History of Rotary Steerable Technology

Speaker Information

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- Aug 31, 2023
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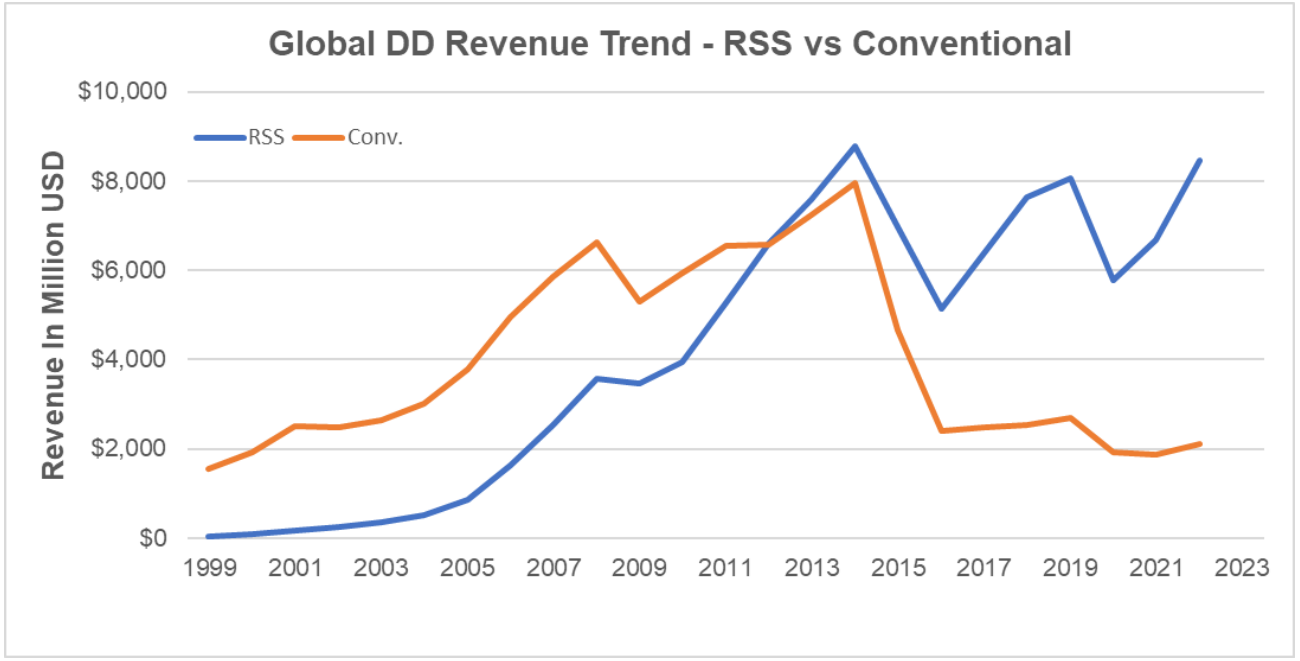
Introduction

Rotary Steerable Tools Have Taken Over Global DD Market



Source: Spears & Associates, July 2023

RSS Usage

> 80% Total Offshore

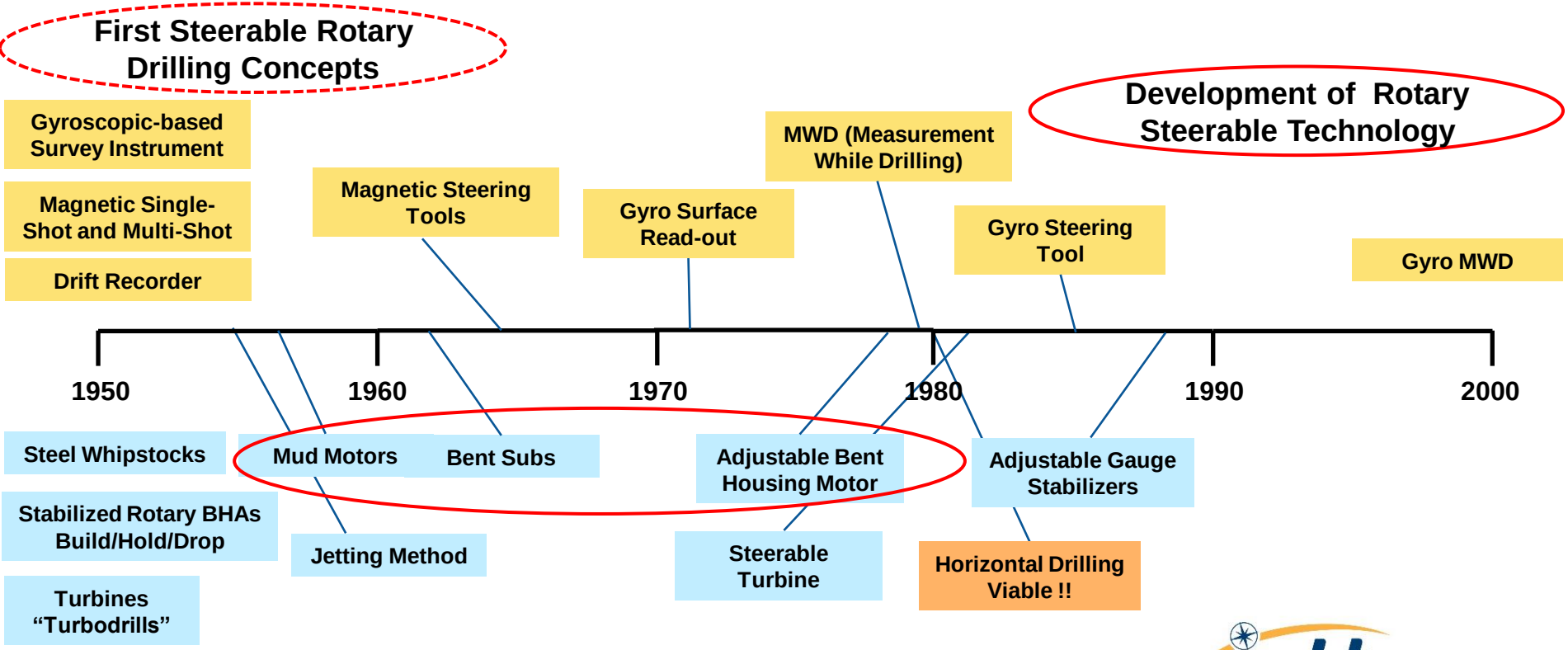
> 50% Intl. Land

> 35% US Land

Source: Kimberlite Research July 2023

iadd International Association Of Directional Drilling

DD Technology in the 2nd Half of Last Century



Source: IADC Drilling Manual, 12th Edition, others

1975 – 1990 Emerging Needs

- Rapid adoption of directional/horizontal drilling w/ steerable motors
  - Exploring benefits and limitations (lateral reach)

- Realization of DD challenges using steerable motors in long wells
  - Increasingly difficult tool face control due to friction with increasing depth
    - Unwanted TF fluctuations ➔ Increasing tortuosity and friction
  - Challenges in weight transfer due to axial friction ➔ low ROP in steering mode
  - High tortuosity/low wellbore quality
    - Torsional oscillations
    - Challenges for completion and production
  - Hole cleaning problems

  Expressed in several industry publications, i.e. SPE papers 23850, 28293, 29382

RSS Technology Roots - UK

- The “Cambridge Tool”
  - UK Patent Application 2.177738A filed on July 13,1985 by Cambridge Radiation Technology Ltd
  - Original Point-the-bit concept with closed-loop gravity tool face control and pre-programmed course control (Inc. & Azi)
  - Funded by BP, Britoil and several other North Sea Operators (DEA(e) Project)
  - Initially named AGS – Automated Guidance System
  - Downhole prototype testing 1993 – 1997 (Montrose, Aberdeen)
  - Start of commercial deployments from 1998 onwards w/ 9 ½” tool
  - Acquired by Gyrodata in 2002
  - Trade name: Well-Guide
  - 6 ¾” tool introduced in 2005, 5” tool in 2013
  - RSS Product Line divested around 2020

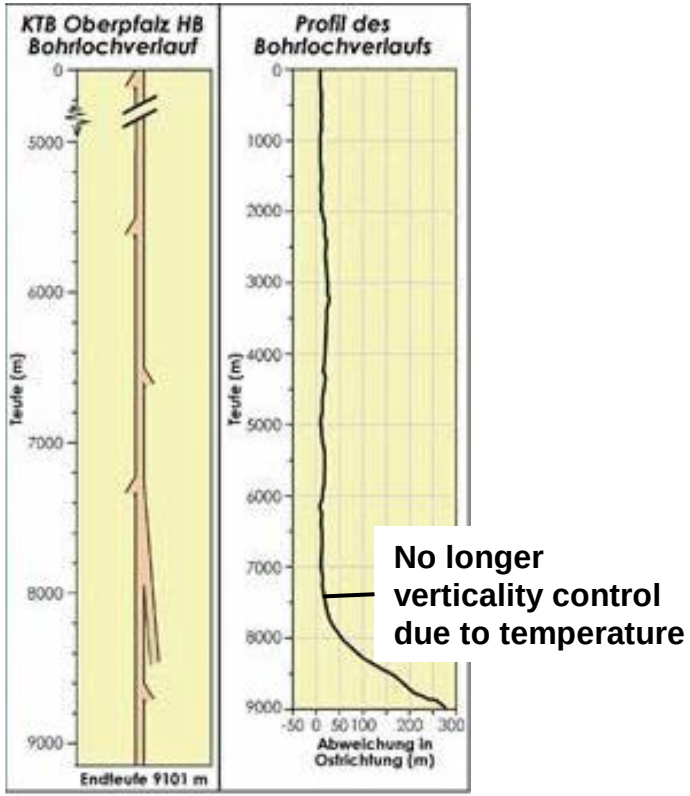
RSS Technology Roots – UK, cont'd

- The "Camco Tool"
  - Project group associated with Reed-Hycalog, part of Camco Drilling Group Ltd at the time
  - Several patents filed between 1991 and 1995 covering a roll-stabilized control unit and a variety of bias unit concepts
  - Developed push-the-bit system with non-rotating internal control unit and bias unit to actuate pads on outside of rotating housing, powered by differential pressure across bit
  - First field test in 1994 at Montrose Drilling Training Centre (Aberdeen) (SPE29382)
  - Prototype/pilot deployments of 6 ¾" tools in extended reach applications at BP Wytch Farm starting in 1996 until end of drilling phase in 1999 (SPE59204)
  - Camco acquired by Schlumberger in 1998
  - Trade name: PowerDrive
- Xceed
  - Schlumberger internal project started in the early 1990s
  - Point-the-bit Steering Concept
  - Extended testing and improvement period
  - Full commercial launch as PowerDrive Xceed in international applications around 2008

RSS Technology Roots – UK, cont'd

- Revolution
  - Precision's Energy Services Division started development project around 2002 in Tewkesbury, England
  - Point-the-bit system with pivot stabilizer acting as fulcrum point below non-rotating housing
  - Development started with 4 ¾" tool size, field testing in Mexico
  - 6 ¾" tool introduced mid 2004, 8 ¼" tool introduced late 2005
  - Precision Energy acquired by Weatherford in 2005
  - Trade name: Revolution®
- Other Systems
  - DART – Andergauge Drilling Systems (acquired by NOV)
  - Target Energy Systems RSS
  - Others

RSS Technology Roots – Germany



KTB (**K**ontinentale **T**ief**b**ohrung) – Continental Deep Drilling Project

- 1987 – 1995
- Geological research well through igneous rock (Ocean Deep Drilling Program)
  - Original target depth 12,000 m, target temperature 300ºC
  - Reached depth of 9,101 m (29,859 ft) and temperature of 265ºC
- Project funded two developments of innovative vertical control drilling technology

RSS Technology Roots – Germany, cont'd

- Mining Industry Roots
  - JV between SCHWING Hydraulik Elektronik GmbH and DMT (Deutsche Montan Technologie)
  - Developed vertical rotary drilling system ZBE 3000 for 8 ½" hole size in the early 80's
  - Push-the-bit system with non-rotating sleeve with four steering ribs actuated by oil-hydraulic system w/ piston pumps and control electronics based on inclinometers
  - First commercial deployment in 1984 in Belgium
  - KTB funded development of larger hole sizes ZBE 4000 (12 ¼" HS) and ZBE 5000 (14 ¾" HS)
  - Further developments to full 3D system by adding Gyros (aborted) and Magnetometers
  - Founded DMT Welldone Services GmbH (1999)
    - 2002 sold tools to Noble Downhole Technology in US (➔ Well Director)
      - Several ownership changes and significant further developments (➔ DoubleBarrel RSS)
  - Management buy-out in 2005 ➔ Smart Drilling GmbH
  - Developed full 3D RSS systems Scout2000 and Scout3000 w/ Operator support
  - Acquired by NOV (National Oilwell Varco) in 2017, further developments
  - Trade names today: VectorZIEL and VectorEXACT (Vertical Drilling Tool)

RSS Technology Roots – Germany, cont'd

- Celle Roots
  - Eastman Christensen GmbH (a Baker Hughes Company) developed a non-rotating vertical drilling system starting in 1988
  - Push-the-bit system integrated in motor bearing housing with inclination sensor, control electronics and piston hydraulics actuating steering ribs
  - Used at KTB in 17 ½" (first in 1990), 14 ¾" and 12 ¼" sections (last in 1993)
  - In cooperation with Italian operator Agip (ENI) later commercialized as VertiTrak
  - Continued cooperation w/ Agip (ENI) resulted in development of a full 3D RSS
  - Push-the-bit system with non-rotating sleeve with 3 steering ribs, central oil hydraulics and control electronics, hard-wired to MWD system and powered by generator
  - Prototype testing in 1994/95 at Montrose Drilling Training Centre (Aberdeen)
  - Commercially launched in 1997 as integrated RSS w/ gamma, propagation resistivity and MWD system in 6 ¾" tool size
  - Trade name: AutoTrak™ RCLS

RSS Technology Roots – North America

- Geo-Pilot
  - Developed by Halliburton (Sperry-Sun and Security DBS) in Nisku, Canada in the late 1990's
  - Point-the-bit system based on controlled drive shaft bending between two bearings inside a non-rotating sleeve, hard-wired to MWD system
  - Field testing of 6 ¾" prototype in Canada, market introduction of system in 2000
  - 9 ½" tool size introduced in 2002, 4 ¾" tool size introduced in 2005
  - Trade name: Geo-Pilot®
- Rotary Steerable Tools (RST)
  - Patent filed in 1995 describing weighted housing concept
  - Development started in 1997 in Houston, prototype field testing started in 1999
    - Publication: AADE 01-NC-HO-21
  - Acquired by Halliburton in 2005 (low-cost RSS option)
  - Trade name: EZ-Pilot (PL abandoned several years later)

RSS Technology Roots – North America, cont'd

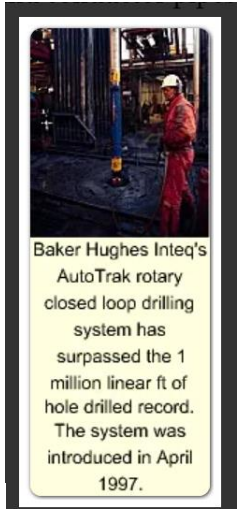
- SRX
  - Scientific Drilling International started RSS development project in 2002 in California
  - Push-the-bit system with non-rotating sleeve with displacement controlled steering ribs
  - Field testing started in 2004, initial focus on applications in California and Rockies
  - Limited success with prototypes in vertical and low angle applications
  - Project aborted in 2013, started new development project in 2014

- TerraVici
  - Founded in 2003 as TerraVici Drilling Solutions to develop a unique point-the-bit system
  - Field testing started about 2006
  - Owned by H&P from 2008 to 2019
  - Trade name Name: TerraPoint™

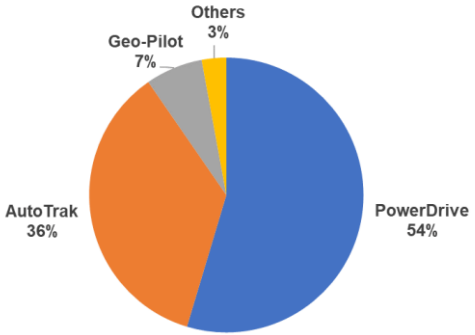
- Numerous other concepts and projects

The Early Days Until 2005 – Rapid Adoption

- BH's AutoTrak dominated emerging RSS market until 2000
  - Launched as integrated system with Steering Unit, Resistivity and MWD
- SLB's PowerDrive fully launched in 2000 and led RSS market from 2001 onwards based on annual footage drilled
  - Standalone steering control device initially, later EM - short hop to MWD
- Activity statements in April 2005 Offshore (Directory of Rotary Steerable Systems)
  - BH's AutoTrak: Since launch 3,000 jobs performed with over 13 million feet drilled
  - GD's WellGuide: Nearly 100 commercial runs
  - HAL's Geo-Pilot: Completed more than 1,200 runs
- Estimated 2004 RSS market share (annual footage)
  - 2004 global RSS footage ≈ 10 million feet
  - > 90% offshore footage
  - SLB's PowerDrive US-Land: 350,000 ft

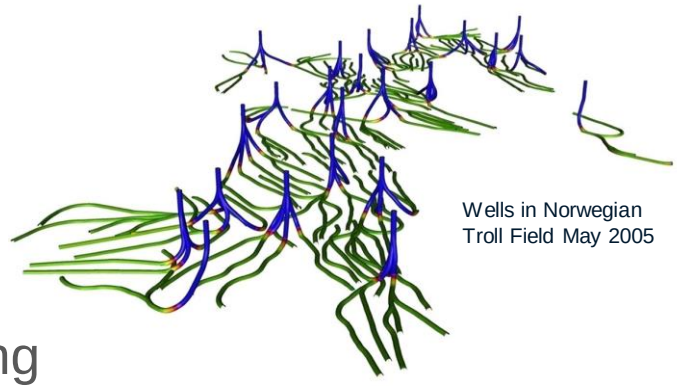


Business Brief in *Offshore* March 2000



Initial Offshore and ERD Focus

- High rig rates
  - Incentive to risk deploying new technology that improves performance
  - High failure cost ➔ focus on reliability
- Increased reach capabilities with RSS
- Low to medium dogleg requirements
- Strong need for LWD systems
  - Complex BHAs, Focus on system integration
- Enabled Geosteering and complex well drilling
- Enabled underreaming operations ➔ GOM Deepwater
- Significant investments by service companies to provide RSS in all hole sizes from 5 7/8” to 28”



Wells in Norwegian Troll Field May 2005

Enhancing ERD Reach

Extended Reach Drilling Database (https://www.gibsonreports.com/erd)

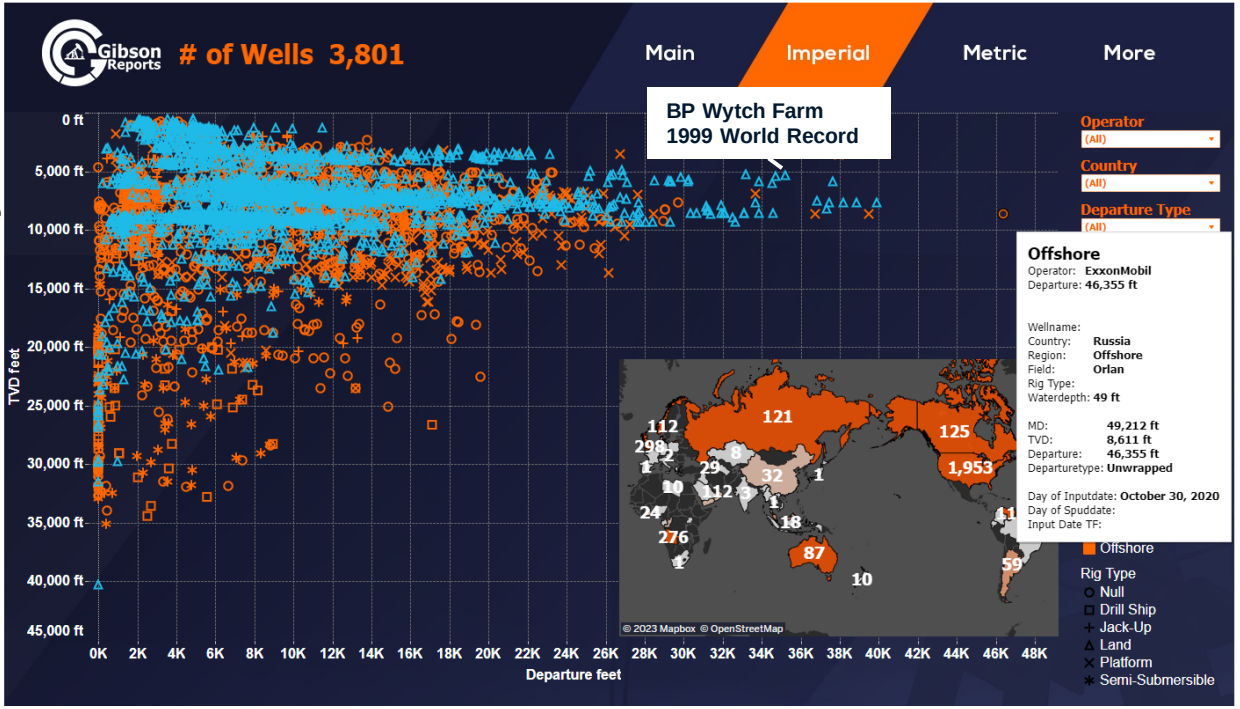
- Originally started in the 1990's by BP in light of their Wytch Farm ERD project

2022 ADNOC Press Release:

"ADNOC drilling delivers new World Record for the Longest Well

Stretching 50,000 ft, ……"

(Remark: Well is not in ERD data base)



2005 – 2010 Expanding to Onshore Markets

- RSS technology first adopted in international land applications such as the Middle-East
  - Conventional reservoirs with significant LWD requirements
  - Mostly moderate build rate requirements
  - Push for drilling performance
    - Baker Hughes added AutoTrak X-treme option (wired motor) to their RSS capabilities

- Emerging unconventional reservoir drilling market in the US
  - Small leases ➔ High build rate requirements up to 15º/100 ft to maximize length of horizontal production sections
  - Limited LWD options in shale ➔ simpler BHAs
  - Cost-sensitive ➔ strong focus on drilling performance
  - Hard and abrasive formations ➔ drill string wear

Need for mud motor to provide power at the bit ➔ **Motor-assist RSS**

2008 – 2015 Engaging US Shale Market

- Schlumberger (PowerDrive)
  - Early market presence and tool architecture fit for shale laterals, able to focus on continuous improvements from the start ➔ High reliability
  - Technology refinements (Incl. hold, fast flow downlinks) to improve useability
  - High build rate tool development
    - PD Archer and later NeoSteer

- Baker Hughes (AutoTrak)
  - Development of new high build rate tool
    - 6 ¾" AutoTrak™ Curve
      - RSS integrated with MWD incl. Azigamma
  - Rapid fleet growth and advance to high reliability

- Attempts of many existing and new RSS tool providers to gain traction in rapidly growing market

- US RSS market leader (#1 in the Permian and other basins)
- Expanded US market position with rental and sales model starting 2013
  - Independent DD companies gained access to proven RSS technology o

- Dominating position in the NorthEast with leading curve/lateral capability and reliability
- #2 market share in the US overall

- Once capability confirmed, still long road ahead to catch up to industry's performance and reliability standards

New Tool Introductions Since 2015

- D-Tech RSS established presence in US and increasingly in international markets
  - Emulate independent RSS business model, can be run with any MWD/LWD system
- Schlumberger added the NeoSteer at-bit steerable system to their RSS offerings for high build rate applications
- Halliburton launched the iCruise® RSS as their new RSS platform for a wide range of applications. Fully integrated with HAL's MWD/LWD product offerings
- Weatherford have introduced the Magnus® RSS and integrated with their MWD/LWD tools and services,
- Baker Hughes introduced the 5" Lucida™ advanced RSS in the Permian and internationally
- SDI's HALO® integrated RSS has reached competitive performance and reliability level in intermediate, curve and lateral drilling applications across US basins
- *Additional new systems are waiting in the starting blocks or are in field trials to join the party*

General RSS Categorization

- **Steering Concept**
  - ~~*Push-the-bit vs. Point-the-bit*~~
  - Static (non-rotating sleeve) vs. Dynamic (roll-stabilized control unit)
- **MWD/LWD Integration**
  - Integrated vs. standalone
- **Power Source – Control Electronics**
  - Battery vs. Generator
- **Power Source – Actuator**
  - Generator/oil hydraulics vs. differential pressure across bit
- **Other specifications**
  - Downlink method and resolution
  - Dogleg capability
  - Steering algorithm, directional control automation
  - …..

RSS Directional Drilling Automation

Downhole Tool Face Control

⇩

Downhole Inclination Hold

Available with most RSS from the start

⇩

Downhole Azimuth hold

Introduced in 2nd half of last decade, now available w/ several RSS

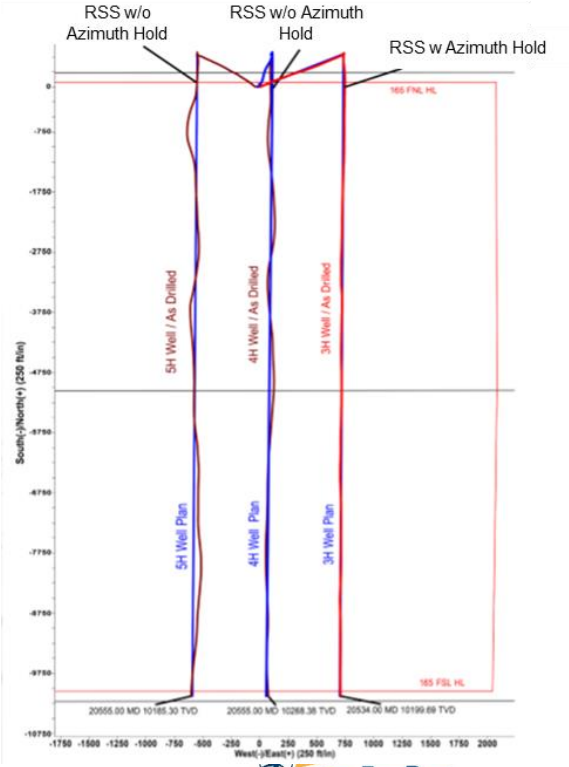
⇩

Full path control

(Ongoing developments and publications, requires surface input via downlink)

More automation in the future

- Rig operation / drilling process
- Geosteering?

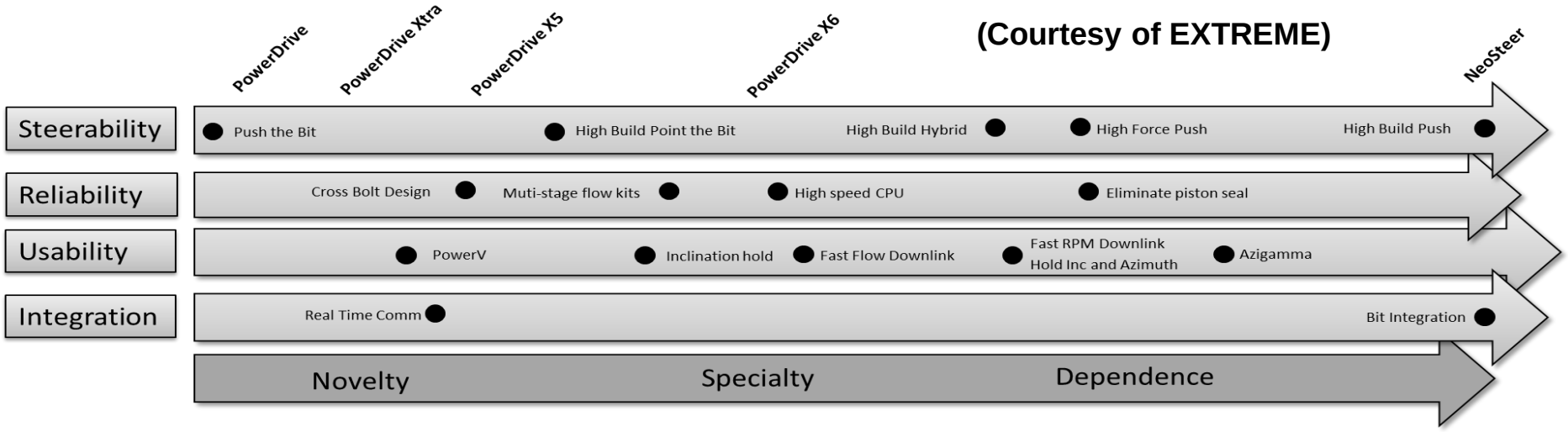


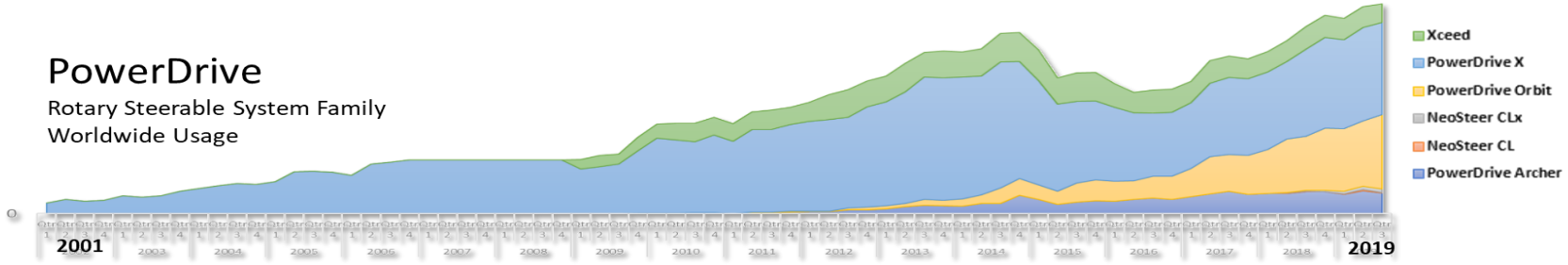
History of Rotary Steerable Technology - Summary

- **Technology roots of modern rotary steerable technology go back almost 40 years ago to first developments in the UK, in Germany and in North America**
  - **Testing of first downhole ready prototypes started less than 30 years ago**
- **Rapid uptake of RSS technology in offshore and ERD applications**
  - **Dramatic impact on field development strategies**
- **Increasing adoption of RSS technology in land applications including the US shale basins**
- **Continuous improvements, adaptation to new environments and specialization have brought performance and reliability of RSS tools to new levels**
- **Today, RSS technology dominates the directional drilling market**

Thank You

Appendix: RSS Evolution Example 1





Appendix: RSS Evolution Example 2

Rotary Steerable Systems Technology Progression

Geo-Pilot® XL	Geo-Pilot® V. mode	Geo-Pilot® Solar	Geo-Pilot® Dirigo	Geo-Pilot® GXT	Geo-Pilot® 11k	Geo-Pilot® Duro	iCruise®	iCruise® X
								
Robust High-Performance RSS	Automated Vertical Drilling RSS	High Temperature (175° C), Ultra High Pressure (30,000 psi)	High Dog Leg Severity RSS	Motor Powered RSS	High Torque (55k ft-lb) RSS	Improved durability and performance in harsh environments	Intelligent Rotary Steerable System	Long runs and harsh environments Intelligent Rotary Steerable System

(Courtesy of Halliburton)

2001 → 2018 → 2021