The Democratization of Vehicle Emissions Testing

David Miller, 3DATX
DavidMiller@3DATX.com

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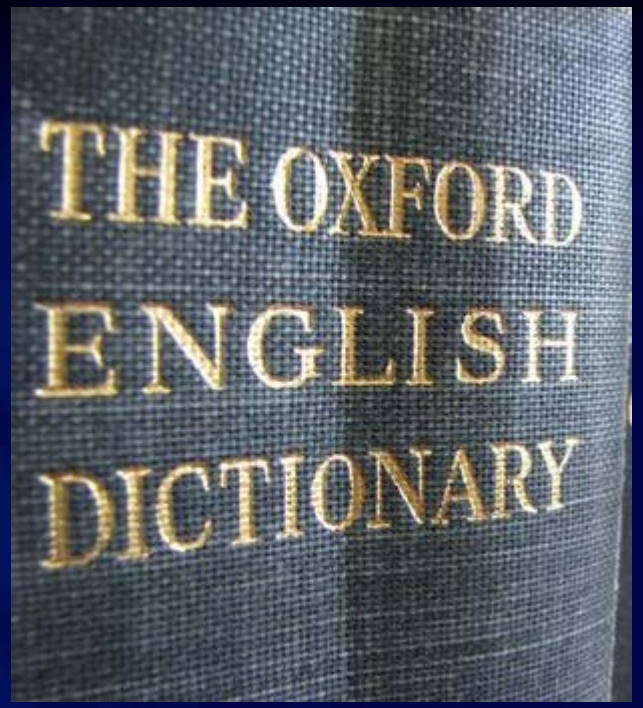
Democratization? Definition:

...according to the Oxford English Dictionary:



de·moc·ra·ti·za·tion [dəˌmäkrədəˈzāSH(ə)n]

NOUN

democratization (noun)

the introduction of a democratic system or democratic principles:

"he has funded efforts to promote democratization in Europe"

"the Reform Bill was the first step towards democratization of Parliament"

or

the action of making something accessible to everyone:

"the democratization of information through technology"

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The Democratization Process

A Linear PEMS Perspective:

- *Early development of Portable Emissions Measurement Systems (PEMS)*
- *How "global regulations" (e.g. "1065") have shaped modern PEMS*
- *How the VW Scandal has re-ordered PEMS requirements*
- *Global trends and challenges (e.g. Real Driving Emissions (RDE))*
- *"Clues" of product development from other industries - clarification on PEMS*
- *Forecasting of next iterations; vision-casting of next-gen PEMS*

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Early History

Vehicle Emissions Testing: 1970's – 1990's

- *California Environmental Protection Agency (now known as California Air Resources Board or CARB) in 1966 began to pioneer many of the early vehicle testing concepts*
- *Chassis dynamometer (dyno) heavily relied upon to accomplish testing goals*
- *1970 – the US Nixon administration simultaneously passed*
  - *The Clean Air Act*
  - *The United States Environmental Protection Agency (USEPA)*

"Ye Olde Chassis Dynamometer" of Yesteryear

From the 1970's until the late 1990's, the chassis dyno for emissions testing was the only method available.

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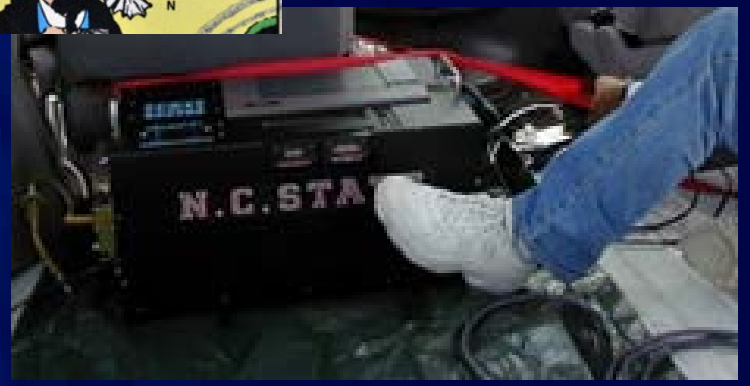
The First On-Road Test Devices

"Rube Goldberg meets the Woodshed": 1990's

- *1995 – **Internal use** USEPA Real-time On-road Vehicle Emissions Reporter (ROVER) developed by Leo Breton (led to 1999 Consent Decree 1 billion USD fine)*

- *1997-99 – **Commercially available** OEM2100 patented and developed by Michal Vojtisek-Lom and David Miller Clean Air Technologies International (CATI)*

The USEPA ROVER



The OEM2100: first-ever mass-produced, commercially available portable emissions device. Sold by CATI to NCSU

NOTE: Michal suggested "POEMS" (Portable On-Board Emissions Measurement System) and Dave declined: OEM2100 Won...

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The First On-Road Test Devices

1995 - 2002

- *1995 – USEPA ROVER*
- *1999 – CATI PEMS "OEM2100" hits the market*
- *2002 – (EPA CRADA/ROVER Patent) Sensors Inc. releases "SEMTECH"*
- *2002 – CATI Montana System*

USEPA-based patent

Privately-developed patent

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First Use of the Word "PEMS"

PEMS as a Product Descriptor: February 2000

- *"Clean Diesel Air Quality Demonstration Program" - New York City Metropolitan Transportation Authority (MTA) bus project Dr. Thomas Lanni (NYSDEC)*
- *In-service Manhattan buses*
  - *DDC Series 50 engines*
  - *Continuously Regenerating Technology (CRTs)*
  - *ultra-low sulfur diesel from February – November of 2000*
- *Evaluation of durability/maintainability of the CRT*
- *Transient cycles on chassis dyno to evaluate emissions reductions with CRT*
- *Newly-christened "CATI PEMS" (OEM2100) equipment identified 'high emitters' to meet criteria for round trip (NYC to the Environment Canada Labs in Ottawa, CA)*
- *CATI PEMS device – 100% effective - won an EPA Clean Air Excellence Award, and led to the industry-wide use of ultra low sulfur diesel and DPFs*

The first-ever use of "PEMS" as a product descriptor: NYC MTA Buses

NOTE: Michal was happy that the rejected "POEMS" label morphed into "PEMS"...
"The NYSDEC/USEPA Shuffle"

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First Use of the Word "PEMS"

Pause: What Does "Portable" Mean?

- *The term "Portable" was chosen because the word means an object can be easily and safely moved by one person*
- *Defined by National Institute for Occupational Safety and Health (NIOSH)*
- *Found in "NIOSH Lifting Equation" and "NIOSH Procedures for Analyzing Lifting Jobs"*

"NIOSH Lifting Equation"

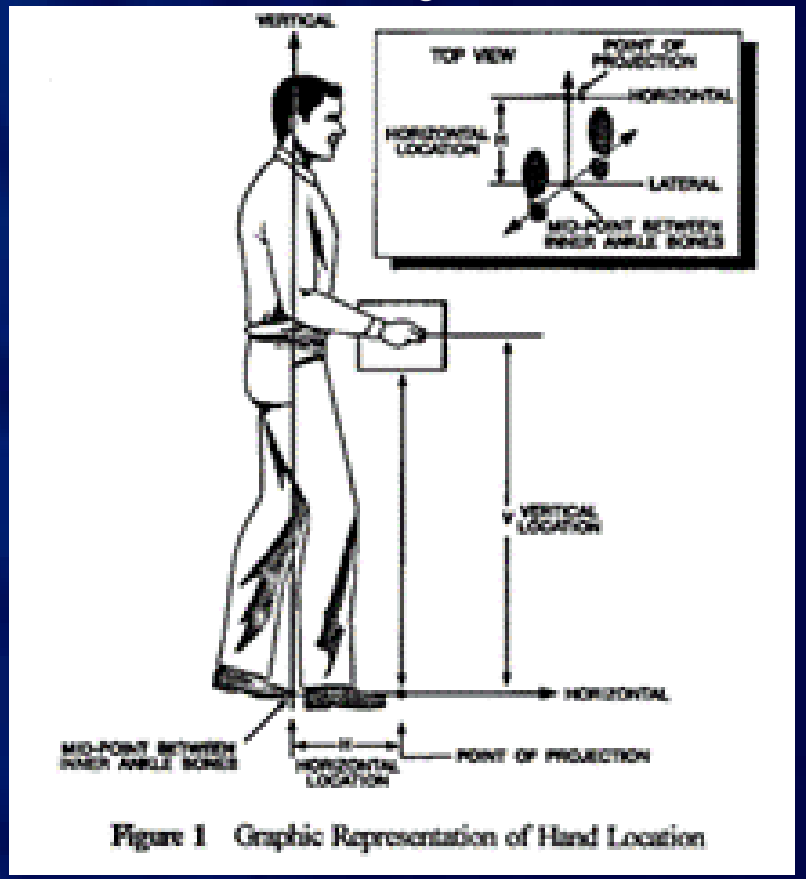

Figure 1 Graphic Representation of Hand Location

NOTE: 40lbs. is the upper limit for an average person to lift a weight from ground level to waist level.

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Early Significant PEMS Projects:

1999 - 2005

- *1999 – 2005: Pioneering work of North Carolina State University (NCSU) and Dr. Chris Frey (using CATI equipment)*
  - *Quantify effect of traffic signal timing on emissions*
  - *Testing light and heavy duty vehicles as well as construction equipment, over-snow vehicles and locomotives*
  - *Evaluation of fuels, technologies, vehicle types, duty cycles, road types, routing, road grade, fuel economy, and emission standards*
  - *Applications to model evaluation (e.g. MOVES)*

NOTE: Data obtained from the project was used to evaluate and update mobile source emission models (e.g. MOVES).

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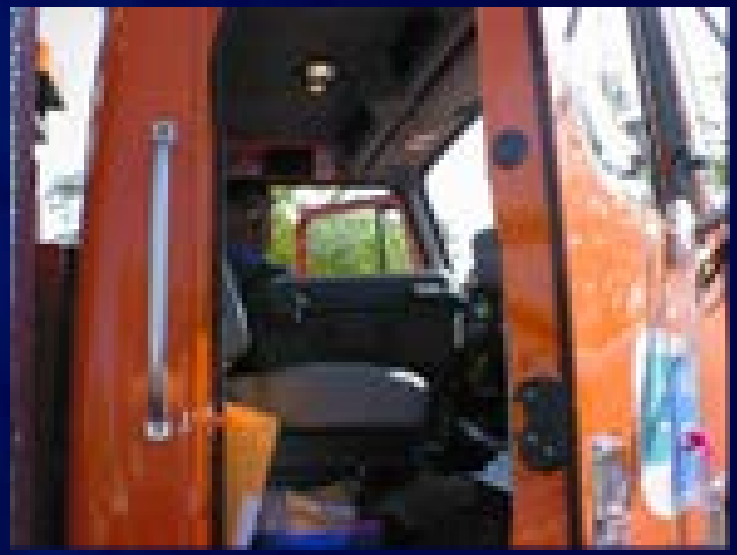
Early Significant PEMS Projects:

2000 - 2005

- *April 2002: CARB On-road Project – Don Chernich (CATI)*
  - *3 CATI PEMS Used*
  - *40 trucks tested over 2 ½ days;*
  - *Of which, 22 trucks tested on-road between two truck stops spaced 3 miles apart (Tulare, Ca.)*
  - *Sponsored by IdleAire Technologies, Inc.*



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Early Significant PEMS Projects:

2000 - 2005

- *Summer 2002: New York City Ferry Boat Testing (CATI)*
  - *2 week project testing steady state emissions*
  - *NYSERDA sponsored project performed to understand marine vessel emissions*
  - *Route was from Staten Island to Lower Manhattan*

Voith Schneider Propeller

John A. Noble

Alice Austin

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Early Significant PEMS Projects:

2000 - 2005

- *April 2003 – 2004: NYSDEC World Trade Center (WTC) Ground Zero Project in lower Manhattan NESCAUM – Glenn Goldstein (CATI)*
  - *Concrete pumpers, bulldozers, graders;*
  - *Diesel cranes on Building #7 - 40 stories high*
  - *Performed in conjunction NESCAUM (North East States for Coordinated Air Use Management)*

NOTE: Led to the development of "Local Law 77" – Green Construction Rules for Lower Manhattan

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Early Significant PEMS Projects:

2000 - 2005

- *2003 and 2004: Bibendum Challenge (Sensors)*
  - *Exhibition event to promote sustainable mobility*
  - *On-site RDE tests of 30 – 40 participating vehicles*
  - *Workshop ICAT 21*
  - *Proved viability of efficient PEMS testing of wide range of light-duty vehicles*

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Early Significant PEMS Projects:

2000 - 2005

- *2004 – 2005: Kansas City PM Characterization Study (Sensors)*
  - *Performed by the Eastern Research Group for the USEPA*
  - *Utilized Sensors Inc. PEMS equipment*
  - *Evaluated exhaust emissions from light-duty gasoline vehicles from approximately 480 randomly selected light-duty vehicles*
  - *Performed in the Kansas City Metropolitan Area*

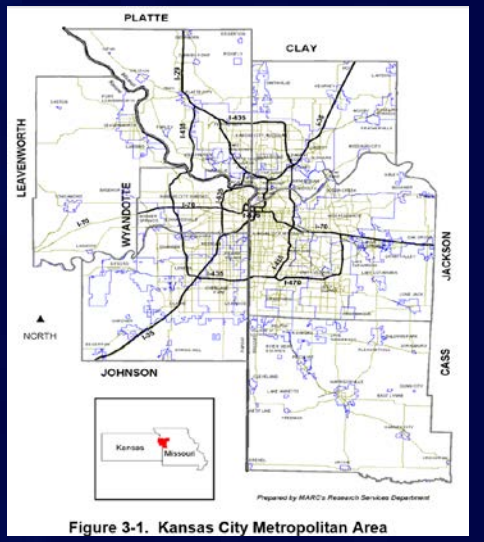

Figure 3-1. Kansas City Metropolitan Area

NOTE: Data obtained from the project was used to evaluate and update mobile source emission models (e.g. MOBILE6 and MOVES).

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Early Significant PEMS Projects:

2000 - 2005

- *2004 – 2005: Winter Vehicle Emissions in Yosemite National Park; Gary Bishop, University of Denver (CATI)*
  - *Methods for measuring emissions under real use conditions and verification of emission reductions*
  - *Comparison of over-snow vehicles*
  - *Montana PEMS used*
  - *Measurements: CO, CO2, HC, NO, O2, PM Engine parameters and GPS*

Snowmobile Surprises: Ski Doo's had little CO reduction with 4-stroke engines; Emissions in g/mi did not increase with speed; Re-started sleds have higher emissions in gate area

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Early Significant PEMS Projects:

2000 - 2005

- *May 2005: Mexican Truck Idling Emissions at the El Paso-Ciudad Juarez Border Location Texas A&M (TAMU) Dr. Josias Zietsman (CATI)*
  - *key stakeholders of this project included motor carriers; • Mexican customs; • U.S. Customs and Border Protection (CBP); and • Texas Department of Public Safety (DPS)*
  - *Develop a methodology to estimate emissions produced by trucks from Mexico crossing the El Paso-Ciudad Juarez border*
  - *Develop a border crossing fleet profile: make, model, and year of trucks crossing the two main border bridges*
  - *Border crossing travel profile: drive cycles (acceleration, deceleration, cruising, idling, and creep idling) of trucks crossing the two main border bridges*
  - *Border crossing emissions profile: estimates of idling emissions and driving emissions of trucks crossing the two main border bridges*

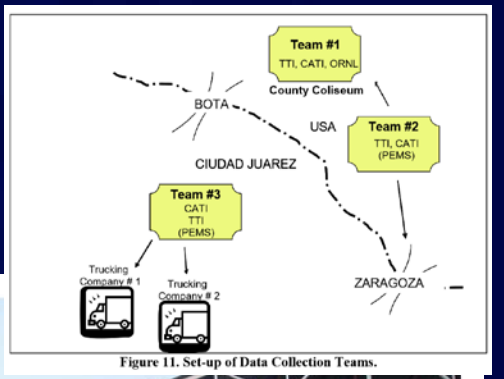

Figure 11. Set-up of Data Collection Teams.


Figure 10. Photograph of Coliseum Testing Site.

NOTE: The first-ever project clearly profiled fleet, travel, and emissions characteristics of trucks crossing the El Paso-Ciudad Juarez border locations.

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PEMS Equipment/Standards:

June 2005 - 40 CFR 86 Part 1065

- *1999 Consent Decree 1.0 billion USD fine paved the way*
- *No 1065 "approval/certification process*
- *Method-centric*

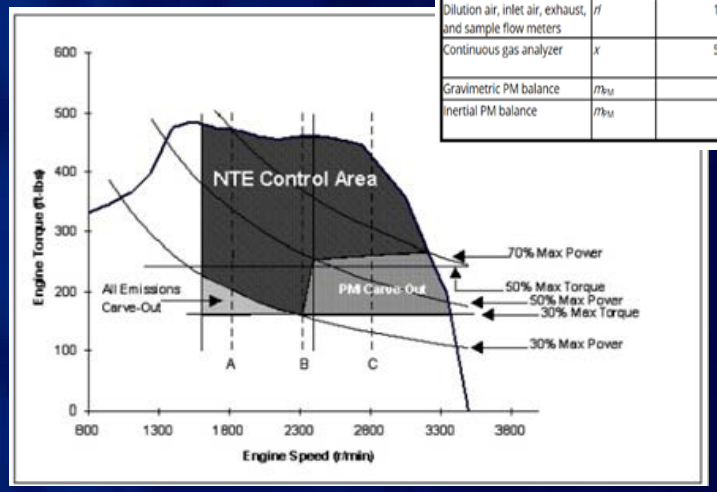
§1065.915 "PEMS instruments"

TABLE 1 OF §1065.915—RECOMMENDED MINIMUM PEMS MEASUREMENT INSTRUMENT PERFORMANCE

Measurement	Measured quantity symbol	Rise time, $t_{10\text{-}90}$, and fall time, $t_{90\text{-}10}$	Recording update frequency	Accuracy[1]	Repeatability[1]	Noise[1]
Engine speed transducer	f_n	1 s	1 Hz means	5% of pt. or 1% of max	2% of pt. or 1% of max	0.5% of max.
Engine torque estimator, BSFC (This is a signal from an engine's ECM)	T or BSFC	1 s	1 Hz means	8% of pt. or 5% of max	2% of pt. or 1% of max	1% of max.
General pressure transducer (not a part of another instrument)	p	5 s	1 Hz	5% of pt. or 5% of max	2% of pt. or 0.5% of max	1% of max.
Atmospheric pressure meter	p_{atmos}	50 s	0.1 Hz	250 Pa	200 Pa	100 Pa.
General temperature sensor (not a part of another instrument)	T	5 s	1 Hz	1% of pt. K or 5 K	0.5% of pt. K or 2 K	0.5% of max 0.5 K.
General dewpoint sensor	T_{dew}	50 s	0.1 Hz	3 K	1 K	1 K.
Exhaust flow meter	rf	1 s	1 Hz means	5% of pt. or 3% of max	2% of pt	2% of max.
Dilution air, inlet air, exhaust, and sample flow meters	rf	1 s	1 Hz means	2.5% of pt. or 1.5% of max	1.25% of pt. or 0.75% of max	1% of max.
Continuous gas analyzer	x	5 s	1 Hz	4% of pt. or 4% of meas	2% of pt. or 2% of meas	1% of max.
Gravimetric PM balance	m_{PM}			See §1065.790	0.5 µg	
Inertial PM balance	m_{PM}			4% of pt. or 4% of meas	2% of pt. or 2% of meas	1% of max.

2007 – 40 CFR 86 Part 1370

- *"Not To Exceed" Zone standards*
- *Created by EPA and Caterpillar, Cummins, Detroit Diesel, Mack, Renault Vehicles Industriels, and Volvo Truck Corp*
- *Penalties are assessed if the NTE Zone is exceeded*



§1370 "NTE zone"

NOTE: 1065 equipment and on-road "NTE" devised for Heavy Duty Diesel (HDD) manufacturers

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The Downhill Slide:

1065 PEMS (designed for HDD) + diminished financial resources =

A Decade Later…

- *1999 "Consent Decree" Monies Begin to Run Dry (2009)*
- *US Great Recession Hits Hard (December 2008 - 2011)*
- *Emissions Defeat Device Cycle Secretly Takes Shape in the Light Duty Market (2006 – 2009)*

…led to:

- *Diminished oversight – (governmental overseers and watchdog groups)*
- *Increased boldness of risk-taking (LD vehicle manufacturers)*

NOTE: By 2006, some LD manufacturers had begun to develop Defeat Software for their Engine Control Units (ECU's)

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The Result: Defeat Devices

Compounding the Tipping Point

- *Significant cost of emissions evaluations*
- *Legislative requirements lacking both teeth and evaluation capabilities*

By September 2009: - Volkswagen Introduced vehicles with defeat device software, including:

- *2009 – 2015 Audi A3*
- *2009 – 2015 VW Beetle*
- *2009 – 2015 Beetle Convertible*
- *2009 – 2015 VW Golf*
- *2015 VW Golf Sportwagen*
- *2009 – 2015 VW Jetta*
- *2009 – 2014 Jetta Sportwagen*
- *2012 – 2015 VW Passat*

NOTE: It is no accident that these changes occurred during this particular timeframe - there was no practical real-world emissions validation plan in place .

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DieselGate

2013 – 2015 – the Investigation

- *Casual 2013 testing with non-1065 PEMS had identified apparent issues with VW diesels*
- *In 2014 West Virginia University (WVU) performed a Formal VW Testing Project with a 1065 PEMS*
  - *Funded by the international Council for Clean Transportation (ICCT)*
  - *Three diesel cars: VW Passat, Jetta, BMW X5*
  - *Certified at a California Air Resources Board facility*
  - *Horiba 1065 PEMS used for all on-road testing*
- *After multiple long-distance runs, it was discovered that the Jetta and Passat significantly exceeded emissions limits under real-world driving conditions.*
- *VW engineer confessed to CARB during a meeting on August 19. 2015*
- *VW supervisor confirmed the defeat device to regulators on September 3, 2015*
- *USEPA and CARB made VW's confession public on Sept. 18, 2015*

Beyond the scandal:
Although 1065 equipment was effectively used to formally identify the defeat software, a simple 5-gas analyzer could have identified the problem.

NOTE: In September of 2015, Volkswagen revealed that they had sold over 11 million vehicles worldwide (including 590,000 2.0 liter engine vehicles in the US) with emissions defeat software. 25 Billion USD fine…(maybe)

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The EU Answer to DieselGate:

Real Driving Emissions (RDE)

- *Measures Criteria Pollutants emitted by cars driven on-road*

- *EU timeline of RDE Packages*
  - *1st Package – March 31st 2016 (2016/427)*
  - *2nd Package – April 20th 2016 (2016/646)*
  - *3rd Package – July 7th 2017 (2017/1154)*
  - *4th Package in discussions – (2018)*

- *Driving conditions include*
  - *Low and high altitudes*
  - *Year-round temperatures*
  - *Additional vehicle payload*
  - *Up- and down-hill driving*
  - *Urban roads (low speed)*
  - *Rural roads (medium speed)*
  - *Motorways (high speed)*

- *All petrol and diesel vehicles tested yearly*
- *Countries failing to reduce diesel emissions may run the risk of banning all diesels in major cities*

NOTE: Identified requirements (thus far): NOx and/or PN in most EU (and Asian countries); CO2 being included in some countries

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The PEMS Bottleneck Problem:

Accuracy V. Efficiency Trade-off Challenge

- *RDE is testing-centric (outcome)*
  - *PLUS Side – many ways to solve a problem (competition increases, costs are reduced)*
  - *MINUS Side – many solutions to be inspected and considered*

  "Analysis Paralysis" in decision-making

- *1065 Regulations are equipment-centric (method)*
  - *PLUS Side – 1 technique to solve a problem (e.g. 1065 PEMS based on USEPA ROVER Patent)*
  - *MINUS Side – many components required by the device*

  Limited suppliers, increased costs for acquisition and maintenance, size and weight

Chinese Proverb: "In every crisis, there is opportunity."

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Problems/Opportunities: "Why?"

Start with the right questions

- *What is the problem?*
- *How do we solve the problem?*
- *Who is impacted by the problem?*
- *Where does the problem present itself?*
- *Why is this problem important?*

The most important question regarding emissions testing is:

"WHY?"

As in:

"Why are we doing this…?"

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Problems/Opportunities: "3 Bins"

Only 3 Bins that Emissions Testing Activities Fall Into…

1) Climate Change *(formerly known as "Global Warming")*
2) Health Impacts
3) Natural Resource Stewardship

ALL regulations, equipment, costs, procedures, conferences, and testing runs created for emissions testing MUST help to resolve, solve, or fall, into one or more of these three categories, or run the risk of being a drain on society's resources.

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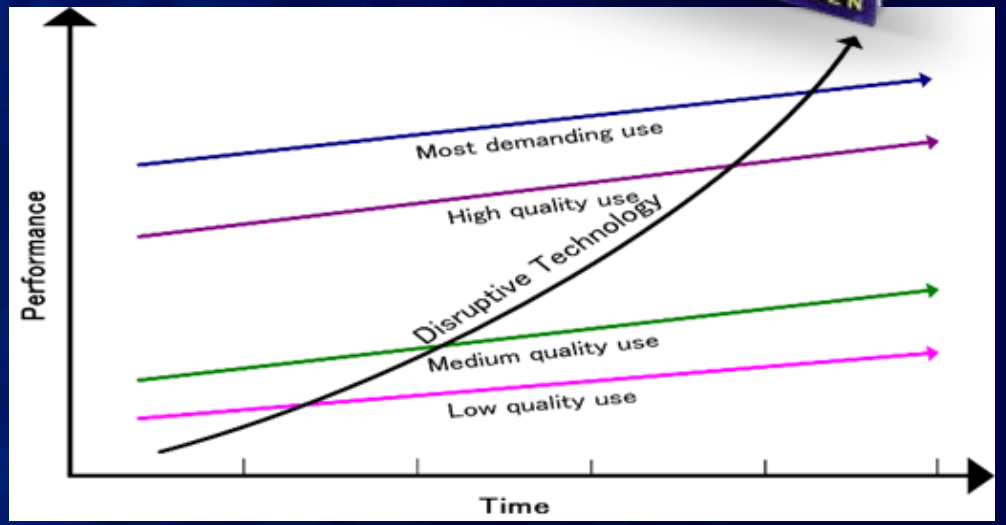
Problems/Opportunities:

The "Disruptive Innovation" Impact – What is It?

- *Harvard professor Clayton Christensen coined the phrase in 'The innovator's dilemma', published in 1997:*
  - *Initially offers a lower performance according to what the mainstream market has historically demanded*
  - *Simultaneously provides some new performance attributes, which in turn makes it prosper in a different market*



"As a disruptive innovation technology improves along the traditional performance parameters, it eventually displaces the former technology."

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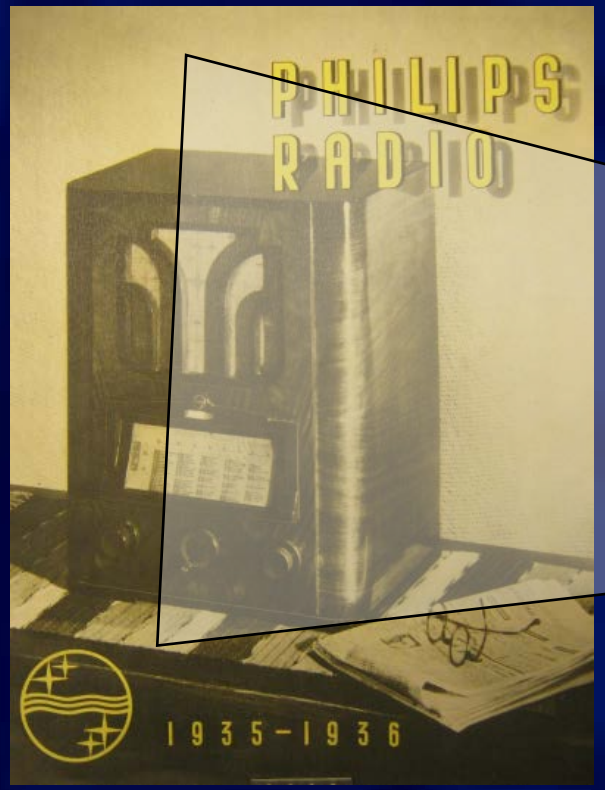
Problems/Opportunities:

Examples of "large and complex" giving way to "small and easy to use":

Console Radio to Transistor Radio



Being portable and offering worse sound quality, the transistor radio was adopted by teenagers who could bring music to the beach.

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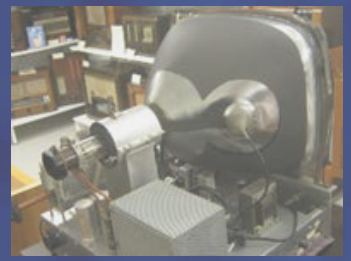
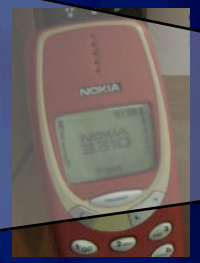
Problems/Opportunities:

Examples of "large and complex" giving way to "small and easy to use"

Cathode Ray Tube (CRT) TV, Computers, Telephones to OLED Cell phone





Analogue phone + LED Screen + computer + camera = cellular device.

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Problems/Opportunities:

Examples of "large and complex" giving way to "small and easy to use":

1065 PEMS (many separate components) becoming an integrated PEMS

"Swiss Army Knife" approach of current PEMS morphs into specific, specialized device(s)

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PEMS 2018 and Beyond

Next Steps and Vision-Casting – beyond 1065 PEMS

- *Integrated PEMS (iPEMS, small PEMS, micro PEMS, mini PEMS, etc.)*
- *Harmonized Global Standards (RDE, MOVES, etc.) and Sustainability*
- *Independent evaluation services (e.g. Emissions Analytics – EQUA Index)*
- *Level Playing Field Development (fuels, roadways, driver education, engines, etc.)*
- *Integrated telematics (further assimilation of sensors and software into the vehicle) – examples – Firefly, parSYNC®,*
  - *NO SKIPPED STEPS*
- *Carbon standard metrics (external and independent measurement tool)*

"MINI"
"MICRO"
"SMALL"
"iPEMS"

NGK "NCEM"

3DATX "parSYNC®"

GlobalMRV "FireFly"

NOTE: It is important to keep the "PEMS" parlance, to prevent confusion and to reinforce the industry identifier.
People don't buy drills, they buy the ability to make holes.

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PEMS 2018 and Beyond

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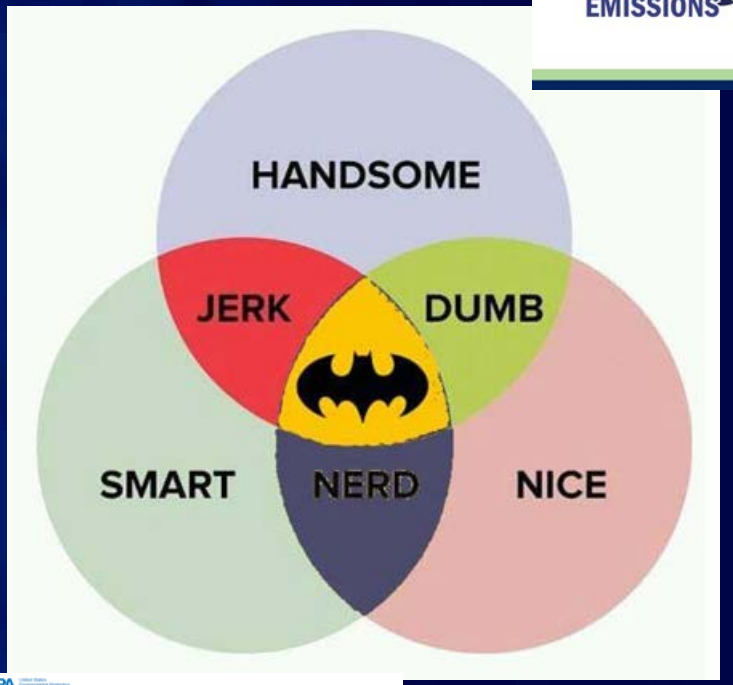
REAL DRIVING EMISSIONS



NOTE: Challenges are geographical requirements of vehicles and fuel availability. Venn Diagram of commonality!

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PEMS 2018 and Beyond

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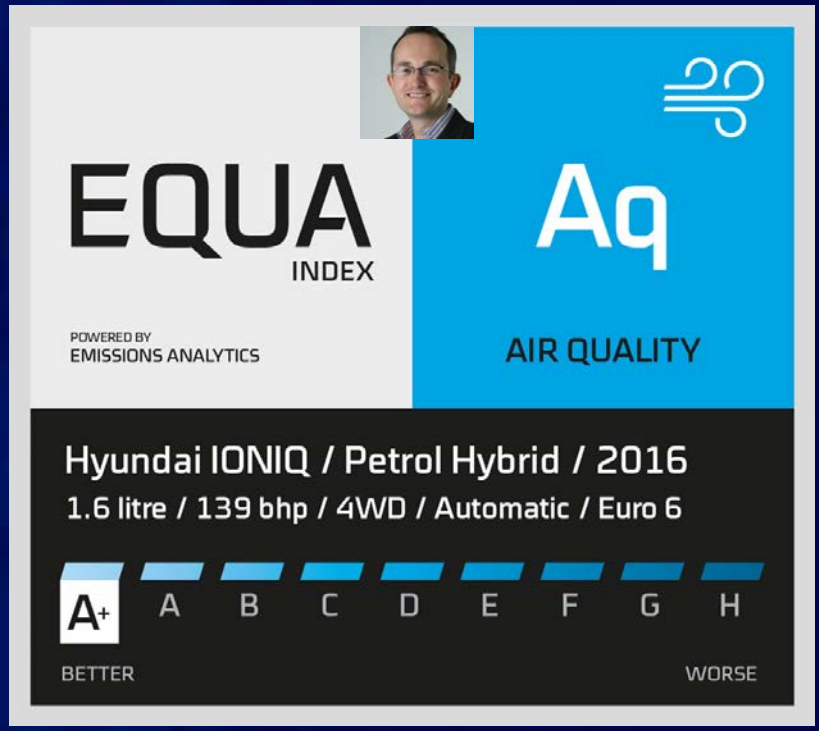

NOTE: Emissions Analytics one of the few companies providing such services.

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PEMS 2018 and Beyond

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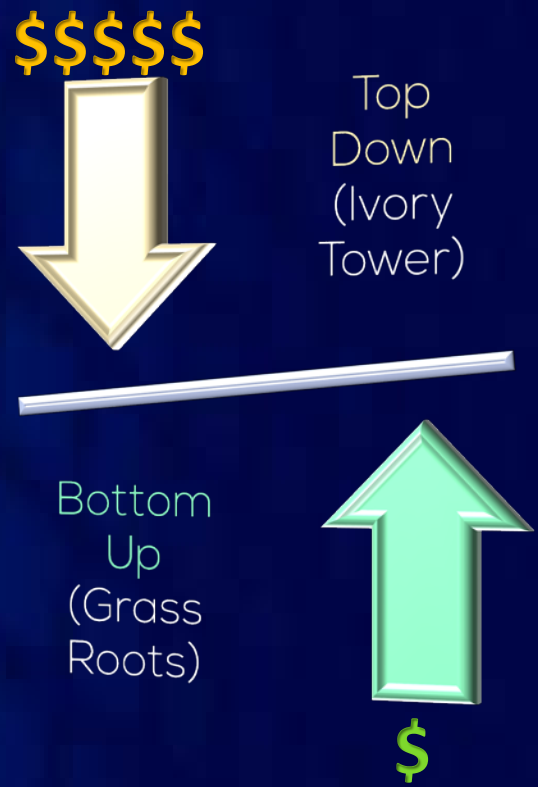

NOTE: Lower cost for an acceptable common standard means balanced, democratic, GLOBAL solutions to problems!

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PEMS 2018 and Beyond

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- *NO SKIPPED STEPS*
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NOTE: A logical progression of innovation is the most efficient way to get to a desired solution. Let innovation take it's natural course.

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PEMS 2018 and Beyond

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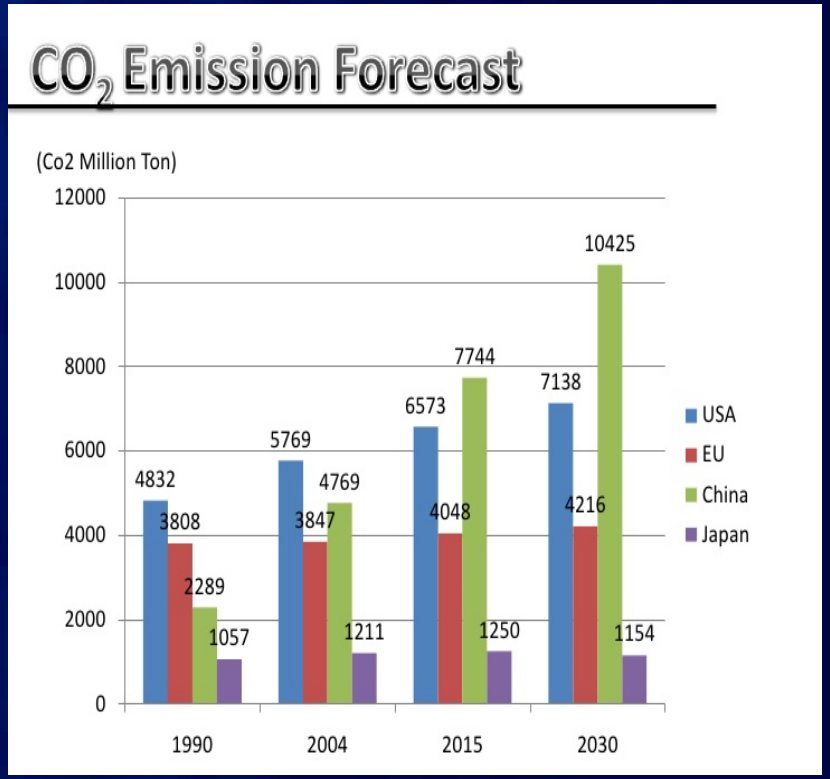
  - *NO SKIPPED STEPS*
- ***Carbon standard metrics (external and independent measurement tool)***



NOTE: A universal value/metric placed on energy and its use/non-use.
A Global Database – Big Data; Block Chain protection and security.

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The Democratization Process

Review:

- *Development of PEMS*
- *Global PEMS Regulations*
- *DieselGate*
- *RDE*
- *Equipment evolution – people don't buy drills, they buy the ability to make holes.*
- *Vision casting and next-gen PEMS*

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Any Questions?

David Miller, 3DATX
DavidMiller@3DATX.com

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