An Inside Look at Permitting Data Centers

KU Environmental Engineering Conference

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RAMBOLL

Bright ideas.
Sustainable change.

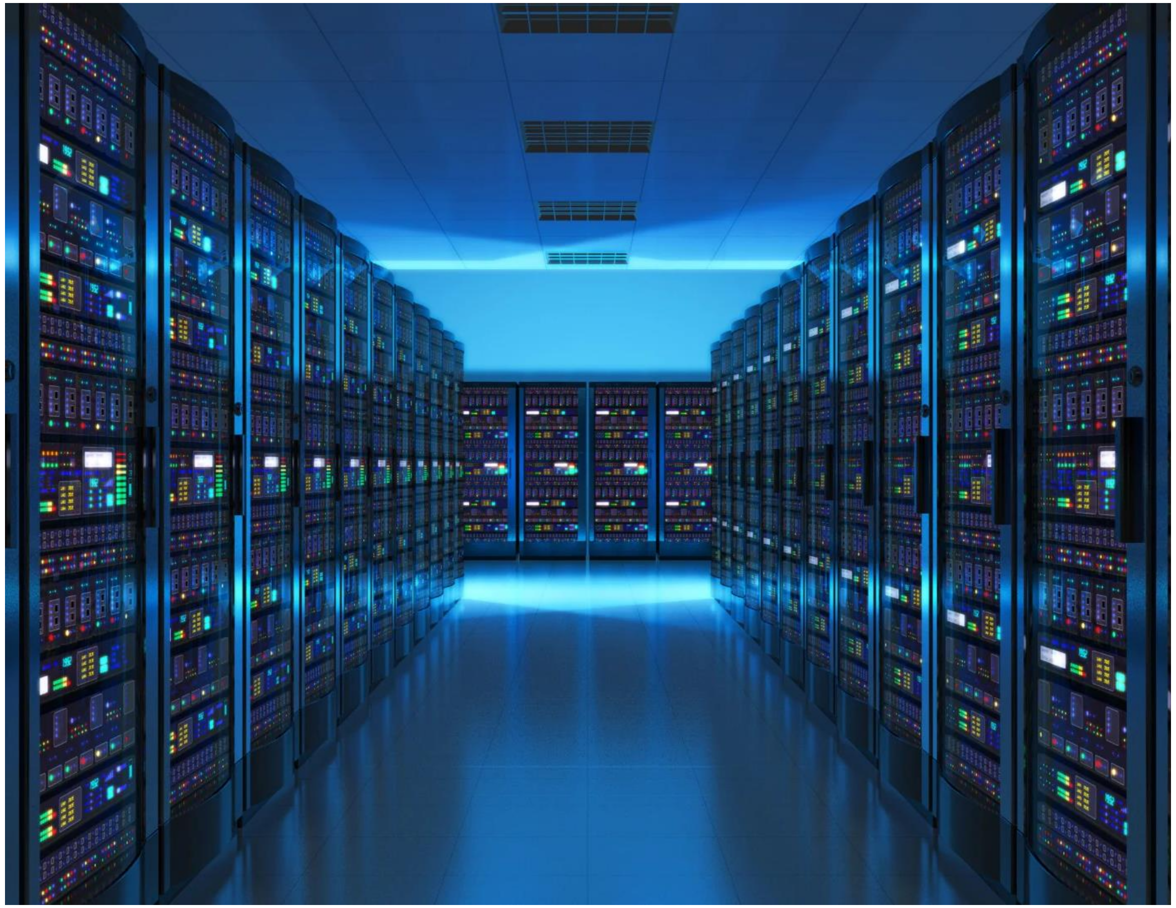
Agenda

1. Data Center Operations & Emission Sources
2. Air Permitting Considerations
3. Air Dispersion Modeling
4. Ongoing Compliance

Data Center Operations & Emission Sources

What is a Data Center, Anyway?

- A physical room, building, or facility where data is processed, organized, and stored
- Inside a data center:
  - Servers
  - Cooling
  - Power
  - Backup and Recovery
  - Security
- Data centers require continuous power
- Should high-line power go down, power is *often* supplied by diesel-fired emergency generators
- These generators require periodic maintenance and testing (M&T) to ensure they will operate as expected when needed



Types of Data Centers

Type	Description
On-premise	Companies manage and protect their own IT equipment.
Colocation	Companies place their hardware in a data center space. Power, Cooling, Connectivity ensured by colocation provider.
Wholesale	Form of colocation, where provider leases large blocks to a single customer.
Cloud	Customer data stored on systems belonging to the cloud provider, and information is managed virtually rather than each server being allocated to a particular client.
Hyperscale	Owned by companies with massive data processing requirements.
Edge	Located in close proximity to client to reduce latency [useful for smartphones, self-driving cars, etc.]

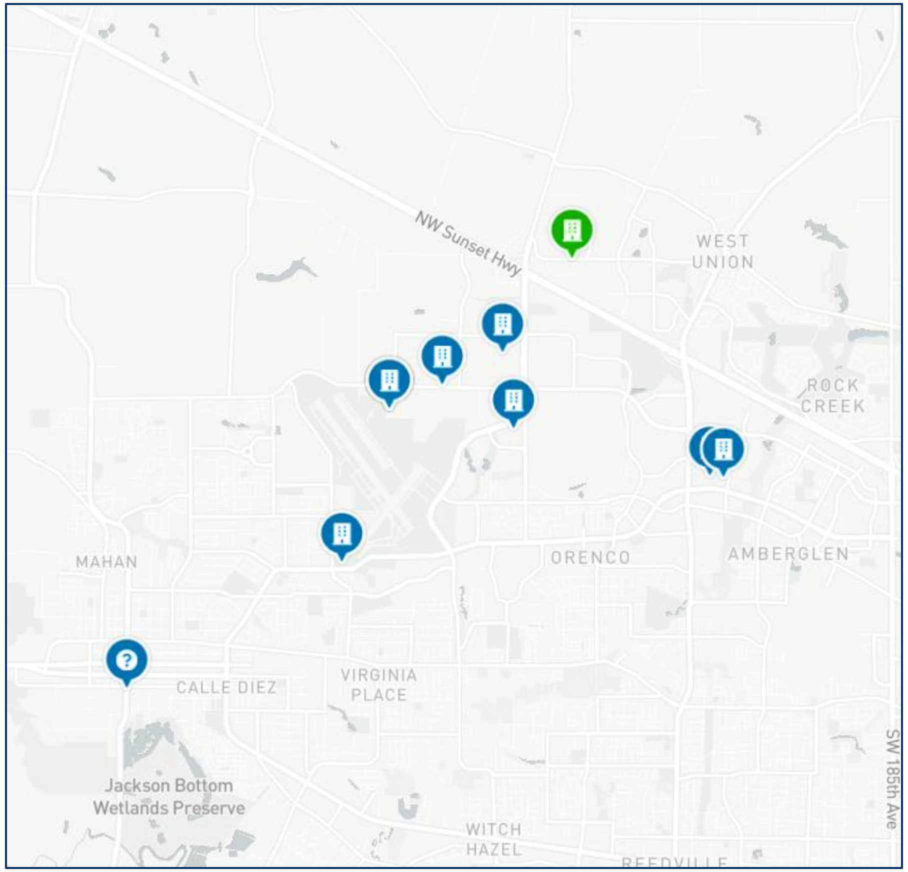
Data Centers as Critical Infrastructure

- Mission-critical development describes infrastructure that cannot fail.
- Operational downtime maximum targets for hyperscale data centers:
    - “The Rule of 9s”
    - Data center clients may range in their targets from 99.9% to 99.9999% operational
    - For example, a hyperscale data center targeting “five nines” will be operational 99.999% of the time, with **no more than 5.26 minutes of downtime per year**
    - Even smaller data centers typically target 99.9% (no more than 8.76 hrs of downtime per year)

Data Centers can have large campuses and cluster near each other

A recent Data Center just completed along NE Huffman Drive, just West of Brookwood. Note the backup generators and roof-mounted AC Units.

Another view of QTS Hillsboro- Photo Google Earth



Cluster of data centers in Hillsboro, OR

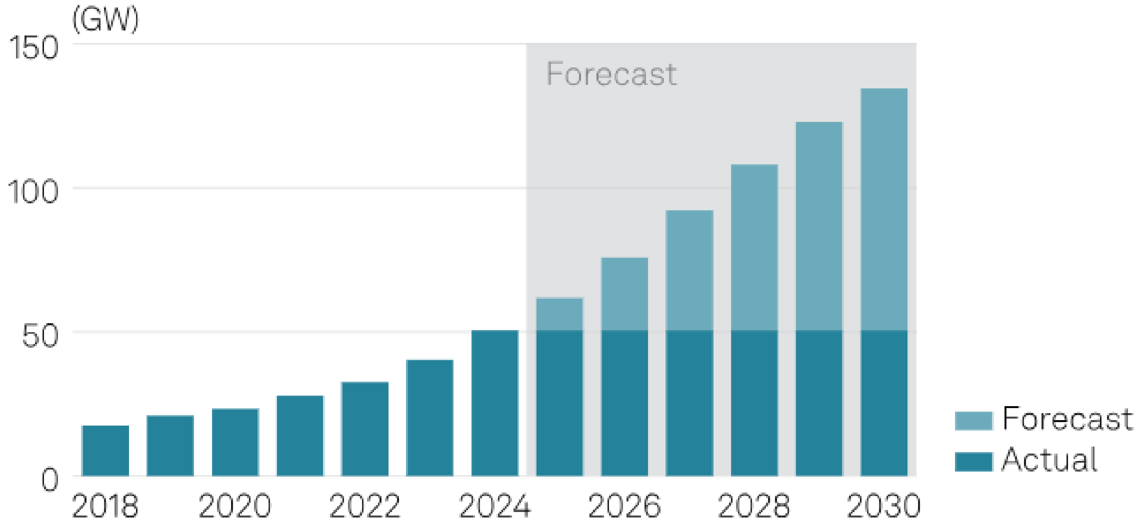
Power Needs

- Data centers require reliable, scalable power
- The "**capacity**" of data centers: the primary measure of capacity for most data centers is power (either supplied power or IT-load)
  - Measured in MW or GW of power
  - IT Load: power delivered to servers/racks
  - Total facility capacity: includes cooling, lights, ancillary structures, etc.
- Power availability (or constraints) has become a primary driver of data center target geographies
- Energy pricing and partnerships
  - As power demands increase nationwide, we are seeing more "behind the meter" solutions
  - Partnerships with existing power providers
  - Certain markets may offer more competitive energy pricing, but stability is key for maintaining operations
- Future trends: on-site generation, energy storage, alternative energy sources

Environmental Impact of Data Centers

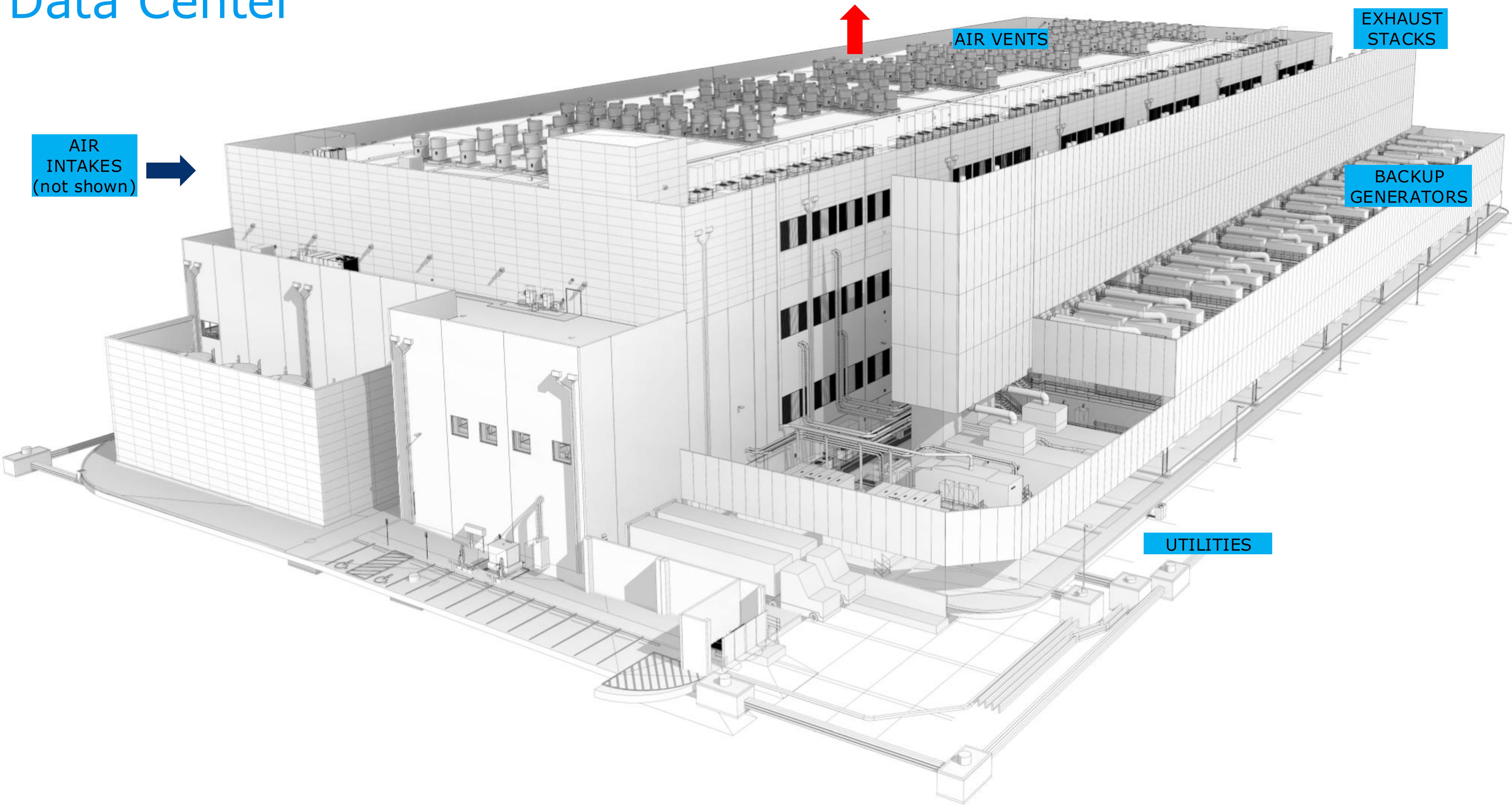
- Water Consumption
- Energy Consumption
- Noise Pollution
- Battery Usage
- Fuel Storage
- Air Pollution

US power demand from data centers expected to more than double from current levels



Utility power represents actual and forecasted total electricity supplied to data centers from the power grid, including IT equipment, cooling, lighting, offices and security systems as of the market monitor release date.
Source: S&P Global Market Intelligence; 451 Research Data center Services & Infrastructure Market Monitor & Forecast: US focused released Sept. 24, 2025.

Data Center


AIR
INTAKES
(not shown)
AIR VENTS
EXHAUST
STACKS
BACKUP
GENERATORS
UTILITIES

Backup Generators

DOUBLE
STACKED

Cooling

Air Chilled Cooling

- Many data centers utilize air-chilled cooling due to water or climate constraints

  → Much more power intensive

Evaporative Cooling

- May still be used in more humid climates with adequate water supply
- Many data centers are moving away from water-intensive cooling

Liquid Cooling

- Uses liquid coolant
- New technologies in development

Air Emissions from Data Centers

Typical Emission Sources:

- Diesel-fired generators
- Diesel belly tanks (VOCs)

Other Emission Sources:

- Natural-gas fired generators
- Turbines
- Cogeneration units
- Fuel cells
- Cooling Towers

Diesel-Fired Generators

Limiting Emissions

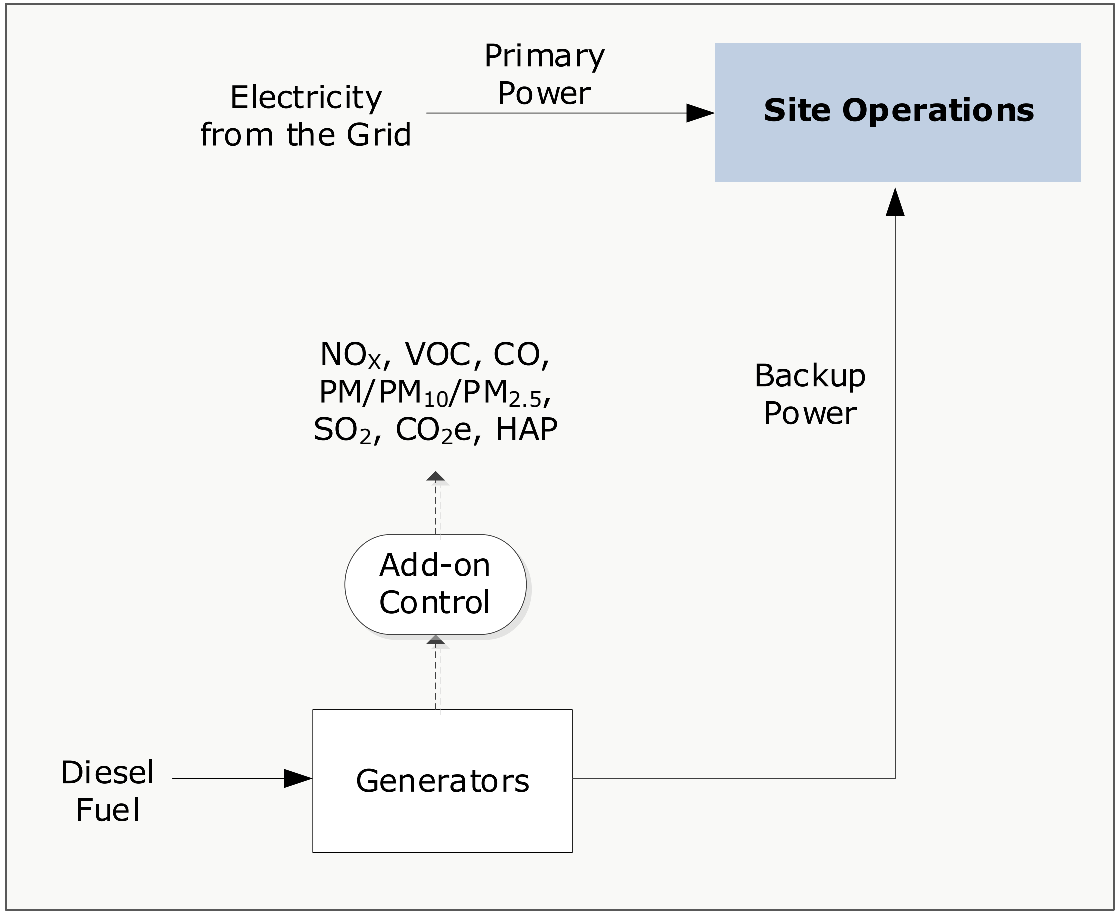
- Typically, NO_X is the most limiting pollutant
- If add-on controls exist, CO may be most limiting
- PM can be limiting from a modeling standpoint

Add-on Controls

- Selective Catalytic Reduction (SCR): NO_X
- Diesel Oxidation Catalyst (DOC): CO, VOC
- Diesel Particulate Filter (DPF): PM

Typical Operations

- Commissioning
- Maintenance and testing
  - Planned, routine [e.g., monthly, quarterly annual preventive maintenance]
  - Unplanned [e.g., equipment breakdown]
- Emergencies
- Other non-emergency operations



Example of Maintenance and Testing (M&T) Schedule

Test	Duration	# Concurrent Gens	Load	Frequency
1) Confidence Testing	20 mins	1 building/day	0%	Once / 2 weeks
2) Preventative Maintenance Testing	10 mins	½ or whole building/day	0%	Once / year
3) Annual Live Load Test	4 hours	½ building/day	Various	Once / year
4) Annual Maintenance Testing	1 hour	2 gens/day	Various	Once / year

- M&T scenarios can be simple or complex
- Some sites need all four of the above tests (or more)
- Some only need test #1 or 2

Emissions and Stack Parameters

- Typically change by load
- Specifications provided by manufacturer:
  - Fuel use, NOx, CO, VOC, PM_{filt}
- Tier 2 vs. Tier 4-equivalent emissions (with SCR, DPF and/or DOC)
- SCRs typically 90% efficient
- SCR takes time to come up to temperature (10-20 min) and may not come to temp at low loads
  - Include estimates for periods of time uncontrolled

AP-42 Emission Factors

Pollutant	Emission Factor [1] (lb/MMBtu)
Condensable PM	7.70E-03
SO_2 [2]	1.52E-03
Benzene	7.76E-04
Toluene	2.81E-04
Xylenes	1.93E-04
Formaldehyde	7.89E-05
Acetaldehyde	2.52E-05
Acrolein	7.88E-06
Naphthalene	1.30E-04
Other PAH [3]	8.20E-05
Total HAPs	1.57E-03

Fuel Usage by Load

Source Type	Diesel Fuel Consumption (gal/hr/engine)					Heat Input (MMBtu/hr/engine) [2]				
	100% Load	75% Load	50% Load	25% Load	10% Load	100% Load	75% Load	50% Load	25% Load	10% Load
Group 1 Engine[1]	168.0	134.0	96.0	96.0	96.0	23.02	18.36	13.15	13.15	13.15
Group 2 Engine	171.3	133.2	97.1	57.2	30.9	23.47	18.25	13.31	7.84	4.23
Group 3 Engine[1]	173.1	133.6	91.1	50.6	50.6	23.72	18.31	12.48	6.93	6.93
Group 4 Engine	53.6	42.8	28.4	16.6	9.5	7.34	5.86	3.89	2.27	1.30

Notes:

1. Per the manufacturer specification sheet. Fuel consumption values were not provided at 25% and 10%. As such, these fuel values have been conservatively assumed to be equal to the fuel consumption value at 50% load.
2. Diesel fuel consumption was converted to heat input based on the diesel high heating value from the USEPA's AP-42, Section 3.4, *Large Stationary Diesel and All Stationary Dual-fuel Engines*, Table 3.4-1, footnote a (October 1996):

Diesel HHV = 0.137 MMBtu/gal

Manufacturer-Provided Emission Factors by Load

Pollutant	Group 1 Emission Factors (g/kWh) [1]					Group 2 Emission Factors (g/hp-hr) [1]				
	100% Load	75% Load	50% Load	25% Load	10% Load	100% Load	75% Load	50% Load	25% Load	10% Load
NO_X	10.4	6.7	5.6	7.6	13.9	6.38	5.15	3.74	3.5	6.47
CO	0.8	1.3	2.3	4.9	9.3	0.76	0.48	0.58	1.47	4.26
VOC [2]	0.34	0.4	0.58	1.22	2.05	0.14	0.18	0.29	0.4	0.89
Filterable PM [3]	0.08	0.15	0.29	0.41	1.4	0.05	0.05	0.07	0.14	0.29

Pollutant	Group 3 Emission Factors (g/hp-hr) [1]					Group 4 Emission Factors (g/hp-hr) [1]				
	100% Load	75% Load	50% Load	25% Load	10% Load	100% Load	75% Load	50% Load	25% Load	10% Load
NO_X	6.12	4.43	3.9	3.76	3.76	5.85	4.05	3.88	4.62	5.42
CO	0.75	0.63	0.52	0.81	0.81	0.41	0.52	0.25	1.85	13.85
VOC [2]	0.04	0.05	0.08	0.15	0.15	0.11	0.15	0.16	0.33	5.59
Filterable PM [3]	0.1	0.1	0.09	0.17	0.17	0.06	0.08	0.07	0.16	0.93

Notes:

1. Per the manufacturer emissions data and specification sheet. Emission factors are conservatively based on the manufacturer's "Rated Speed Potential Site Variation" (i.e., not-to-exceed) emissions data. For cases where emission factors were not provided at 10% load, it was assumed to be equal to the values at 25% load.
2. It is conservatively assumed that all hydrocarbons (HC) are VOC.
3. It is conservatively assumed that all PM is less than 2.5 microns in diameter.

Hourly Emissions per Engine by Load

Pollutant	Group 1 Hourly Emissions per Generator (lb/hr/gen) [1, 2]						Group 2 Hourly Emissions per Generator (lb/hr/gen) [1, 2]					
	100% Load	75% Load	50% Load	25% Load	10% Load	Maximum	100% Load	75% Load	50% Load	25% Load	10% Load	Maximum
Criteria Pollutants												
NO_X	62.82	30.35	16.91	11.48	8.40	62.82	51.10	31.34	15.58	7.94	7.09	51.10
CO	4.83	5.89	6.95	7.40	5.62	7.40	6.09	2.92	2.42	3.33	4.67	6.09
VOC	2.05	1.81	1.75	1.84	1.24	2.05	1.12	1.10	1.21	0.91	0.98	1.21
Filterable PM	0.48	0.68	0.88	0.62	0.85	0.88	0.40	0.30	0.29	0.32	0.32	0.40
$PM_{10}/PM_{2.5}$ [3]	0.66	0.82	0.98	0.72	0.95	0.98	0.58	0.44	0.39	0.38	0.35	0.58
SO_2	0.03	0.03	0.02	0.02	0.02	0.03	0.04	0.03	0.02	0.01	0.01	0.04

Pollutant	Group 3 Hourly Emissions per Generator (lb/hr/gen) [1, 2]						Group 4 Hourly Emissions per Generator (lb/hr/gen) [1, 2]					
	100% Load	75% Load	50% Load	25% Load	10% Load	Maximum	100% Load	75% Load	50% Load	25% Load	10% Load	Maximum
Criteria Pollutants												
NO_X	49.11	26.66	15.65	7.54	7.54	49.11	14.34	7.50	4.92	3.21	1.85	14.34
CO	6.02	3.79	2.09	1.63	1.63	6.02	1.01	0.96	0.32	1.28	4.73	4.73
VOC	0.32	0.30	0.32	0.30	0.30	0.32	0.27	0.28	0.20	0.23	1.91	1.91
Filterable PM	0.80	0.60	0.36	0.34	0.34	0.80	0.15	0.15	0.09	0.11	0.32	0.32
$PM_{10}/PM_{2.5}$ [3]	0.99	0.74	0.46	0.39	0.39	0.99	0.20	0.19	0.12	0.13	0.33	0.33
SO_2	0.04	0.03	0.02	0.01	0.01	0.04	0.01	0.01	0.01	0.00	0.00	0.01

Air Permitting Considerations

Air Permitting for Data Centers

Historical Permitting Regime

- Emergency engines categorically “exempt” in many states
- Diesel belly tanks & cooling towers “hand-waved” due to magnitude of emissions
- Applicable regulations usually limited to RICE MACT and NSPS IIII/JJJJ

FAST-FORWARD

Why is this changing?

- Previous regulations not well-suited to facilities permitting ~100s x ~3 MW emergency engines at once
- More data centers are expanding above major source thresholds
  - More need for prime power
  - Federal construction permitting (i.e., BACT/LAER) establishing new precedent

How is this changing?

- States are trying to react with new regulations and “best permitting practices”
- Observing a shift for:
  - dispersion modeling
  - need for emissions controls
  - complex permit conditions

Federal Regulations Related to Generators

- **40 CFR 63, Subpart ZZZZ**
  - Also known as RICE MACT or RICE NESHAP

- **40 CFR 60, Subpart IIII**
  - Also known as NSPS IIII
  - Compression Ignition (CI) engines – Diesel

- **40 CFR 60, Subpart JJJJ**
  - Also known as NSPS JJJJ
  - Spark Ignition (SI) engines – Natural gas, gasoline, propane

- Combined, these regulations cover the stationary engines in the United States

- For emergency engines: Hour meter, specific maintenance required engine after certain hours of runtime, logging times/type of operation

Data Center Air Permitting Considerations

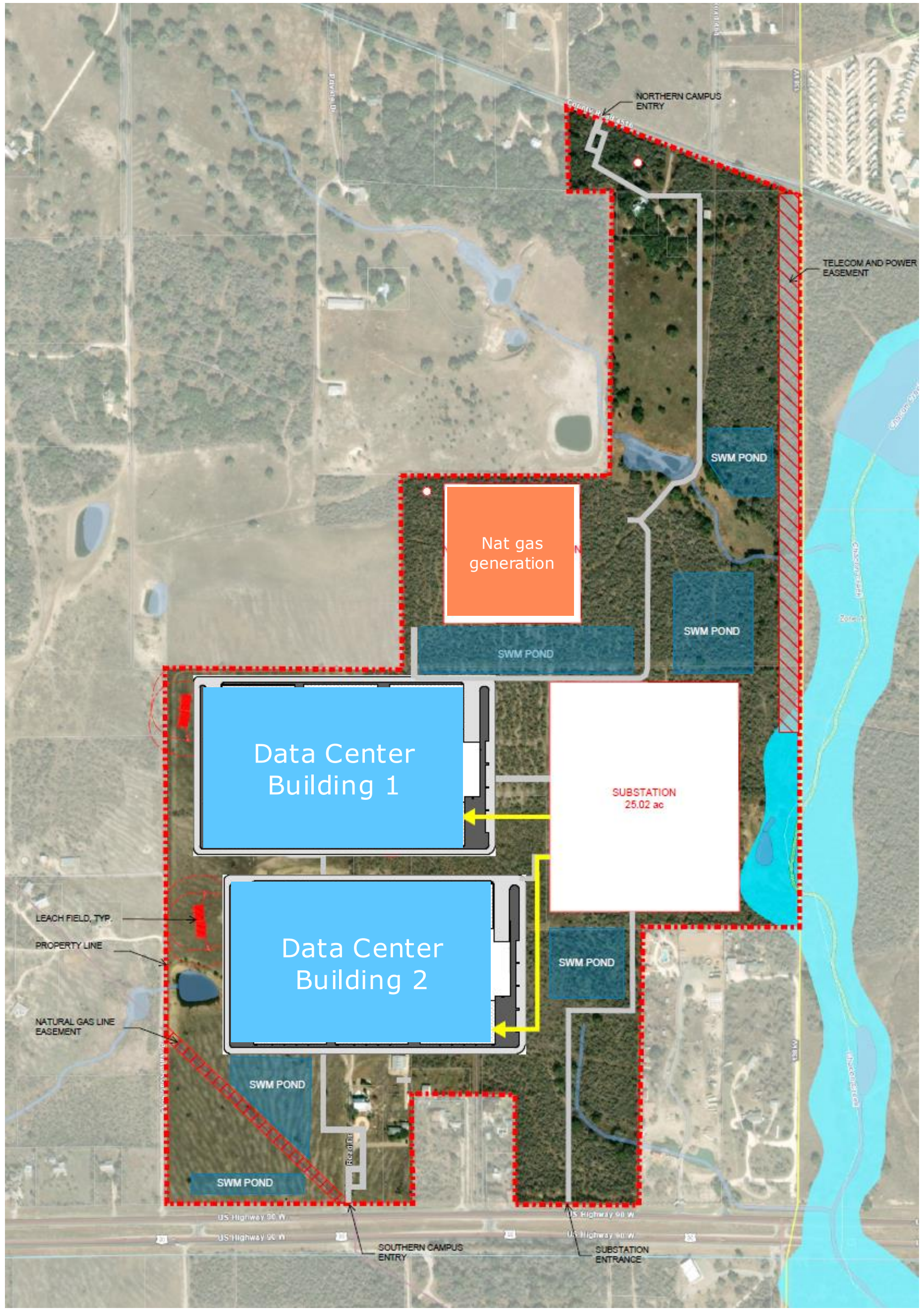
- Location
  - Attainment/non-attainment – major source thresholds
  - Source status, future full-build
  - Site aggregation – other data centers, power generation
- Source types & emissions
  - Emissions data from engine manufacturer
  - Confirm adequate runtime availability
  - Determine if controls are needed

- Limiting pollutant is typically NOx (but may be CO if controls exist)
  - In attainment areas, data centers will typically take limitations:
    - < 100 tpy for regulated pollutants for Title V
    - < 250 tpy for PSD
- Is modeling required? If so, how/what is modeled?
- Permit limits
  - Emission-based, hours-based, fuel-based, time of day restrictions

Other considerations

Aggregation

- Many sites clustered together with complex ownership/access
- Adjacent prime power sites
- Review definition of stationary source:
  - Common control
  - SIC
  - Continuous or adjacent



Permit Terms

- Limits:
  - Emission-based
  - Hours-based
  - Fuel-based
- Best management practices:
  - Limits on time-of-day for M&T activities
  - Limits on hours per year for M&T

Pollutant	Hourly Emissions per UNCONTROLLED Generator (lb/hr/gen)						Hourly Emissions per CONTROLLED Generator (lb/hr/gen)					
	100% Load	**75% Load**	**50% Load**	**25% Load**	**10% Load**	**Maximum**	**100% Load**	**75% Load**	**50% Load**	**25% Load**	**10% Load**	**Maximum**
NO_x	70.72	47.91	26.93	14.03	11.93	**70.72**	7.07	7.19	4.04	5.61	7.75	**7.75**
Notes	*Wide variation across loads. Obtaining an hours-based limit here would leave runtime flexibility on the table.*						*Low variation across loads. Obtaining an hours-based limit here would be favorable.*					

Pollutant	Hourly Emissions per UNCONTROLLED Generator (lb/gal/gen)						Hourly Emissions per CONTROLLED Generator (lb/gal/gen)					
	100% Load	**75% Load**	**50% Load**	**25% Load**	**10% Load**	**Maximum**	**100% Load**	**75% Load**	**50% Load**	**25% Load**	**10% Load**	**Maximum**
NO_x	0.34	0.31	0.25	0.27	0.58	**0.58**	0.03	0.05	0.04	0.11	0.37	**0.37**
Notes	*Low variation across loads. Obtaining a fuel-based limit here would be favorable.*						*Wide variation across loads. Obtaining a fuel-based limit here would leave runtime flexibility on the table.*					

Air Dispersion Modeling

Modeling Challenges for Data Centers

- AERMOD has a degree of conservatism
- **Stringent 1-hour NO_2 NAAQS**
- Lowering $PM_{2.5}$ standards
- Intermittent sources
- NOx chemistry
- Potentially complex source operation
  - Different M&T scenarios
  - Tier 2 vs. Tier 4 engines
- **Lack of guidance**

Federal 1-Hour NO_2 Modeling Guidance

- From Tyler Fox Memo (March 2011)

"…The potential overestimation in these cases results from the implicit assumption that worst-case emissions will coincide with worst-case meteorological conditions … In fact, the probabilistic form of the standard is explicitly intended to provide a more stable metric for characterizing ambient air quality levels by mitigating the impact that outliers in the distribution might have on the design value" … this "effectively impose(s) an additional level of stringency beyond that intended by the level of the standard itself."

(EPA, Additional Clarification Regarding Application of Appendix W Modeling Guidance for the 1-hour $N0_2$ National Ambient Air Quality Standard, 2011)

- Describes challenges of modeling compliance with 1-hour probabilistic standards: maximum emissions paired with worst-case meteorology for 5 years.
- Provides discretion for reviewing authorities to exclude intermittent emissions or annualize emissions from emergency generators from short-term modeling (1-hr NO_2)

Federal 1-Hour NO_2 Modeling Guidance

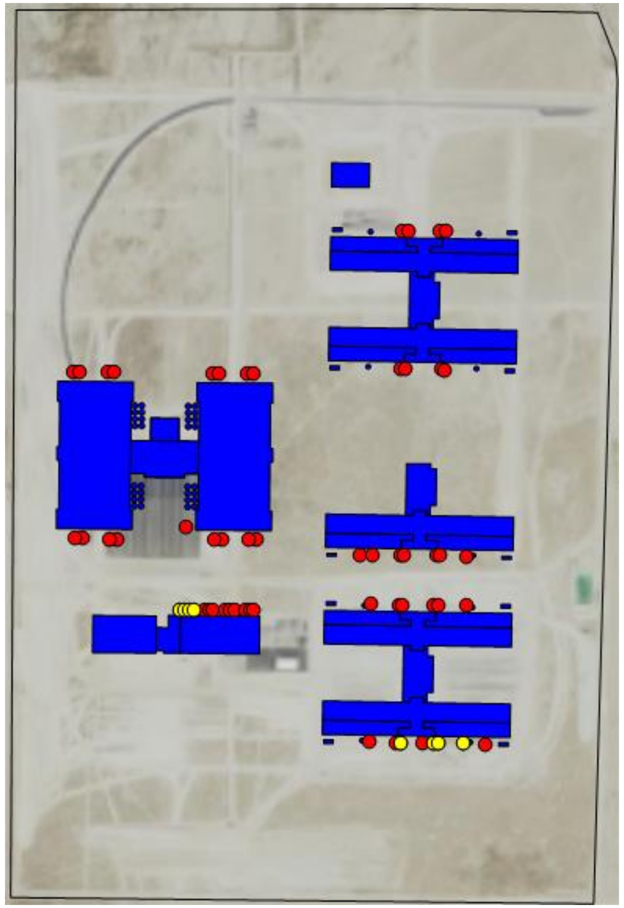
- June 2021 Regional, State, and Local Conference Round Table EPA stated that:
  - Prior memo was not developed with consideration of use of emergency generators at data centers (large number of generators)
  - Maintenance and testing can be scheduled and should be accounted for in a compliance demonstration.

- Since data centers to-date have remained minor sources, EPA has not intervened
- But they also have not provided tools or guidance that states could rely on

- For applicants, this leads to:
  - Inconsistent permitting and compliance strategies between states
  - Reduced operational flexibility
  - Over-control of sources

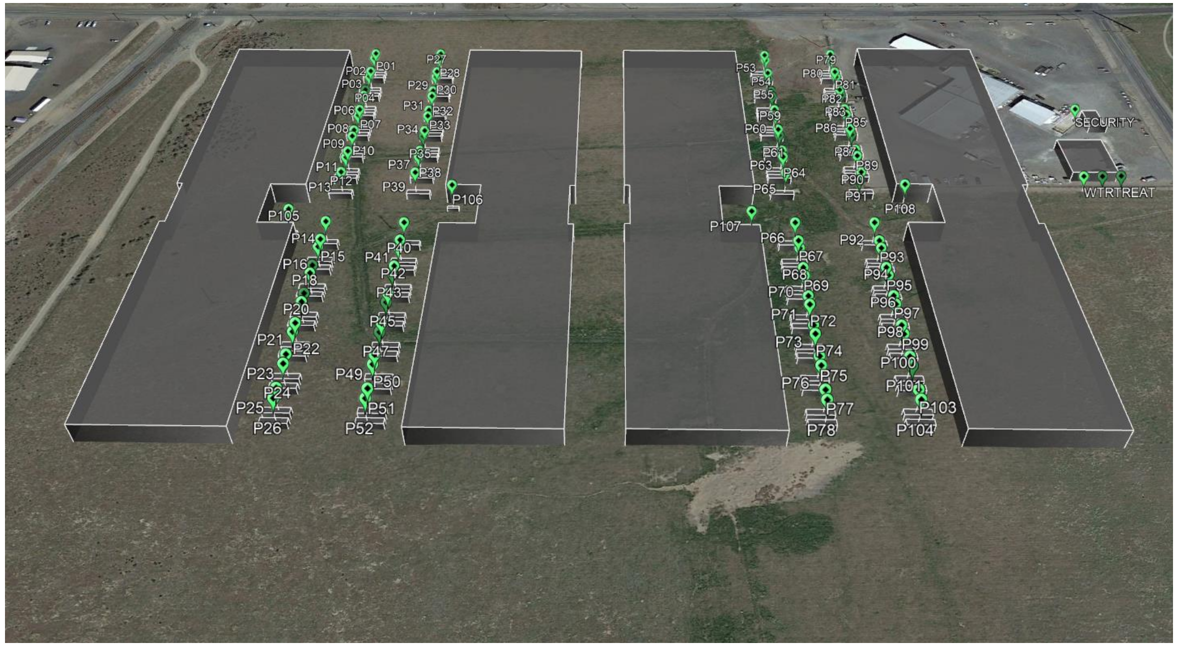
Traditional Approaches for NO_2 and $PM_{2.5}$ Modeling

- On practical level, impossible for all but the smallest facilities to pass attempting to model all engines running simultaneously
- For sites with a large number of generators (like data centers), a screening approach is often used
- Example on right: Data center on right has approximately 60 generators
- Screening modeling was performed to determine eight generators causing the worst ambient impacts – four from the west half or the facility, four from the east half
- A final run with emissions from only those eight engines showed compliance against the NAAQS
- Of course, the condition that only eight engines (four west/four west) can be tested at once became a permit condition for this facility
- Some facilities want more operational flexibility…



Data Center Modeling

- Many data center clients are using different loads and durations in their testing and maintenance programs – for example:
  - 10% load for 10 minutes, once per month
  - 50% load for 30 minutes, once per quarter
  - 100% load for an hour, once per year
- Different loads = different emissions = different stack parameters = different impacts
- How to think about compliance with the different loads and impacts?
- Allows for less operational restrictions



Possible Refinements

- Refinements that can be made in compliance demonstrations:
  - Time of day limitations (enhanced dispersion during daytime)
  - Adding controls
  - Adjusting stack parameters
  - Limitations on generators running concurrently
  - Refined NO_X to NO_2 chemistry (ARM2 v. OLM, PVMRM, GRSM)
  - Refined NO_2 backgrounds (March 2011 Tyler Fox memo)
  - In-stack ratios (ISR)
  - Monte Carlo Analysis

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Ongoing Compliance

Compliance is Complicated

- Historically, data centers demonstrated compliance with a spreadsheet
- Data centers often have limited EHS personnel
- Many are increasingly using more complex compliance systems
  - Enablon, Tableau, custom solutions

- NSPS regulations
- State regulations
- Air permit limitations:
  - Recordkeeping – hours, reason in operation, load, fuel use, etc.
  - Maintenance records
  - Reports
  - Stack testing (if req’d)

- One of the biggest issues → What is emergency operation?

Questions?

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