MRI Load Profile Characterization Across Scanner Manufacturers and Field Strengths - Opportunities for Energy Efficiency Improvements

O. Ghatpande,[1] **K. Trenbath,**[1] G. Robinson,[2] A. Van Sant,[1] D. Mendonsa,[3] R. M. Pillai,[3] E. A. Morris,[3] Y. Jung,[3] and A. M. Hernandez[3]

[1] National Renewable Energy Laboratory, Golden, CO
[2] Stanford University, Stanford, CA
[3] University of California Davis Health, Sacramento, CA

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Background

Medical Imaging Equipment Energy Use

- Medical imaging equipment (MIE) energy use is estimated to be around 5% of site energy use. [Trenbath, et al. 2023]
- Limited data sets are available on MIE energy consumption in different operation modes. [Heye et al. 2020; Woolen et al. 2023]
- MRIs consume more than 2x the energy (111 MWh/unit/yr) of CT scanners (41 MWh/unit/yr) and more than 10x compared to X-rays (9.5 MWh/unit/yr). [COCIR 2018]
- Many MRI machines in use are on “ready-to-scan” mode for quick startup.


The goal of this work is to characterize the load profile and energy consumption of MRIs and identify potential energy efficiency improvements without compromising their medical efficacy.

MRI Modes of Operation for This Study

The MRI machine could have other functional modes.

- **Scan Mode** - System is actively scanning the patient to generate images.
- **Ready-to-Scan Mode** - System is ready to acquire images; often the state of the system between individual scans.
- **Low-Power Mode** - System functions at its lowest energy-consuming state without user selection.
- **Off Mode*** – The system is shut down by the user at the operator console and is in a steady state.

* Superconducting based magnets consume significant energy even in off mode [Trenbath, et al. 2023]. Some resistive magnet-based MRIs can be powered down to draw no energy.

MRI Machines and Metering Specifications


https://health.ucdavis.edu/graphicstandards/templates/zoom-backgrounds.html

MRI machines were selected from the fleet at UC Davis Health based on the type and strength of magnet, manufacturer, and market availability.

MRI Machine Information

MRI Machine	Magnet (T)*	Operating Hours	Location
Orange_3T (3T Machine 1)	3	7:30 a.m. – 9:00 p.m.	Outpatient Care
Yellow_3T (3T Machine 2)	3	12:00 a.m. – 12:00 a.m.	Main Hospital
Green_1.5T (1.5T Machine 1)	1.5	7:30 a.m. – 9:00 p.m.	Outpatient Mobile Trailer
Purple_lowT (Low T Machine)	0.064	NA	Portable for ER and ICU

Metering Information

- Orange_3T, Yellow_3T, Green_1.5T
  - Three-phase split-core current transformers
  - HOBO MX1105 four-channel analog data logger
- Purple_lowT - Single-phase 120 V plug load monitor (HOBO UX120-018).

Test Procedure and Data Collection

Image Credit: Robin Tuttle (NREL)

Sensor Setup

- Sensors (CT) monitor the main current input to the superconducting MRI machines.

Orange_3T MRI

- **Spot measurements** for Ready-to-Scan and Low-Power modes.
- Recorded long-term current and scanner log data.

Yellow_3T MRI

- **Spot measurements** for Ready-to-Scan and Low-Power modes.
- Recorded long-term current data.

Green_1.5T

- **Spot measurements** for Ready-to-Scan and Low-Power modes.
- Recorded long-term current data.

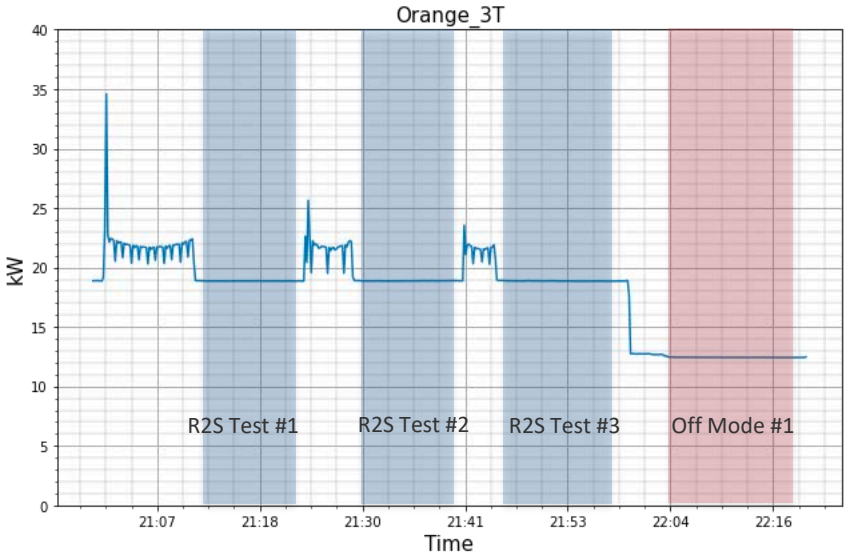
Purple_lowT

- **Spot measurement** (power) for Ready-to-Scan and Low-Power modes.

Results - Orange_3T MRI Spot Measurements

Test	Ready-to-Scan (R2S)	Off Mode
	Active Power (kW)*	Active Power (kW)*
Test #1	18.86	12.44
Test #2	18.87	-
Test #3	18.86	-
Test #4	18.92	12.53

*Assumption: Installation manual provided a power factor of 0.9. This was used to calculate active power.

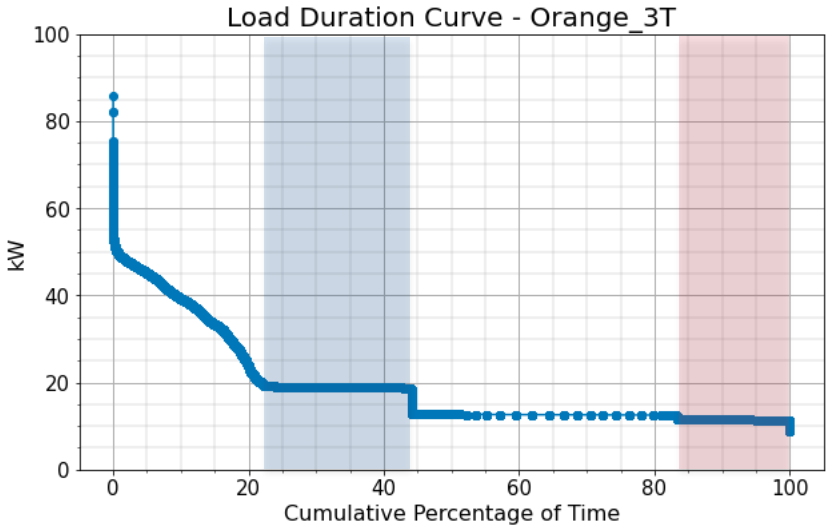


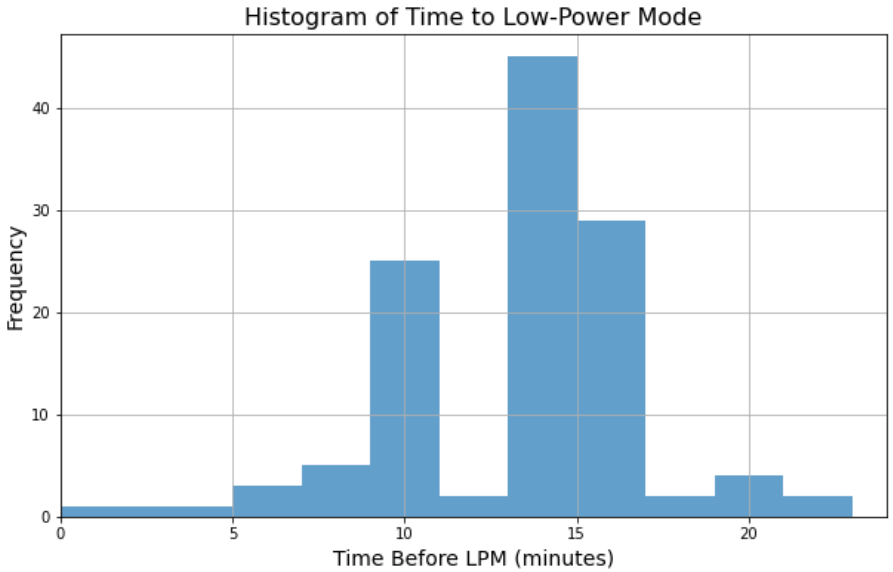
Ready-to-scan test was repeated 3 times with different preceding active scanning protocols to determine if it is affected by the power draw.

Results - Orange_3T MRI Long-Term Data Collection

MRI	Ready-to-Scan (% Time)	Off Mode (% Time)	Total Time (Hours)
Orange_3T*	22.5%	16.5%	1,596

*Mode assumed based on the load duration curve power levels.





- Orange_3T entered low-power mode after only **48%** of exams based on the power and scanner log data.
- The time to enter low-power mode was an average of **15 minutes**.

Results - Orange_3T Simulation

Orange_3T enters low-power mode 10 minutes after each scan.

- No known negative effect on technologist workflow.
- Scanner enters low-power mode after 81% of exams.

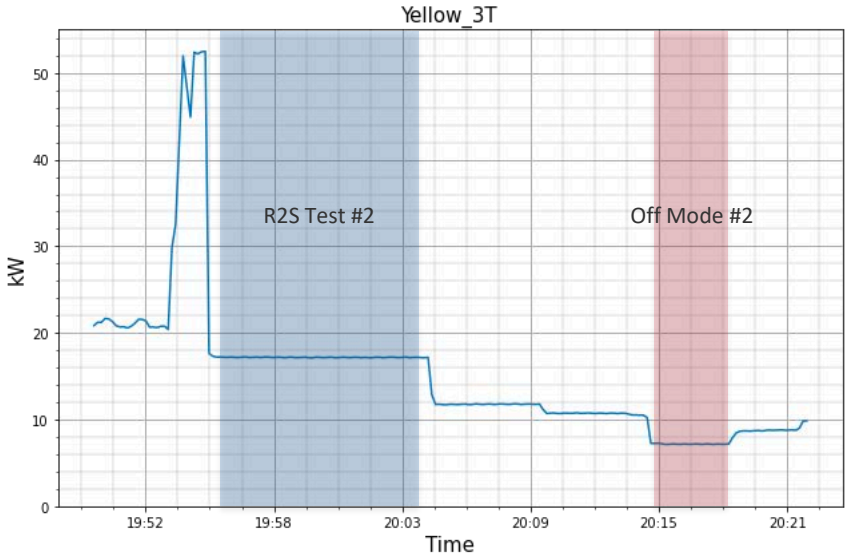
Single Exam Savings	Annual Scanner Savings	Annual National Savings
1.56 kWh average electrical energy savings per exam.	• 6.66 MWh • 2.6 $MTCO_2$ • 998.42 USD	• 47.72 GWh • **18,631 $MTCO_2$** • **6.9 million USD**

Assumptions: 0.15 USD per kWh electricity cost in Sacramento, CA, 0.879 lbs. of CO_2 per kWh, and 30 million MRI scans per year in the U.S.

Results - Yellow_3T MRI Spot Measurements

Test	Ready-to-Scan (R2S)	Off Mode
	Active Power (kW)*	Active Power (kW)*
Test #1	17.32	7.40
Test #2	17.18	7.17

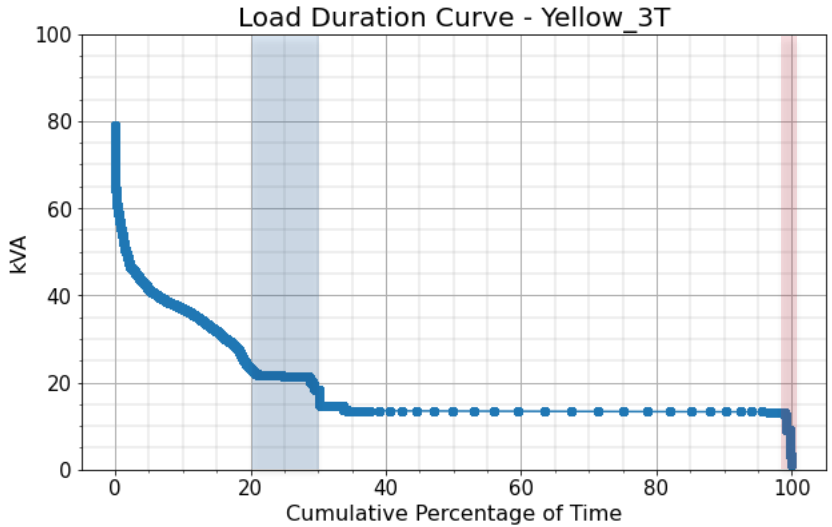
*Assumption: Based on installation manual, used a power factor of 0.8 to calculate active power.



Results - Yellow_3T MRI Long-Term Data Collection

MRI	Ready-to-Scan (% Time)	Off Mode	Total Time (Hours)
Yellow_3T*	13.5%	<1%	1,037

*Mode assumed based on the load duration curve power levels.



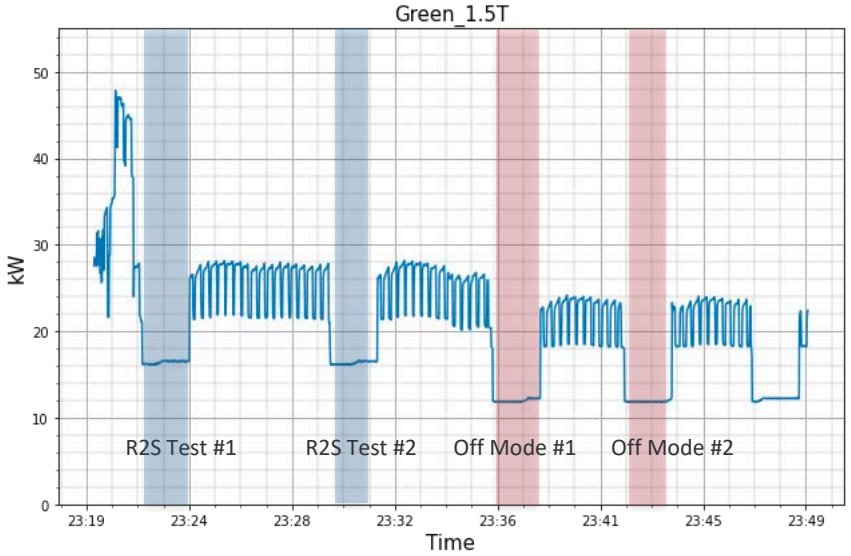
- Yellow_3T enters low power mode sooner than the Orange_3T.
- Yellow_3T was mostly in low power mode and was rarely switched to off mode by the user

Results - Green_1.5T MRI Tests

Power values for Green_1.5T includes trailer's HVAC system and MRI's cryogen cooler.

Test	Ready-to-Scan (R2S)	Off Mode
	Active Power (kW)*	Active Power (kW)*
Test #1	16.40	11.97
Test #2	16.40	11.89

*Power factor of 0.9 assumed to calculate active power based on the installation manual from same manufacturer.



Results - Purple_lowT MRI Tests

Test	Ready-to-Scan (R2S)	Off Mode
	Active Power (kW)	Active Power (kW)
Test #1	0.123	0.0086

Purple_lowT is a portable MRI scanner that can be unplugged when not in use, consuming no energy.

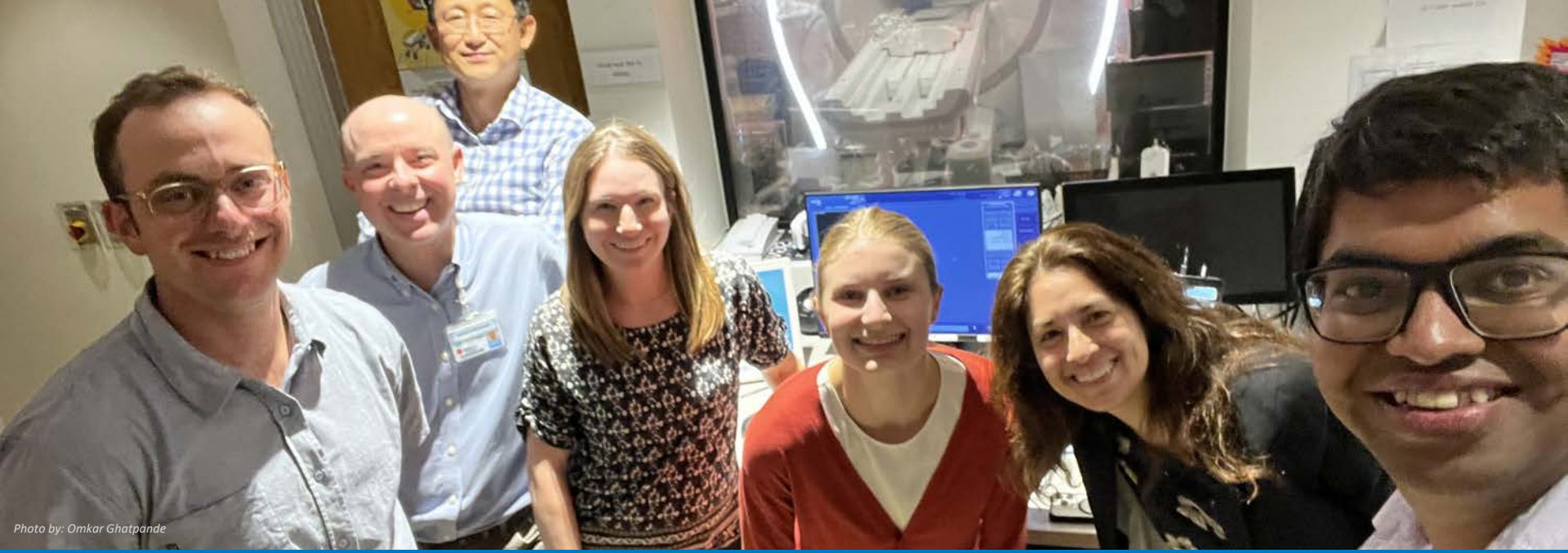
Conclusions

Spot measurement Power (kW) averages

MRI	Ready-to-Scan	Off Mode
Orange_3T	18.9	12.5
Yellow_3T	17.3	7.3
Green_1.5T*	16.4	11.9

- Load profiles and average power vary depending on scanner make/model, field strength, and manufacturer.
- Energy efficiency measures are possible without impacting patient care.
- MRI efficiency strategies are good options for addressing sustainability goals.

*Green_1.5T includes trailer's HVAC system (compressor and MRI's cryogen cooler).



Thank You!

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- Kim Trenbath, Ph.D. kim.trenbath@NREL.gov
- Omkar Ghatpande omkar.ghatpande@NREL.gov
- Andrew Hernandez, Ph.D. amhern@ucdavis.edu

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Data Collection Dates

MRI	Spot Measurements	Long-Term Data Collection
Orange_3T	Tues. June 20 and Mon. Aug. 7, 2023	6/13/23 – 6/21/23 7/4/23 – 8/16/23 8/23/23 – 8/29/23
Yellow_3T	Tues. June 20 and Mon. Aug. 7, 2023	7/12/23 – 7/19/23, 7/31/23 – 8/29/23
Green_1.5T	Tues. June 20 and Mon. Aug. 7, 2023	7/12/23 – 7/26/23 7/31/23 – 8/10/23 8/23/23 – 8/29/23
Purple_lowT	Tues. June 20, 2023	NA