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Technical Note ENG FL-1 – Combustion System Improvement
Combustion Engines and Powered Equipment

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General

Florida NRCS conservation practice standard (CPS) Combustion System Improvement, Code 372, is the applicable standard for replacing or retrofitting agricultural internal combustion (IC) engines for improvement of energy efficiency. Replacing or retrofitting IC engines for energy efficiency improvement is applicable to equipment such as grain dryer fans, irrigation pumps, waste management pumps, etc. CPS 372 requires that the IC replacement or retrofit be certified to be least twenty (20) percent more energy efficient than the system being replaced.

The intent of CPS 372is to encourage the complete abandonment of older inefficient IC engines for new fuel efficient clean burning agricultural diesel engines or retrofitting existing systems to improve energy efficiency by adding a device(s) that allows for reduced operation (e.g. variable frequency drive or automated sensors and controls).

For example, a diesel engine burning 5.00 gal/hr can only be replaced with a diesel engine which burns no more than 4.00 gal/hr to drive the same load in order to meet the minimum 20% in energy improvement. [(5.00-4.00)/5.00) x 100 = 20%)]

This technical note provides guidance in determining the improvement of energy in accordance with criteria in CPS 372.

Definition

An existing system or engine is defined as a fully functioning and operating agricultural engine or machine that has some remaining life. Real efficiency improvements are achieved when existing less efficient engines are permanently removed from service and replaced with more energy efficient engines or retrofitted with new technologies to improve energy efficiency.

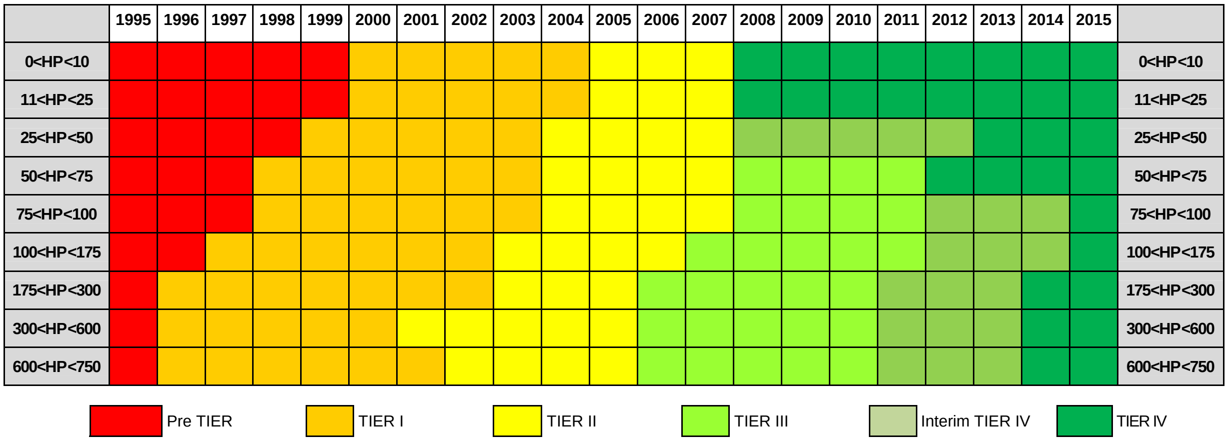
Purpose

In addition to energy efficiency, new engines must meet Environmental Protection Agency (EPA) tightened exhaust emissions regulations for off road diesel engines manufactured since 1996. EPA tightened exhaust emissions regulations for off road diesel engines manufactured through a set of phased in regulation time tables (see Figure 1). The emissions standards are enforced by the date of manufacture of the engine and not the sale date to the end-user as follows:

- Power units over 175 hp were required to meet TIER 4 Interim beginning January 1, 2011, and dealer stock conforming to TIER 3.

- Power units in the 75 to 175 hp classes were required to meet TIER IV Interim regulations beginning January 1, 2012.
- Beginning January 1, 2013, power units in the 25 to 50 hp class will be TIER 4.

Figure 1 – Illustration of Tightening of Diesel Engine Emission Standards by EPA



Note: Each successive TIER represents lower emissions requirements.

Manufacturers typically design and manufacture a diesel engine with multiple end-uses in mind. Top speed is usually in the range of 2100 to 2400 rpm for diesel engines commonly used in the agricultural market. The maximum power of a diesel engine is developed from a base speed setting of maximum speed and use of maximum power should ordinarily be intermittent. The TIER classification of an engine is determined from the maximum power rating. Manufacturers usually recommend a slower speed setting for steady 24 hour 7 day (24/7) operation, and de-rate the maximum power development. Irrigation pumps and grain dryer fans are typically designed for operation at speeds comparable to commercially available electric motors—speeds such as 1800 or 1200 rpm. For these reasons, the power rating of diesel engines marketed for use on irrigation pumping plants is usually specified at 1800 rpm. Table 1 lists several makes and models of commercially available new power units that have been investigated for rated power.

Table 12-3 of the National Engineering Handbook (NEH) Part 652 Irrigation Guide, shows that diesel engines are the most efficient type of reciprocating IC engines. Therefore, combustion system improvements are generally directed to be from non-diesel engines toward diesel engines, unless a conversion to electricity is desired.

NRCS conservation practice standards provide different requirements depending on whether the conservation practice is implemented for energy efficiency or air quality.

Table 1 – Power Ratings of Common Commercially Available Power Units per Manufacturer's Literature

Make	Model	Power, hp@1800 rpm
CaseIH	P70	70
CaseIH	P85	87
CaseIH	P110	114
CaseIH	P140	141
CaseIH	P170	160
CaseIH	P190	190
CaseIH	P215	216
CaseIH	P240	248
Deere	4T49	35
Deere	4T80	64
Deere	4H99	82
Deere	4H115	104
Deere	6H140	127
Deere	6H156	141
Deere	6H185	167
Deere	6H200	180
Deere	6H225	203
Deutz	D2011L03	28
Deutz	D914L04	62
Deutz	D914L06	93
Deutz	TCD914L06	151

Design Considerations

Two general methods of engines and powered equipment improvement as mentioned in CPS 372 are as follows.

- **Replacement** of a system means to replace the entire engine or convert to electricity.
- **Retrofit** means to swap out existing engine components or add new engine components which will assist the engine to run with lower emissions of regulated compounds and/or improved thermal efficiency.

1. Resource Concern of Energy Efficiency

Replacement or **retrofit** of the IC (engine) — The replacement of a gasoline, propane, or natural gas engine with a diesel engine will *generally* meet the minimum 20% improvement of energy efficiency required by CPS 372.

- Replacement of a diesel engine with gasoline, natural gas, or propane engine will not likely meet the minimum 20% improvement of energy efficiency required by CPS 372 standard.

- Replacement of any IC engine with a gasoline engine will likely not meet the standard.
- Replacement of any IC engine to an electric motor generally meets the minimum 20% improvement of energy efficiency required by CPS 372. IC engines typically have efficiencies in the 20% to 35% range whereas electric motors have efficiencies of up to 90%.
- Retrofit of any IC may involve adding a device such as variable frequency drive or automated sensors and controls that allows for reduced operation of an existing combustion system.

In any case, the new combustion or retrofit system must demonstrate a minimum of 20% improvement in energy efficiency over the existing system.

2. Condition of an Existing System

To qualify for energy system improvement under CPS 372, the existing system or engine must meet the following criteria:

- has not been vandalized,
- has not been stripped of parts, and
- is fully functional and, in operational condition

As a minimum, documentation of the existing system will include the make, model, serial number, and condition shall be recorded. A clear photo of the serial number plate and the system or engine provides excellent documentation.

3. Requirements of a New System

To qualify for energy system improvement under CPS 372, the new system or engine will meet the following criteria:

- The new replacement IC engine must be equipped with a non-resettable, operation time meter (commonly called an hour meter).
- Fuels consumed by the new engine, whether petroleum-based, renewable, or blends of petroleum-based and renewable fuels, must conform to new engine warranties and shall meet applicable air quality standards and specifications.
- Engines or electric motors installed at pumping plants must adhere to Florida NRCS CPS Pumping Plant, Code 533 criteria. An engineering analysis may be required.
- Where the existing engine was grossly mis-matched to the system load (irrigation pumping plant, grain bin fan, etc.), an analysis of the power requirements shall be conducted as part of the process of sizing the new engine. Documentation from the manufacturer or supplier is strongly recommended. For irrigation pumping plants, an analysis can be provided through a qualified energy audit or by following documentation procedures for CPS 372 and CPS 533 located in the National

Engineering Handbook, Part 650, Chapter 1, Florida Supplement. For grain dryer fans, manufacturer specifications will typically state the required power input.

The minimum identification of the new system shall be the make, model, serial number, model codes, and EPA TIER class. A clear photo of the serial number plate provides excellent documentation.

Determining Improvement in Energy Efficiency

Ideally, energy efficiencies of engines take into account the power output of the engine, or conversely, the system load against which the engine operates. The system load is characterized by the shaft torque and speed, which are difficult to measure for most agricultural systems. However, if the system load is operated at the same speed by both the existing and new combustion systems, the torque and power should be identical. Therefore, improvement in energy efficiency can be based solely on the engine fuel usage.

An energy audit meeting the requirements of Conservation Activity Practice 122 Agriculture Energy Management Plan-Headquarters and/or Conservation Activity Practice 124 Agricultural Energy Management Plan - Landscape, if available, will typically provide the needed data to document an improvement in energy efficiency. National policy requires that comparisons of energy usage be made on time intervals of one year. Therefore, along with a measurement (or estimate) of the fuel consumption rate of the engine, an estimate of the annual hours of use is needed. A two or three year average is permissible when consistent with the cropping pattern of the given farm operation.

In order to calculate energy, the following information is needed:

- Energy consumption based on type of fuel,
- fuel usage rate (rate of energy use), and
- annual hours of use,

<u>Energy Consumption</u>

Fuels have different energy content and energy consumption is dependent on the type of fuel used by the engine. Table 2 shows the energy content of common farm fuels. To calculate the energy used by an engine the type of fuel used is converted to the common energy unit of British thermal unit (Btu). This will be demonstrated by Example of this technical note.

Table 2 – Energy Content of Common Farm Fuels

Fuel Energy Content [1/]				
Diesel	Gasoline	Propane	Natural Gas	Electricity
128,450 BTU/gal	116,090 BTU/gal	84,250 BTU/gal	92,500 BTU/CCF	3,412 BTU/kWh

[1/] These values were obtained from tables compiled by EPA. A different value may be used only if used in the applicable energy audit.

One British thermal unit (BTU) is the energy needed to increase the temperature of 1 pound of water 1 degree Fahrenheit. With SI prefixes, MBtu would represent 1,000,000 BTU. However, the English and American heating industry has used the Latin prefix of M(ille) to represent 1000. Thus, MM is often used to represent 1,000,000 in the form of a thousand thousand.

Common U.S. Reference Units are:

- MMBtu = 1 million BTU
- MBtu = 1,000 Btu

<u>Other useful conversion factors are:</u>

One electrical horsepower is equal to 746 watts:

1 hp = 746 W

So the power conversion of horsepower to watts is given by:

$$P_{(W)} = 746\ P_{(hp)}$$

Example

Convert 10 hp to watts:

$$P_{(W)} = \frac{746\ W}{1\cancel{hp}} \times 10\cancel{hp} = 7{,}460\ W$$

<u>Fuel Usage</u>

Fuel usage can be obtained from manufacture's literature or based on information received from the landowner. See Figure 2 for a typical manufacturer's chart for fuel usage. When obtaining information such as hours of operation and/or fuel usage from the landowner, the NRCS planner must document the information from the landowner. Good judgment must be used to deem the landowner's information is reasonable for the particular operation.

Figure 2 – Sample Chart for Fuel Usage

Engine model	Rated speed	Continuous		Fuel data†	rpm	Continuous		Fuel data†
	rpm	kW	hp	gal/hr		kW	hp	gal/hr
4024T*	2800	31	41	2.6	1800	27	35	1.9
4045T**	2400	55	74	4.5	1800	50	67	3.7
4045H	2200	74	99	5.3	1800	76	102	5.0
4045H	2400	104	139	7.0	1800	100	134	6.6
6068H	2200	129	173	8.8	1800	130	174	8.6
6068H	2200	149	200	10.1	1800	156	209	10.2
6090H	2200	224	300	15.1	1800	229	307	14.9
6090H	2200	242	325	16.2	1800	256	343	16.1
6135H	2100	373	500	24.9	1800	393	527	25.3

In some instances, the fuel consumption can be obtained from the manufacturer. See Figure 3 for a typical chart for fuel consumption.

Figure 3 – Sample Chart for Specific Fuel Consumption

Technical data

Engine type		D 914 L3	D 914 L4	D 914 L5
No. of cylinders		3	4	5
Bore/stroke	mm | in	102/132 |4.0/5.2	102/132 |4.0/5.2	102/132 |4.0/5.2
Capacity	l | cu in	3.2 |195	4.3 |262	5.4 |330
Compression ratio		21:1	21:1	21:1
Nominal speeds	min^{-1} | rpm	2000 - 2300	2000 - 2300	2000 - 2300

Power output[1)]		D 914 L3	D 914 L4	D 914 L5
Power output as per ISO 14396	kW | hp	43 |58	58 |78	72.5 |97.2
at speed	min^{-1} | rpm	2300	2300	2300
Max. torque	Nm | lb/ft	204 |150.5	273 |201.4	337 |248.6
at speed	min^{-1} | rpm	1500	1500	1500
Minimum idling speed	min^{-1} | rpm	700	700	650 - 700
Specific fuel consumption[2)]	g/kWh | lb/hph	225 |0.37	220 |0.362	218 |0.358
Weight as per DIN 70020 Part 7A[3)]	kg | lb	277 |611	307 |677	380 |838

Where specific fuel consumption is provided in pounds/gallon (lbs./gal) as shown in the Figure 3, it can be converted to gallons per hour (gph) using the density of the fuel as shown in Table 3 and demonstrated in Example 1.

Table 3 – Densities of Common Farm Fuels

Fuel Densities [1/]	
Fuel Type	**Density**
Diesel	7.00 lb./gal
Gasoline	6.22 lb/gal
Natural Gas	44.8 lb/mft3
Propane	33.7 lb/ft3

[1/] Source: http://www.carbonlighthouse.org/wp-content/uploads/2010/10/UnitsAndConversions.pdf

Example 1

Determine the fuel consumption of a 58 hp diesel engine with a specific fuel consumption of 0.37 lbs./hp-hr to gph. The fuel density is obtained from Table 3.

The fuel consumption conversion of lbs./gal to gph is given by the formula:

$$\textit{Fuel Consumption} = \frac{\text{Specific Fuel Consumption (lbs./hp-hr)}}{\text{Fuel Density (lbs./gal)}} \times \text{Engine Power Output (hp)}$$

$$\textit{Fuel Consumption} = \frac{0.37\ \text{\sout{lbs.}/hp-hr}}{7.00\ \text{\sout{lbs.}/gal}} \times 58\ \text{hp}$$

$$= 0.052\ \text{gal/}\sout{\text{hp}}\text{-hr} \times 58\ \sout{\text{hp}} = \underline{3.07\ \text{gph}}$$

Following are two examples show how to determine energy savings.

Example 2

The landowner operates a diesel engine for irrigation. The landowner operates the system for 2040 hours per year and the fuel consumption is 7.44 gal/hr. The landowner plans on replacing the existing power system with a diesel system that uses 5.5 gal/hr and will be operate the system for 2040 hrs/yr.

Annual Energy Usage of Existing System (Baseline)

Annual Energy Usage = Fuel Usage x Annual Hours of Use x Energy Content

= 7.44 gal/hr x 2040 hrs/yr x (128,450 BTU/gal/1,000,000 BTU/MMBTU)

= 1,950 MMBTU/yr

Annual Energy Usage of New System

Annual Energy Usage = Fuel Usage x Annual Hours of Use x Energy Content

= 5.5 gal/hr x 2040 hrs/yr x (128,450 BTU/gal/1,000,000 BTU/MMBTU)

= 1,441 MMBTU/yr

Net estimated energy savings in Annual Energy Usage

Net estimated energy savings = Usage of Existing System – Usage of Planned System

= 1950 MMBTU/yr – 1,441 MMBTU/yr

= 510 MMBTU/yr

Energy Improvement

Energy Improvement, percent = Net estimated energy savings /Baseline x 100%

= (500 MMBTU/hr)/(1940 MMBTU/yr)

= 26%

Example 3

The landowner operates a 70 hp diesel engine for irrigation that has a fuel consumption of 3.7 gal/hr. The landowner operates the system for 2040 hours per year and the fuel consumption is 7.44 gal/hr. The landowner plans on replacing the existing power system with an electric motor system that uses 70 hp and will be operate the system for 2040 hrs/yr. It is estimate that the new electric motor will be 90% efficient.

Annual Energy Usage of Existing System (Baseline)

Annual Energy Use = Fuel Usage x Annual Hours of Use x Energy Content

= 3.7 gal/hr x 2040 hrs/yr x (128,450 BTU/gal/1,000,000 BTU/MMBTU)

= 970 MMBTU/yr

Annual Energy Usage of New System

1 hp = 0.746 kW

$$\text{Annual Energy Use} = \text{Fuel Usage} \times \frac{\text{Annual Hours of Use} \times \text{Energy Content}}{\text{Motor Efficiency}}$$

$$= \text{hp} \times \frac{0.746\ \text{kW}}{1\ \text{hp}} \times \frac{\text{Annual Hours of Use} \times \text{Energy Content}}{\text{Motor Efficiency}}$$

$$= 70\ \cancel{\text{hp}} \times \frac{0.746\ \text{kW}}{1\ \cancel{\text{hp}}} \times 2040\ \text{hrs} \times \frac{(3{,}412\ \text{BTU/kWh/BTU/MMBTU})}{0.9 \times 1{,}000{,}000\ \text{BTU}}$$

= 403 MMBTU/yr

Change in Annual Energy Usage

Net estimated energy savings = Usage of Existing System – Usage of Planned System

= 970 MMBTU/yr – 403 MMBTU/yr = 566 MMBTU/yr

Energy Improvement

Energy Improvement, percent = Net estimated energy savings /Baseline x 100%

= (566 MMBTU/hr)/(970 MMBTU/yr)

= 58.3%

In Example 2 and 3, Form FL-ENG-372 (See Exhibit 1) can be used to calculate and document the change in annual energy use.

Disabling an Existing System

CPS 372 requires that an existing IC engine that is replaced be rendered inoperable or used to replace higher emitting or lower-efficiency combustion systems. The engine may be disabled by one of the following methods.

(1) crushing the entire engine or

(2) creating a 4-inch diameter hole in the block—to include a portion of the oil pan rail (sealing surface). Such hole may be punched or cut.

Either method should be performed in a safe manner that avoids personal injury risks. Engine fluids and filters should also be drained and disposed of properly.

Integral parts of the combustion system shall not be salvaged or "parted out" before or after disablement. Integral parts are typically characterized by one or more of the following:

- a casting,
- have milled surfaces,
- require a gasket or sealing compound at mating surfaces, and/or
- highly engineered.

Examples of integral parts on a typical power unit include but are not limited to the following:

- the block,
- crankshaft,
- rods,
- piston,
- oil pan,
- the head,
- turbocharger,
- intake manifold,
- exhaust manifold,
- carburetor,
- ignition distributor,
- diesel pump,
- cooling water pump, and/or
- any secondary parts contained within these.

The serial number plate must remain on the engine.

Parts that are acceptable to salvage include the following:

- starter battery,
- alternator,
- trailer or transport frame,
- radiator,
- gages and throttle controls, and/or
- PTO clutch.

The power unit may be disabled by the owner and stored on-farm or may be taken to a commercial metal recycler for destruction and disposal. Photographs will be taken of the power unit as part of the practice certification and copies of the photos included with the documentation. Photographs will include the following:

- a clear photo of the engine serial number plate,
- frame-filled photos of each side of the engine or vehicle before disablement showing model decals or other features unique to the model, and
- frame-filled photo of each side of the engine after disablement.

When the disabled engine is delivered to a commercial recycler for disposal, a signed receipt shall be required and a copy provided to the local NRCS Service Center. The disabled engine or recycler receipt shall be kept on-hand by the landowner for three years.

Exhibit 1 – Florida NRCS Form FL – ENG-372 – used to calculate the energy savings.

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COMBUSTION SYSTEM IMPROVEMENT, CODE 372

Cooperator:		Date:	
Location:		Job No.:	
Conservation District:		Field No.:	
Field Office:		Eng. Job Class	
Identification No.:			
Purpose:			
Current Fuel Type:			
Planned Fuel Type:			

	Load,	Run-Time, hr/yr	Energy Content,	Energy, MMBTU/yr
Baseline:				
Fall				
Winter				
Spring				
Summer				
Totals				

	Load,	Run-Time, hr/yr	Energy Content,	Energy, MMBTU/yr
Planned:				
Fall				
Winter				
Spring				
Summer				
Totals				

Net Estimated Estimated Energy Savings (MMBTU/yr):	
Energy Improvement, percent:	

Planned By:		Date:	
Designed By:		Date:	
Checked By:		Date:	
Approved By:		Date:	

Exhibit 1 – Florida NRCS Form FL – ENG-372 – used to calculate the energy savings. – Continued

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Specific Fuel Consumption Conversion

Fuel Type ____________

Engine Power Output ____________

Manufacturer's Specific Fuel Consumption (metric units)	Fuel Density	Power Unit Fuel Consumption

Fuel Type ____________

Engine Power Output ____________

Manufacturer's Specific Fuel Consumption (english units)	Fuel Density	Power Unit Fuel Consumption

Fuel Densities (Metric Units)	
Fuel Type	**Density**
Diesel	0.837 kg/L
Gasoline	0.745 kg/L
Natural Gas	0.717 kg/m^3
Propane	0.540 kg/L

Fuel Densities (English Units)	
Fuel Type	**Density**
Diesel	7.00 lb/gal
Gasoline	6.22 lb/gal
Natural Gas	44.80 lb/mft^3
Propane	33.70 lb/ft^3