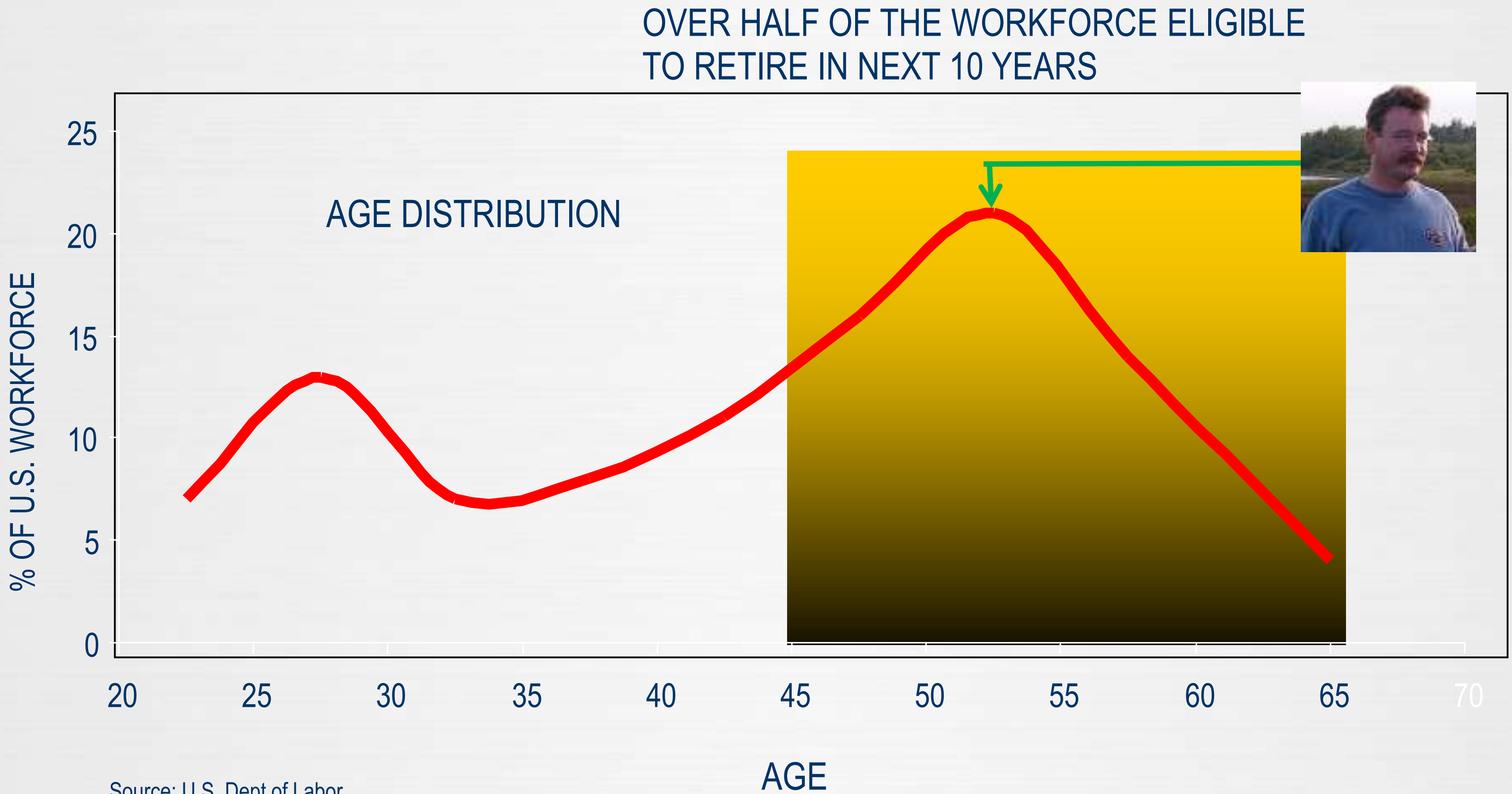
However….there are challenges

Known Oil Reserves



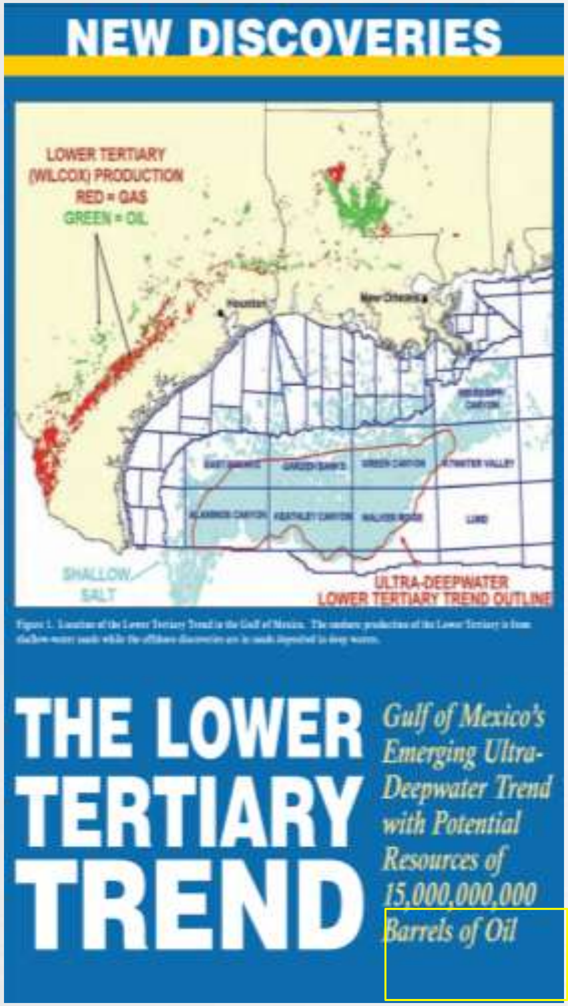
Source: USGS

Why is this "Your" Problem?



Source: U.S. Dept of Labor.

Subsea Integration – Gulf of Mexico



10-25 BBOE recoverable is today's estimate (J. Dribus)

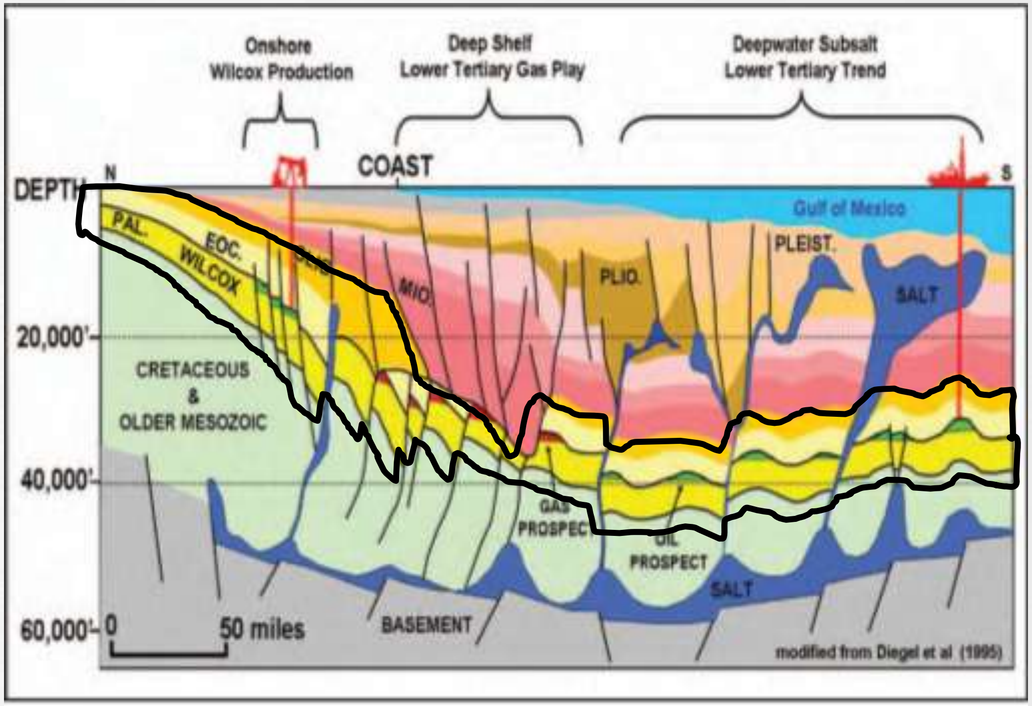
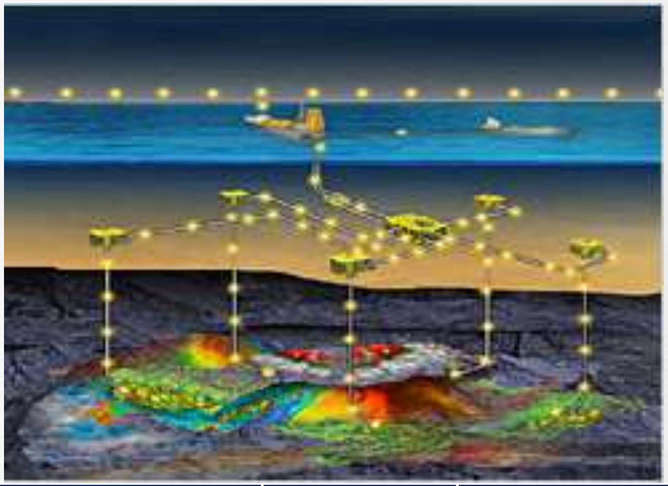


Figure 2. A generalized schematic of the relationship of the Lower Tertiary Trend (Oligocene, Eocene, Paleocene) sediments from onshore to deepwater offshore.

MMS Ocean Science Nov/Dec 2006

- The Lower Tertiary in the Gulf of Mexico presents the greatest opportunity for Subsea Integration
- Benefits from SS Integration extends well beyond GoM

Key Deepwater Exploration and Production Plays



Market Segment	Reservoir Characteristics	Target Horizon	Representative Projects	Wells Drilled	Boreholes Planned* (5 yrs)
Deepwater Mid-Lower Miocene	■ 20,000 to 30,000 feet ■ 180 to 250 degF ■ 15,000 to 20,000+ psi	■ Middle-Lower Miocene	■ Tahiti (CVX) ■ Thunderhorse (BP) ■ Heidelberg (Anadarko)	>1500	~500
Deepwater Lower Tertiary	■ 25,000 to 35,000 feet ■ 225 to 300 degF ■ 20,000 to 30,000+ psi	■ Oligocene (Frio) ■ Eocene (Wilcox) ■ Paleocene	■ Jack/St Malo (CVX) ■ Kaskida (BP) ■ Cascade/Chinook (PBR)	~30	~70
Deepwater Jurassic	■ 23,000 – 26,000 feet ■ 300 to 350 degF ■ 18,000 to 22,000 psi	■ Norphlet	■ Vito (Shell) ■ Appomattox (Shell) ■ Vicksburg (Shell)	4	>20

Subsea: Key Challenges

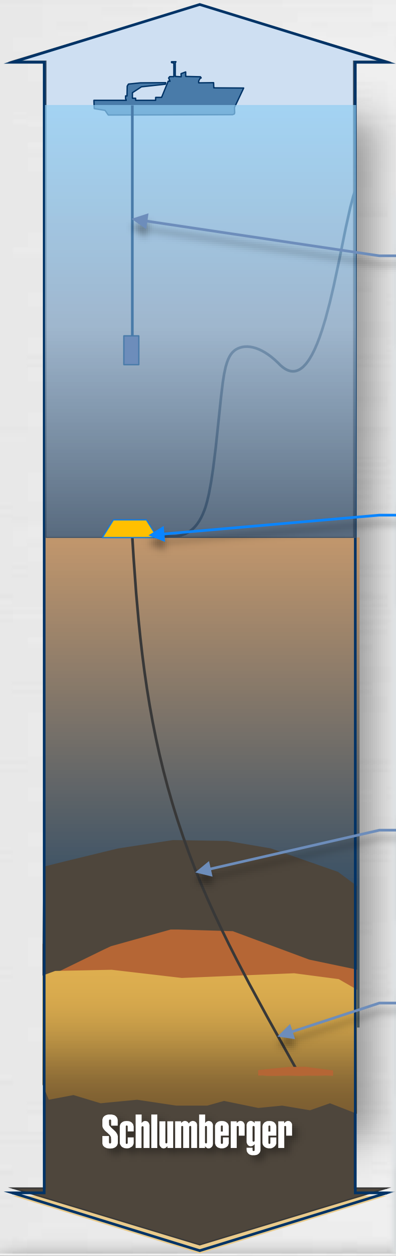
Health, Safety & Environment	• Risk Management • Regulatory Compliance • Liability
Operational Efficiency	• Rig Time --NPD • Cost of Interventions • High Cost of Lost Production
Demanding Environment	• High Pressure • High Flow Rates • High Temperatures
Life of the Well	• Monitoring & Control • Reconfiguring • Secondary Recovery

What is Needed:

A fully integrated, highly reliable and safe system that can be deployed efficiently that can intelligently monitor key reservoir parameters, and automatically adjust the producing configuration to yield optimized production over the life of the well.

Piece of Cake, Right?

Subsea Integration



Systems	Products	Life of Field Solution & Services
Rigless Intervention	Coiled Tubing Deployment Wireline/Cable Depl.	Flexible life of field solution for optimum production in all phases
Seabed Pump Stations	Seabed Boosting Manifolds/MultiManifolds Subsea Processing Subsea Metering Power Distribution Subsea Controls & Monitoring Subsea Sampling	Commissioning and installation team Field services Integrated System Operation System Health Monitoring Production Surveillance & Optimization Field Recovery Management
Secondary Recovery	ESP Gas Lift	
Completion	4D-Seismic Intelligent Completions Down-hole instr. /monitoring Zonal Inflow Control Sand Management	

PRE FEED/ FEED STUDY → PROJECT EXECUTION (PM /Eng, / Manufacturing / Testing) → INSTALLATION START-UP → OPERATION

Next Generation Subsea Systems

Fully Integrated Systems

- From Reservoir to Export Point
- Downhole & Seabed facilities
- Fully Monitored & Controlled
- Optimization & Answer Products

Subsea Systems

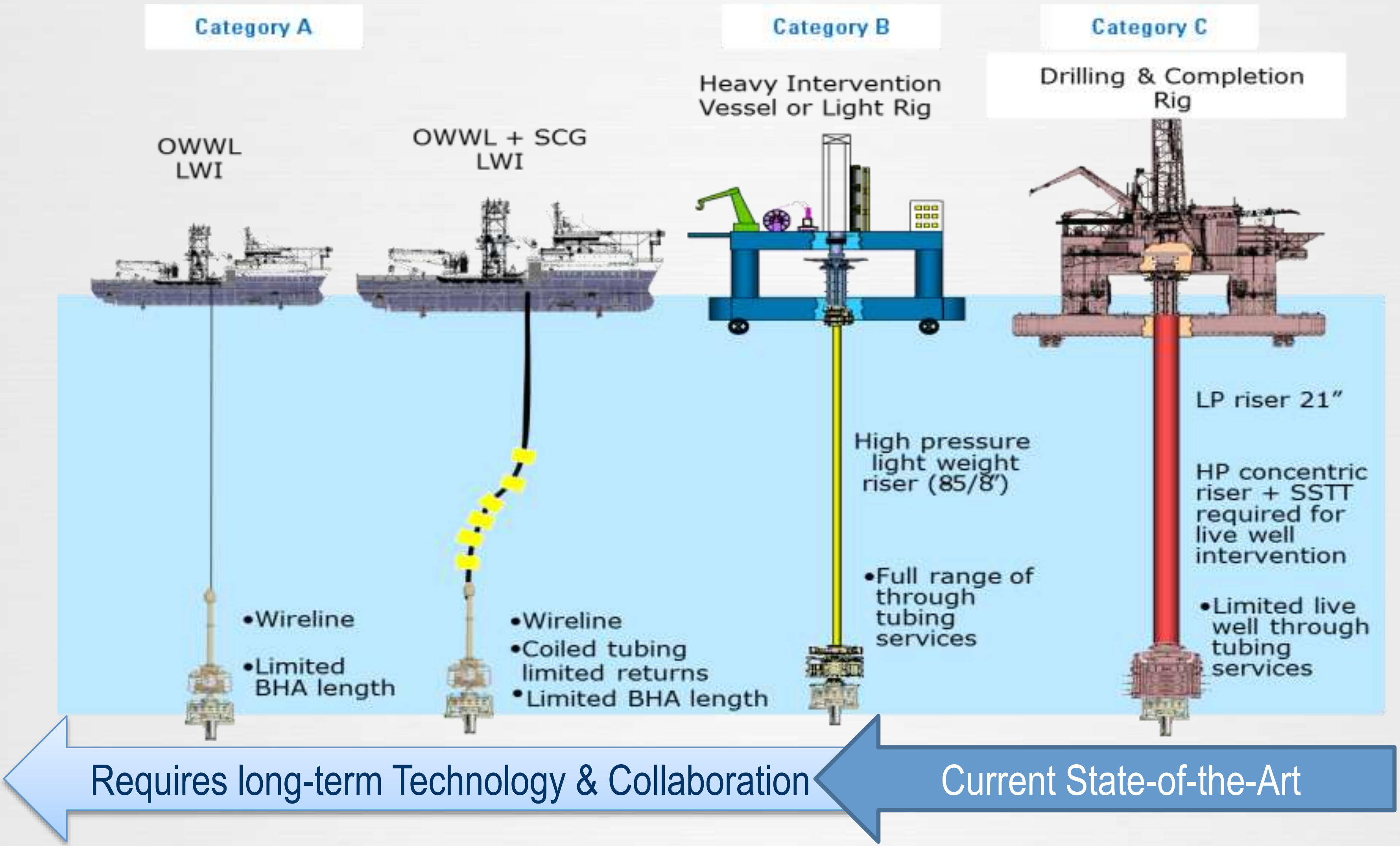
- 5+ Year Reliability
- Robust Design Principles
- Reliability Modeling
- Testing & Integration
- Enhanced Quality Control

Life of the Well

- Rigless Workovers
- Highly Reliable Artificial Lift
  - (Gas Lift & ESP)
- Reconfigurable Completions
- Flow Assurance

Integration — Reliability — Intervention

Subsea Intervention Alternatives



Schlumberger Approach to Reliability Engineering

Schlumberger Concurrent Lifecycle Management System requires Reliability to be designed into products and processes, using the best available science-based methods

- Knowing how to calculate reliability is important, but knowing how to achieve it is equally important. i.e. Robust design engineering

- Reliability program includes both probabilistic and deterministic approaches
  - Probabilistic approach utilizes probability and statistics theories
  - Deterministic approach utilizes root cause analysis

What is Reliability?

The probability of a product performing *without failure*
for specified functions
under given conditions
for a given period of time.

Quality Control Handbook, Third Edition; McGraw Hill

$$R(t) = \Pr\{T > t\} = \int_{t}^{\infty} f(x)dx$$

Reliability Factors

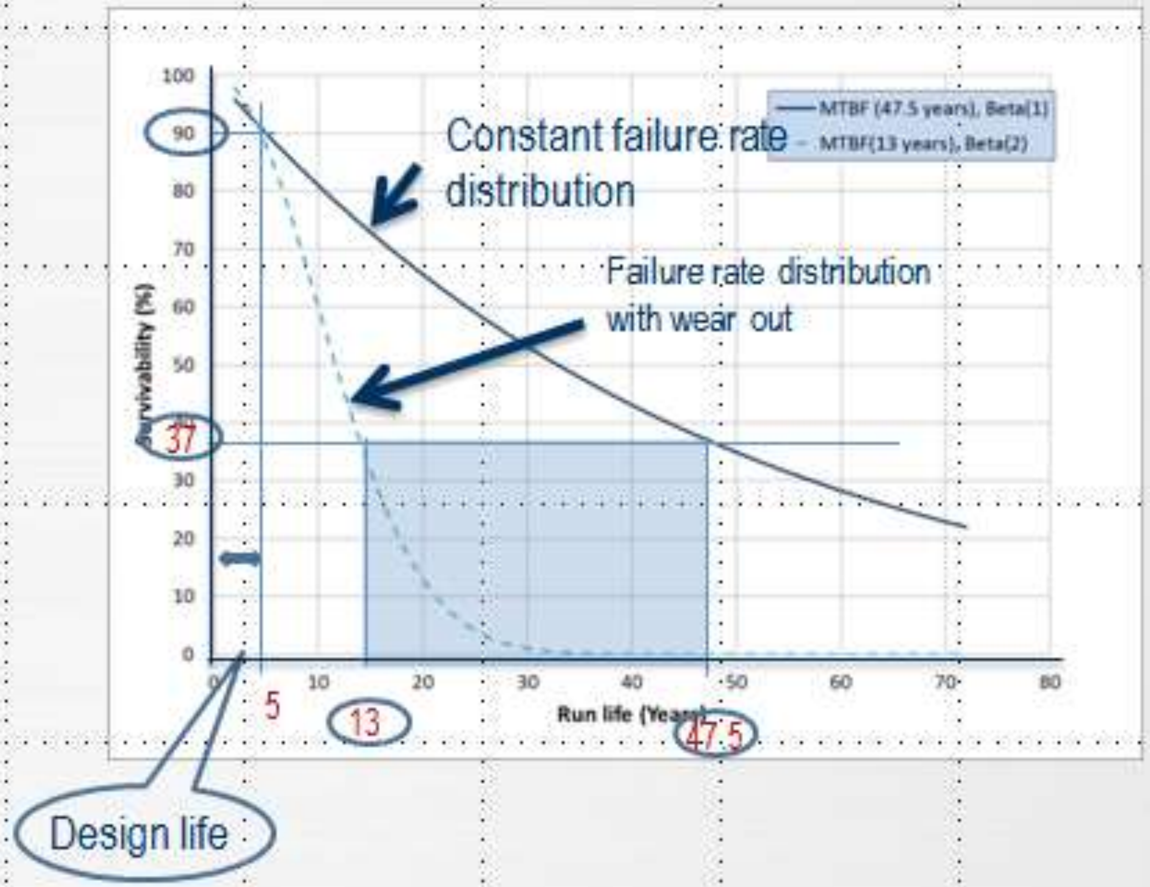
System reliability depends on a multitude of factors:

- Equipment Design
- Technology Qualification
- Manufacturing & FAT
- Transportation
- Installation
- Operation
- Personnel Training
- Cost
- Accurate Well Conditions

Survivability:
A better metric

MTBF can vary based on the Beta value

Survivability (%) for useful life is a better metric



Test strategy

Demonstrate the reliability requirements for the useful life (i.e. 99.44% for 5 years at component level) rather than demonstrate the MTBF.

This is done by test to failure, degradation testing and accelerated testing

Bridging the Gaps

Current product reliability

~ 75% for 3 years

- Standard Operating environment
- Data set of ~2000 units (across geographies and diverse well conditions)

Challenges ahead for Subsea

90% for 5 years

- HPHT environment
- High intervention costs
- 2 year test window

How do we get there?

Robust Design

- Higher design margins
  - Trade off (performance vs. reliability)
- Build in Redundancy
  - Add components in parallel
- De-couple functions
  - Axiomatic design principles
- Process rigor
  - In-depth understanding of life cycle profile
  - Concurrent life cycle management system

Typical Component Classification

System

Degradable

- Rotating part (R-D), Stationery part (S-D)
- Degradable over time
- Time is the random variable
- Demonstrated through degradation testing, accelerated testing

Functional series (Yes)

- Failure of the component leads to system failure

Non Functional series (No)

- Failure of the component does not lead to system failure

Non Degradable

- Rotating part (R-N/D), Stationery part (S-N/D)
- Non Degradable over time
- Load, pressure etc. is the random variable
- ~100% reliability
- Demonstrated through simulation, test to failure - design margins, safety factor

Reliability Testing

Accelerate dominant stress level(s) which would cause product failure in the long run, e.g.:

- Operating temperature (for electronics)
- Amount of abrasives produced (mechanical system)

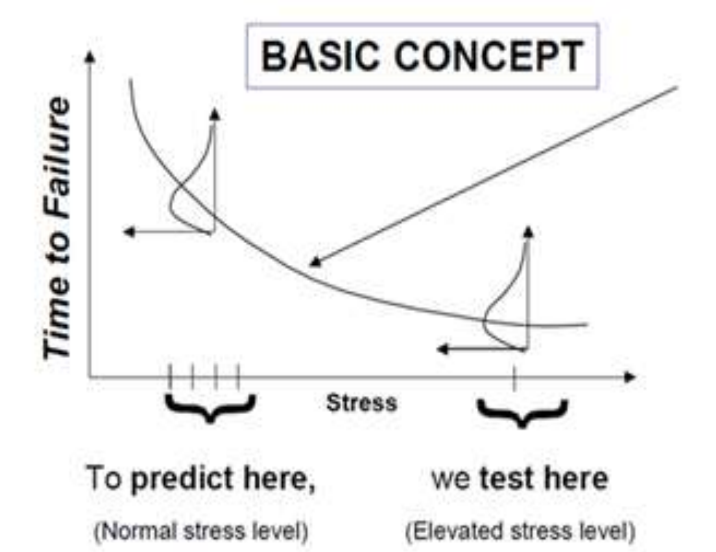
Test at multiple accelerated stress levels

- Most no. of DUTs at stress level closest to use condition

Use the appropriate life-vs.-stress relationship to analyze the data:

- For thermal stress (temperature, humidity): Arhenius, Eyring
- For non-thermal stress (voltage, mechanical, fatigue): Inverse Power Law
- Graph of data may also readily show life vs. stress relationship

Accelerated Life Testing (ALT)



Purpose:

- Estimate life expectancy at a stress level seen in operation – up to its rating
- Verify whether product reliability meets requirement

Method

- Test to Failure - Operate multiple samples on accelerated stress level(s) until failure
- Degradation Testing - to enable extrapolating expected lifetime based on test
- or until total runtime of all samples reach the calculated equivalent at operating condition
- Utilize life data analysis technique to calculate life expectancy at a stress level (operational condition) below test stress levels

Component Testing Program

- Reliability tests are applicable to components in functional series
- Typical assemblies have hundreds of parts in functional series

➢ All components in functional series would be subjected to different test regime such as Accelerated tests, Degradation tests, test to failure wherever applicable (to understand time to failure distribution)

➢ Components not in functional series and non-degradable components would be subjected to qualification tests

➢ Sub-system level test and SIT to supplement

Destructive Erosion test to determine design margins

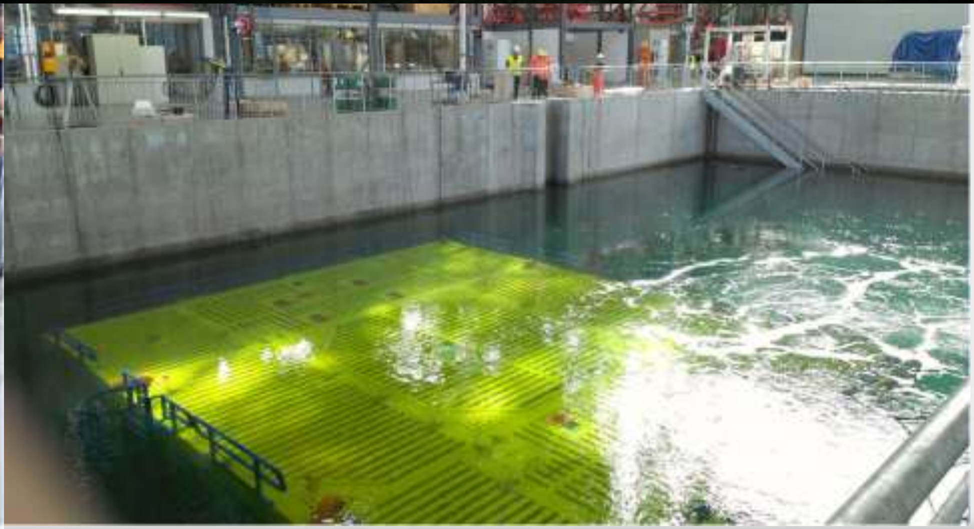
Reliability Testing Facilities

- Component level testing
- Sub-assembly testing
- System Integration Test

System Integration Testing

Subsea Testing Facility

Horsoy, Norway



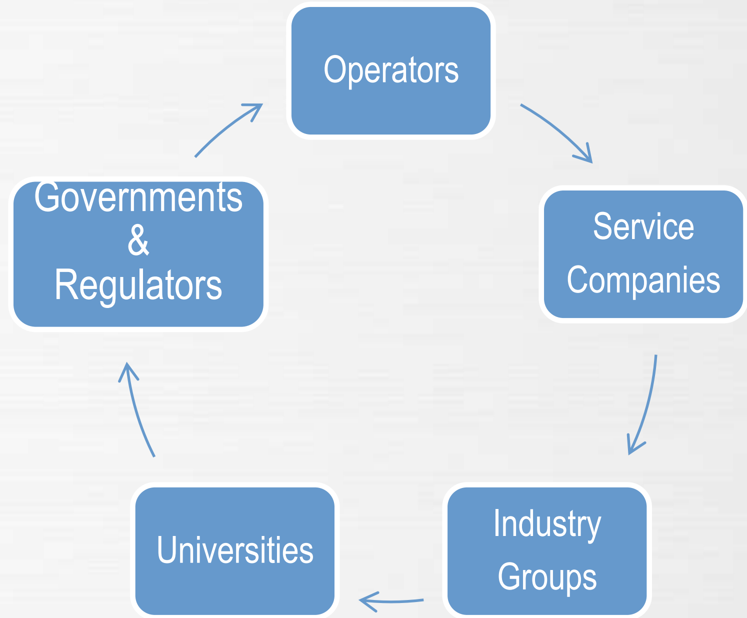
Conclusions

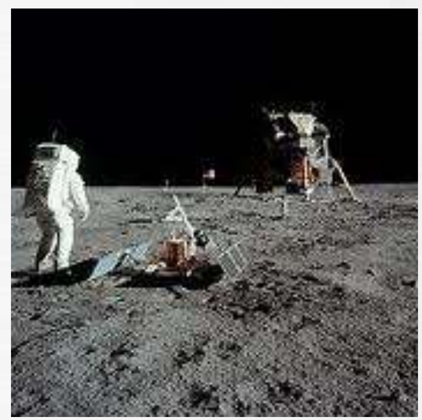
The Challenges are Immense
The Risks are High,
The Investments are Enormous.

Why Do it?
Because we MUST….

We need our best…and our brightest
We MUST make safe,
We MUST make it work,
It will take a team to do it right.

I’m from Houston,
so don’t tell me it can’t be done…..





Questions / Comments?