FINAL REPORT

California Off-Road Engines and Components Life Span Assessment

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Introduction

The useful life and warranty periods for off-road equipment in California for engines rated at 37 kilowatts (kW) and greater have not been updated since the Tier 1 rule phased in from 1996 to 2000; for engines rated below 37 kW, not since the Tier 2 and Tier 3 rules phased in from 2000 to 2008. The California Air Resources Board (CARB) staff is seeking information regarding useful life and warranty to evaluate whether amendments to those requirements are necessary after two decades of technology advancement.

Cal Poly researchers called 55 service providers across the state of California to collect information regarding useful life of engines, repair of emission-related components, and warranty information associated with various off-road agricultural & construction equipment. The responses below reflect 40 completed interviews. The data was collected via telephone interview with the service manager of each company. The interviews took place during the post-harvest, pre-plant season of November 2022 through early May 2023. Most interviews took from 20 – 40 minutes to complete.

Participants were asked about the types of equipment and most common range of horsepower (HP) engines they saw in their shop. The equipment each service provider dealt with mostly depended on the type of agriculture surrounding their area. Tree and vineyard crops typically use smaller HP tractors (less than 100), while large row crop operations in the southern San Joaquin Valley more commonly use 200 – 500 HP equipment. Construction equipment providers reported the largest horsepower, in the 400 – 600 HP range, though that varied depending on whether they were dealing with bulldozers, graders, or smaller equipment such as skid steers. Of the 40 service managers interviewed, 32 represented agricultural shops, six were exclusively construction and two shops worked on both agricultural and construction equipment, but tilted more heavily toward agriculture. The following data was collected for each participating service provider.

- Types of equipment and horsepower range
- Percentage of rebuild vs. replacement engine work
- Issues with replacement engines
- Customer decision factors for rebuilding vs. replacement
- Rebuild information for off-road engines
- Hourly Rate in Shop/Field
- Useful life & repair costs for various engine and emissions components:
    - Selective Catalytic Reduction
    - Turbochargers
    - Diesel Oxidation Catalysts (DOC)
    - Exhaust Gas Recirculation (EGR) Valve and EGR Coolers
    - Oxides of nitrogen (NOx) Sensors
    - Diesel Particulate Filters (DPF)
    - Fuel Injectors
    - Diesel Exhaust Fluid (DEF) Doser/Header
    - DEF Quality Sensors
    - Engine Control Unit (ECU)
    - Exhaust Manifold

The power range of equipment most commonly serviced by each provider is noted in Table 1. Though most providers reported working on a wide variety of machinery, most had an engine size range that was more common, as noted below. The construction dealers were the most variable, while the agriculture equipment dealers typically had more common ranges of sizes based on the type of agriculture in the area.

Table 1. Service Provider Most Common Power Range of Equipment

Horsepower Serviced	# Providers
< 50 HP	5
50 – 100 HP	7
100 – 200 HP	11
200 – 400 HP	8
Over 400 HP	7

Labor Rates

All service managers reported charging hourly rates, from a low of $110 per hour for shop service and $125 for field service to a high of $200 shop/$225 field rates. Table 2 details descriptive statistics for the sample. Some shops charged mileage or a lower travel cost rate for field work, but most charged the hourly field rate door to door. Some service managers commented that for warranty work, they could only charge the manufacturer's recommended number of hours, which sometimes fell far short of the actual time spent on a repair under warranty. It is important to note that though average hourly shop service rates may be lower than field service rates, the overall cost to repair a particular piece of equipment in the shop may actually be higher due to additional costs associated with equipment transport.

Table 2. Service Provider Shop and Field Rates for Service ($/hr.)

		Shop Rate	Field Rate
Full Sample	Average	$154.29	$168.74
	Standard Deviation	$22.27	$22.13
	Count	41[3]	35
Agriculture	Average	$153.59	$165.93
	Standard Deviation	$23.31	$20.90
	Count	34	28
Construction	Average	$157.71	$180.00
	Standard Deviation	$17.37	$25.00
	Count	7	7

[3] One service manager reported two shop rates: one for account holders and one for retail customers, resulting in 41 reported shop rates from the 40 interviews.

Rebuilds

"Rebuild is going the way of the dodo, because of the cost of labor, availability of parts, technical capacity of the workforce and warranties on new engines." – Service Manager, Ag Tractors

The majority of service providers reported 10% or less rebuilds on engines as compared to engine replacement, Table 3. The only exceptions were the providers servicing the larger engines, above 200 HP. In those cases, the cost of labor relative to the cost of the engine was less of an issue and customers might be more likely to choose to rebuild, especially if they were running an older engine (Tier 1 or Tier 2). Some service managers reported that owners of old equipment would spend more than the equipment was worth to keep it running, mostly to avoid upgrading to higher emissions tiers and their related maintenance and operational difficulties.

Table 3. Percentage of Work on Rebuilds vs. Replacement/New Engines

Percent of work on Rebuilds	# Providers
< 5%	20
5 – 10%	7
10 – 50%	6
50% or greater	7

Table 4 outlines the frequency of ranking various reasons for replacing an engine versus rebuilding the engine. Service managers most commonly reported cost as the most significant reason for replacing engines with either remanufactured (reman) engines or new engines. The cost of labor is the deciding factor, as the cost of rebuilding an old engine may either be the same or only 10% less than replacing the engine.

The second and third most common reasons for replacing engines rather than rebuilding were operational cost and warranties, which are related factors. Service managers reported that some owners who chose to replace engines rather than rebuild did so to reduce the chance of additional repairs that might occur with a rebuilt engine. Rebuilt engines are typically only warrantied for 90 days from the shop, while a reman or new engine typically comes with a one or two-year warranty. Parts availability and expertise of labor were also cited as factors, but much less frequently. Supply chain issues have made it more challenging to access the many parts required for an engine overhaul, so it's typically easier to source a new or reman engine. In a few cases service managers also noted the lack of skilled workforce who are able to do the technical work required of a rebuild. Construction service managers also reported customer's downtime as a reason for replacing an engine vs. a rebuild. Replacing an engine, even if it has a more expensive service ticket, is usually less expensive in terms of lost job time.

Table 4. Reasons for Replacing Engine vs. Rebuilding

Ranking of Factors	Cost to Rebuild	Operation cost	Functionality	Availability of parts	Availability of a rebuilder	Warranty	Downtime	Other
1	36	0	0	4	0	0	0	0
2	1	17	4	4	1	10	1	0
3	1	6	10	3	0	4	1	1
4	0	2	7	9	0	0	0	0
5	0	1	0	3	11	0	0	0
6	0	0	0	0	2	0	0	0
Total Responses	38	26	21	23	14	14	2	1

Certified Engine Availability

Nearly all service managers reported that finding new or reman engines for replacement was not a problem for newer equipment. General post-Covid supply chain issues were cited as the most common problem with getting parts, with managers citing examples of several-month wait times for components. Most service managers sourced their replacement engines directly from the manufacturer, but occasionally the manufacturer had a backlog. About 20% of the service managers reported difficulties in getting replacement engines for older equipment.

Useful life & Warranty

Service managers were asked if there were any unique characteristics of agriculture or construction in California that would change the repair costs of off-road equipment. Rather than commenting on the industry differences, they primarily commented on the business and regulatory environment.

"Repairs are more expensive in California because of labor rates – it's quite a bit more than other states. I attend training classes in Kansas or Iowa; we have to charge $40 to $50 more per hour for shop time." – Service Manager, Ag Tractors

Nearly all service managers reported a similar sentiment. Some work for companies that own dealerships in neighboring states such as Nevada, Arizona, and Oregon. In California, not only is the minimum wage higher than those states, but mechanics have a specific regulatory rule that requires employers to pay double the minimum wage to any technician who has their own tools – which is $31 per hour.[4] This rule applies regardless of training or experience. In addition to high costs of labor, service managers also noted the high cost of living, which drove up rent and other overhead expenses for their business. Average hourly rates for shop and field work are reported in Table 2.

Most service managers also commented on emissions regulations as a cost driver. Many managers noted that emissions-related repairs comprised a majority of their repair business and increased costs to equipment owners. While Tier 4 standards are unified nationwide, some managers commented that the unique ways in which equipment is used in California agriculture increases the likelihood of repairs – for example, when equipment runs at lower RPMs for slow-moving jobs such as harvesting sweet potatoes or sweeping almonds, diesel particulate filters get clogged. Many areas in the Central Valley are very dusty and that also causes problems with various emissions sensors and filters. High heat in the

[4] California Industrial Welfare Commission Order No. 4-2001(9)(b) states that when tools or equipment are required by the employer or are necessary for the performance of a job, the employer pays twice the state's minimum wage.

Central Valley also factors into equipment failures, as DEF overheats under high heat conditions. This is a fairly new problem and is concentrated in the Central Valley. Even if the repair is still under warranty, the lost time is significant in terms of opportunity cost. Downtime for ag tractors is particularly onerous during harvest. Construction equipment service managers noted that emissions repairs were a major source of downtime, which adds up to lost revenue for the construction business.

Many service managers reported difficulty in finding qualified technicians and having to pay high labor rates to keep them; most noted that they were constantly hiring and struggling to keep up with demand for repair services, especially during busy harvest seasons.

Engine Hours for Rebuild

Compiling information for this section was somewhat difficult as rebuilding engines is a relatively rare enterprise in the current business climate. If a service manager reported that they did very few rebuilds, the question was revised to learn how many hours it took for engine failure that would require an engine replacement or rebuild.

"Engines should get to 12,000 hours if taken care of. Most failure is due to neglect." – Service Manager, Ag Tractors

Most managers reported a wide range of hours regarding engine failure, but the sentiment expressed above was one of the most common throughout all of the interviews. There was a difference reported between large (over 100 HP) engines and smaller engines (less than 100 HP). Larger engines were universally thought to have longer lifespans (if well-maintained), easily over 10,000 hours. Smaller engines (again, if well-maintained) would be expected to last between 7,000 – 8,000 hours. These hours were mostly reported for agricultural equipment. Many service managers commented that Tier 4 engines had shorter lifespans, even when well-maintained, because the emissions systems cause the engines to run much hotter, which eventually leads to more component failure.

Construction service managers reported that the differences in lifespans were mostly due to how the equipment was used – for example if a backhoe was being used for jackhammer, trenchwork or lighter work; it depended on the load. The harder the engine worked, the sooner failure would occur, sometimes in the 5,000-hour range or less. Construction managers also noted that maintenance was the next biggest factor in longevity.

All service managers reported doing overhaul/rebuild/engine replacement work in shop, though a few noted that they could do the work in the field if absolutely necessary. Equipment owners are rarely able to do this type of work unless they have mechanical or technical training and appropriate tools.

Overhaul Cost vs. Replacement Engine

Service managers reported that, while smaller engines could cost less to rebuild than replace, many owners opted to replace the engines for the benefits of a longer warranty and less overall repair time. New or reman engines come with longer warranties (one to two years depending on manufacturer) while shop work is typically warrantied for only a few months. The price difference flips at the larger engines (Table 5), though; and the service managers reporting 50% or above on rebuilding engines were all dealing with engines above 200 HP.

Table 5. Rebuild Cost vs. Replacement Engine by Size Category

	< 50 HP	50 – 150 HP	Over 150 HP
Cost to rebuild	$5,000 - $9,000	$30,000 - $35,000	$35,000 - $50,000
Cost to replace	$6,000 - $10,000	$27,000 - $30,000	$40,000 - $150,000

Emission System Components

Service managers were asked about useful life and repair costs of the various parts of the emission system. We report the findings in Table 6 below.

Table 6. Emission/Engine Component Life Span and Repair Costs

Component	Hours to Failure	Repair or Replacement Cost	Comments
Selective Catalytic Reduction	8,000 – 10,000 (though some reported 2,000 – 3,000 hrs. to failure)	$5,000 - $12,000	Cost depends on engine size; repair depends on maintenance and proper operation of regen cycle. DEF crystallizes otherwise. Most common that a sensor fails, not the entire system.
Turbochargers	Variable Gate: 4,000 – 5,000; Waste Gate: 6,000 – 10,000	Variable Gate: $4,000 - $10,000; Waste Gate: $2,000 - $6,000	Variable Gate turbos less reliable and more expensive; also, larger engines have higher cost for turbo repairs
Diesel Oxidation Catalyst	4,000 – 10,000	$2,000 - $6,000	Cost depends on size, but reported failures were rare
EGR Valve & EGR Coolers	1,500 – 4,000	$1,200 - $6,000	Cost depends on size, EGR coolers are more problematic than EGR valves
NOx Sensors	500 – 3,000	$800 - $3,000	Failure usually happens within warranty
Diesel Particulate Filters	2,000 – 5,000	$500 - $5,000	Complete replacement is rare, usually DPF is “baked” to clean, much lower cost, $500 - $1,000
Fuel Injectors	2,000 – 6,000	$1,000 - $10,000	Some brands are more sensitive, and labor is a more significant cost than parts
DEF Doser	100 – 5,000	$400 - $2,000	A lot of operator error, poor system design, many service calls

Component	Hours to Failure	Repair or Replacement Cost	Comments
DEF Quality Sensor	200 – 2,000	$500 - $2,000	High failure rates, and some sensors are embedded in header, so whole system must be replaced, not just sensor
Engine Control Unit	3,000 – 10,000	$2,500 - $4,000	Fails when another component fails, or if water/sulphur corrodes electronics, relatively rare otherwise
Exhaust Manifold	8,000 – 10,000	$2,500 - $3,000	Failure is very rare

Among the components reported in Table 6, the most common parts to require repair or replacement were the following:

- EGR Valve & EGR Cooler *"They are the worst; they get dirtiest the fastest" – Ag Service Manager*
- NOx Sensor *"These go out all the time, 1,000 hours is generous*" *– Ag Service Manager*
- DPF "*Most common operator error – failure to run regen, which causes a derate" – Construction Service Manager*
- DEF Doser/Header – "*The worst component – we have gone through 100 in the last year" – Ag Service Manager*
- DEF Sensor – *"We swap out sensors like underwear – we stock them like crazy, they seem to go out every 100 hours" – Ag Service Manager*

Final Comments from Service Managers

All service managers were asked if they would like to provide any further comments or insights based on their experience with engine life, emissions systems, and warranties. Many noted that modern engines were mechanically superior, but that emissions systems put a lot of stress on the engine and that the majority of their service calls were related to emissions systems failures. Equipment operators (who in many cases are not the equipment owners) do not understand the complicated emissions systems and the requirement to let regen cycles run their course. The emissions systems are also not designed well for certain types of agricultural or construction work that requires lower RPMs. The engines are designed to run hot at high RPMs, and equipment that runs at lower speeds will likely have more problems with the emissions systems because the particulates are not burned out and eventually clog the diesel particulate filters.

Other managers noted equity issues with respect to emissions. Several of the service managers were from areas with a lot of vineyards where the equipment is only used for a month or so.

"Seasonal machines should have an hourly limit so that they won't be subject to emissions [where] growers only use the equipment 150-200 hours and then they sit for 10 months. We need a different classification for seasonal equipment." – Ag Service Manager

Most service managers said they understood and appreciated the necessity for cleaner air, and that the emissions systems certainly helped. However, many expressed concerns about the owners' cost of maintaining the equipment after the warranty period expired. Right now, many of the emission system repairs are covered under warranty, but as the machines age and accumulate more hours, the owners will bear a higher burden of the cost. Some believed that those who could afford it might just buy a new piece of equipment rather than deal with expensive repairs after the warranty period runs out.