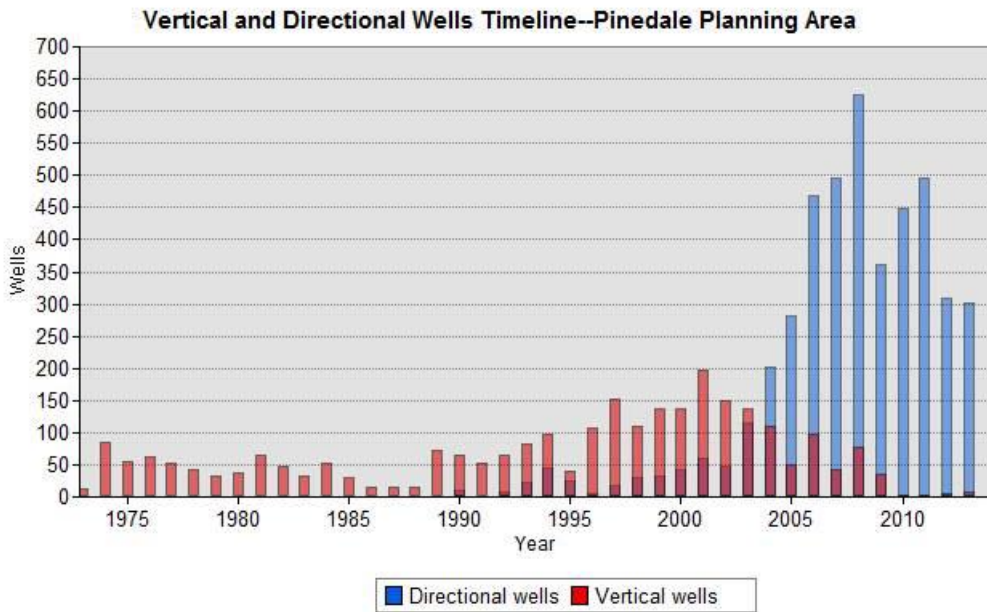


**Exhibit C**  
**Modern Oil and Gas Technology and Operations**  
 From: Ramey, Thorley, and Ivey (2015)

**Supplemental Materials S2.**

**Summary of improvements in technology that reduce impacts to sage grouse**

Improvements in drilling, completion, and production technologies have lessened potential impacts to sage grouse, and other species, by reducing the duration of potentially disruptive activities, surface disturbance, and noise. The most significant of these technologies has been directional drilling (directional wells that turn 90 degrees are also known as horizontal wells). This technology allows operators to access subsurface resources over a broad area (over a mile in some cases) using multiple wells per pad (up to 50), thereby reducing surface disturbance compared to multiple vertical wells drilled from separate pads (Arthur and Cornue 2010; BLM 2006a; Ramey, Brown, and Blackgoat 2011; Seto 2011; Applegate and Owens 2014). This is a more efficient way to access the resource because most oil and gas fields are in horizontal strata that used to require many vertical wells to tap. The transition in 2004 from drilling predominantly vertical wells to directional wells represented a major shift in drilling efficiency and consequently less surface disturbance (i.e. more wells from fewer pads). Directional wells now account for virtually all of the wells drilled in the Pinedale Planning Area (PPA).



**Figure S2.1. Annual number of vertical and directional wells drilled by the oil and gas industry in the Pinedale Planning Area from 1973 to 2012.** The annual number of traditional, vertical bore wells is indicated in red, and directional wells (including horizontal wells) are indicated in blue. The transition from predominantly vertical wells to directional wells took place in 2004. As of 2010, virtually all new wells drilled in the Pinedale Planning Area are directional wells.

More efficient technology has also resulted in shorter drilling and well completion times. While the averages we report show marked improvement (from spudding to completion), it should be noted that these completion times also include periods of inactivity at a well site due to interruptions from logistical and seasonal constraints. Therefore, actual drill and completion times (not including inactive periods), may provide a more accurate portrayal of the duration of potentially disturbing activities to sage grouse. For example, companies reported that drilling a well on the Pinedale Anticline (with an average depth of 13,000 feet) took an average of 65 days in 2002 and this decreased to 35 days by 2006 (OGJ 2007). By 2011 this had improved further, to an average of 14 days of drilling to depth, and in 2013, QEP Resources reported that they had achieved a well to depth time of 9.3 days, a new record (QEP 2013). Similar improvements in drilling and completion efficiency have been reported elsewhere (DTC Energy Group 2013). Overall, uninterrupted completion times have dropped from six months to as few as 2 to 3 days in 2013 (AECOM 2013).

Directional drilling of multiple wells from the same well pad has also led to a new type of operational efficiency, one that was not possible during the single-well-per-pad-era: the collocation of facilities and simultaneous operations on a single well pad. This means that site preparation, drilling, hydraulic fracturing, completion, and production can be simultaneously carried out on different wells drilled from the same well pad. This translates into less equipment moving on and off site, and less manpower required. Rig moves, that used to take 150 or more truck trips to move between pads, and are accomplished by skidding the rig to a nearby location on the same pad (Kreckel, 2011).

Other advancements in operational efficiency, with secondary benefits to sage grouse, have also been implemented in the PPA, both as voluntary and regulatory efforts. The most significant of these to sage grouse have included:

- Installation of a liquid gathering system designed to eliminate 165,000 truck trips per year (initiated in 2005 and completed in 2012; BLM 2005).
- Installation of remote telemetry systems to monitor wells and condensate tanks (initiated in 2008 and completed in 2012; BLM 2008a,b).
- Electrification of the Pinedale Anticline (BLM 2012), allowing equipment to be powered with electricity rather than internal combustion generators and motors. While this change was originally intended to reduce high levels of ozone accumulation in the PPA, it has the secondary benefit of reducing engine noise and truck traffic (needed to refuel and maintain internal combustion engines).
- Introduction of rotary steerable systems (RSS). These are a "steerable" downhole drilling apparatus that was introduced on the Pinedale Anticline in 2008 and its widespread adoption has led to dramatic decreases in drilling time (Okafor et al. 2009).
- Required use of EPA compliant Tier II diesel engines on drill rigs, with phase out into more efficient and Tier III and IV designs, all of which reduce noise (and pollutants) compared to non-compliant engines in use prior to 2006.

Collectively, these improvements in efficiency translate into reduced drilling time and completion times, and therefore, reduced disturbance to sage grouse and other species. Virtually all of the innovations above came *after* the primary studies were conducted at Pinedale (from 1997 to

2006).

Although the development of more efficient oil and gas development and production technology is mainly driven by economic considerations, the benefits to the environment are obvious: reduced drilling and completion time, which translates into less noise, less traffic, and less overall disturbance to wildlife.

Another difference between past and current oil and gas development, particularly in the PPA has been the implementation of extensive mitigation measures designed to reduce overall impacts to sage grouse and enhance their habitat. The mitigation measures became notable with development of the Pinedale Anticline starting in 2000 (BLM 2000, 2008a) followed by the Jonah Drilling Infill Project (BLM 2006b) and culminating in the Pinedale Resource Management Plan Record of Decision (BLM 2008b). They have resulted in 183,608 ha of sage grouse habitat in the PPA set aside by the BLM as unavailable to oil and gas development (BLM 2008b). Seasonal restrictions placed on an additional 122,126 ha to safeguard sage grouse winter concentration areas and nesting habitat, and no surface occupancy stipulations placed on any new development are also in place. Additionally, required mitigation funds (BLM 2006b) have funded habitat improvement projects, offsite mitigation, and contributed to the purchase 34,772 ha of conservation easements in the PPA through 2012. Truck traffic, which has been reported to disturb sage grouse, has been reduced by requiring the installation of telemetry systems at wells and tanks so they can be monitored remotely. Installing liquid gathering systems to eliminate tanker trucks altogether has been accomplished. And finally, Executive Orders issued by the Governor of Wyoming, beginning with Core Population Area designation and protection in 2008, and subsequently updated (State of Wyoming. 2014), limit surface disturbance to an average of 5% in core areas statewide (or an average of 1 well pad per square mile).

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