CLEAN FUELS PROGRAM ADVISORY GROUP AGENDA
SEPTEMBER 14, 2023, 9:00 AM – 3:45 PM
Conference Room CC8
21865 Copley Drive
Diamond Bar, CA 91765

TELECONFERENCE LOCATIONS (possible noticed outside locations)

Fuels and Transportation Branch California Energy Commission 715 P Street Sacramento, CA 95814	Volvo Group 7900 National Service Road Greensboro, NC 27402	Univ of Nevada, Reno Ross Hall 201 1664 N. Virginia Street Reno, NV 89557

A meeting of the South Coast Air Quality Management District Clean Fuels Program Advisory Committee will be held at 9:00 a.m. on Thursday, September 14, 2023, through a hybrid format of in-person attendance in Conference Room CC8 with CC2 as an overflow room for additional attendees at the South Coast AQMD Headquarters, 21865 Copley Drive, Diamond Bar, California, and remote attendance via videoconferencing and by telephone. Please follow the instructions below to join the meeting remotely. Please refer to South Coast AQMD's website for information regarding the format of the meeting, updates if the meeting is changed to a full remote via webcast format, and details on how to participate:

INSTRUCTIONS FOR ELECTRONIC PARTICIPATION
Join Zoom Webinar Meeting - from PC or Laptop
https://scaqmd.zoom.us/j/91964955642
Zoom Webinar ID: 919 6495 5642 (applies to all)
Teleconference Dial In +1 669 900 6833
One tap mobile +16699006833, 91964955642#

Audience will be allowed to provide public comment through telephone or Zoom connection.

INSTRUCTIONS FOR ELECTRONIC PARTICIPATION AT BOTTOM OF AGENDA

AGENDA

Members of the public may address this body concerning any agenda item before or during consideration of that item (Gov't. Code Section 54954.3(a)). If you wish to speak, raise your hand on Zoom or press Star 9 if participating by telephone. All agendas for regular meetings are posted at South Coast AQMD Headquarters, 21865 Copley Drive, Diamond Bar, California, at least 72 hours in advance of the regular meeting. Speakers may be limited to two (2) minutes each.

	Welcome & Overview 9:00 – 11:00 AM	
(a)	Welcome & Introductions	Aaron Katzenstein, Ph.D., Deputy Executive Officer *
(b)	Grant Updates and Opportunities	Mei Wang, Assistant Deputy Executive Officer *
(c)	Goals for the Day	Vasileios Papapostolou, Sc.D., Technology Demonstration Manager*
(d)	Tire Emissions Measurement, and Comparative VOC Analysis of European and US Products	Nick Molden, Ph.D., Emissions Analytics
(e)	Blending Consumer Air Quality Sensor Data with Regulatory Monitoring Data to Reduce Exposure to Poor Air Quality	Scott Epstein, Ph.D., Program Supervisor**
(f)	Feedback and Discussion	Advisors and Experts
(g)	Public Comment (2 minutes/person)	

1.	**Alternative Power Generation** **11:00 AM – 12:30 PM**	
(a)	Challenges in Deploying Heavy-Duty Charging Infrastructure	Sam Cao, Ph.D., Program Supervisor*
(b)	Hyliion Overview and KARNO Generator	Bobby Cherian, Hyliion
(c)	Renewable Power Anytime, Anywhere	Craig Klaasmeyer, Kaizen Clean
(d)	Feedback and Discussion	Energy Advisors and Experts
(e)	Public Comment (2 minutes/person)	
	Lunch **12:30 PM – 1:30 PM**	
2.	**Vehicle Technologies** **1:30 PM – 3:00 PM**	
(a)	Vehicle Electrification Technologies	Seungbum Ha, Ph.D., Program Supervisor*
(b)	Electric-powered Trailer for Heavy-Duty Vehicles	Bert Kaufman, Range Energy
(c)	Hydrogen Internal Combustion Engines	Jim Nebergall, Cummins
(d)	DEUTZ Solution Park – H2	Christoph Scholtes, DEUTZ
(e)	Feedback and Discussion	Advisors and Experts
(f)	Public Comment (2 minutes/person)	
3.	**Wrap-up** **3:00 PM – 3:45 PM**	
(a)	2024 Clean Fuels Plan Update & Wrap-up	Vasileios Papapostolou, Sc.D., Technology Demonstration Manager*
(b)	Advisor and Expert Comments	All
(c)	Public Comment (2 minutes/person)	

* South Coast AQMD Technology Advancement Office
** South Coast AQMD Planning, Rule Development, and Implementation Division

Other Business
Any member of the Advisory Group, or its staff, on his or her own initiative or in response to questions posed by the public, may ask a question for clarification; may make a brief announcement or report on his or her own activities, provide a reference to staff regarding factual information, request staff to report back at a subsequent meeting concerning any matter, or may take action to direct staff to place a matter of business on a future agenda. (Gov't. Code Section 54954.2)

Public Comment Period
At the end of the regular meeting agenda, an opportunity is provided for the public to speak on any subject within the Advisory Group's authority that is not on the agenda. Speakers may be limited to two (2) minutes each.

Document Availability
All documents (1) constituting non-exempt public records; (ii) relating to an item on the agenda for a regular meeting; and (iii) having been distributed to at least a majority of the Advisory Group after the agenda is posted, are available by contacting Donna Vernon at 909-396-3097 from 7:00 a.m. to 5:30 p.m., Tuesday through Friday, or send the request to dvernon@aqmd.gov.

Americans with Disabilities Act
Disability and language-related accommodations can be requested to allow participation in the Clean Fuels Program Advisory Group meeting. The agenda will be made available, upon request, in appropriate alternative formats to assist persons with a disability (Gov't Code Section 54954.2(a)). In addition, other documents may be requested in alternative formats and languages. Any disability or language-related accommodation must be requested as soon as practicable. Requests will be accommodated unless providing the accommodation would result in a fundamental alteration or undue burden to South Coast AQMD. Please contact Donna Vernon at 909-396-3097 from 7:00 a.m. to 5:30 p.m., Tuesday through Friday, or send the request to dvernon@aqmd.gov.

INSTRUCTIONS FOR ELECTRONIC PARTICIPATION

Instructions for Participating in a Virtual Meeting as an Attendee
As an attendee, you will have the opportunity to virtually raise your hand and provide public comment.

Before joining the call, please silence your other communication devices such as your cell or desk phone. This will prevent any feedback or interruptions during the meeting.

Please note: During the meeting, all participants will be placed on Mute by the host. You will not be able to mute or unmute your lines manually.

After each agenda item, the Chairman will announce public comment.

Speakers will be limited to a total of three (3) minutes for the Consent Calendar and Board Calendar, and three (3) minutes or less for other agenda items.
A countdown timer will be displayed on the screen for each public comment.

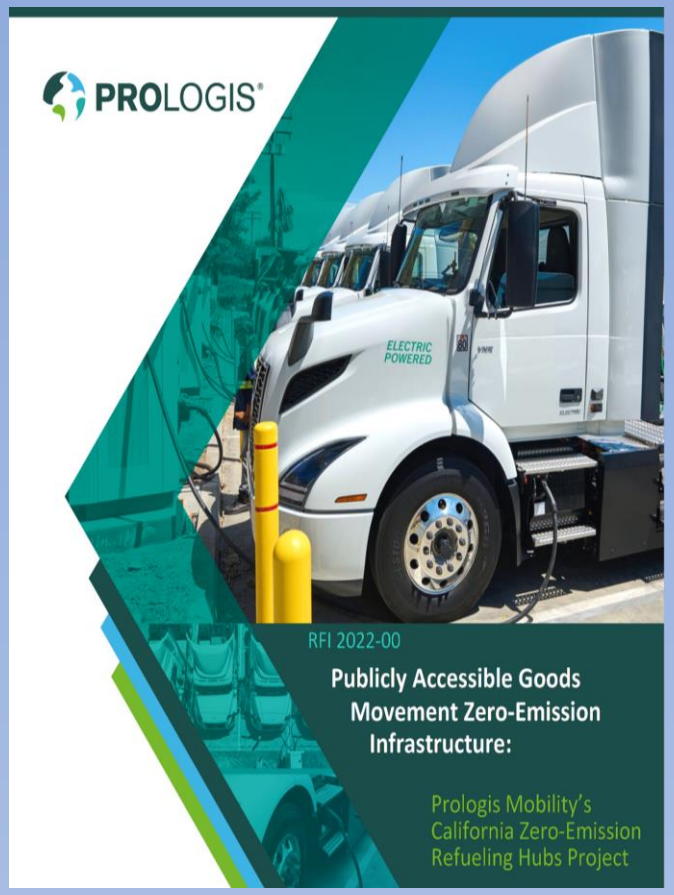
If interpretation is needed, more time will be allotted.

Once you raise your hand to provide public comment, your name will be added to the speaker list. Your name will be called when it is your turn to comment. The host will then unmute your line.

Directions for Video ZOOM on a DESKTOP/LAPTOP:
- If you would like to make a public comment, please click on the **"Raise Hand"** button on the bottom of the screen.
- This will signal to the host that you would like to provide a public comment and you will be added to the list.

Directions for Video Zoom on a SMARTPHONE:
- If you would like to make a public comment, please click on the **"Raise Hand"** button on the bottom of your screen.
- This will signal to the host that you would like to provide a public comment and you will be added to the list.

Directions for TELEPHONE line only:
- If you would like to make public comment, please **dial *9** on your keypad to signal that you would like to comment.

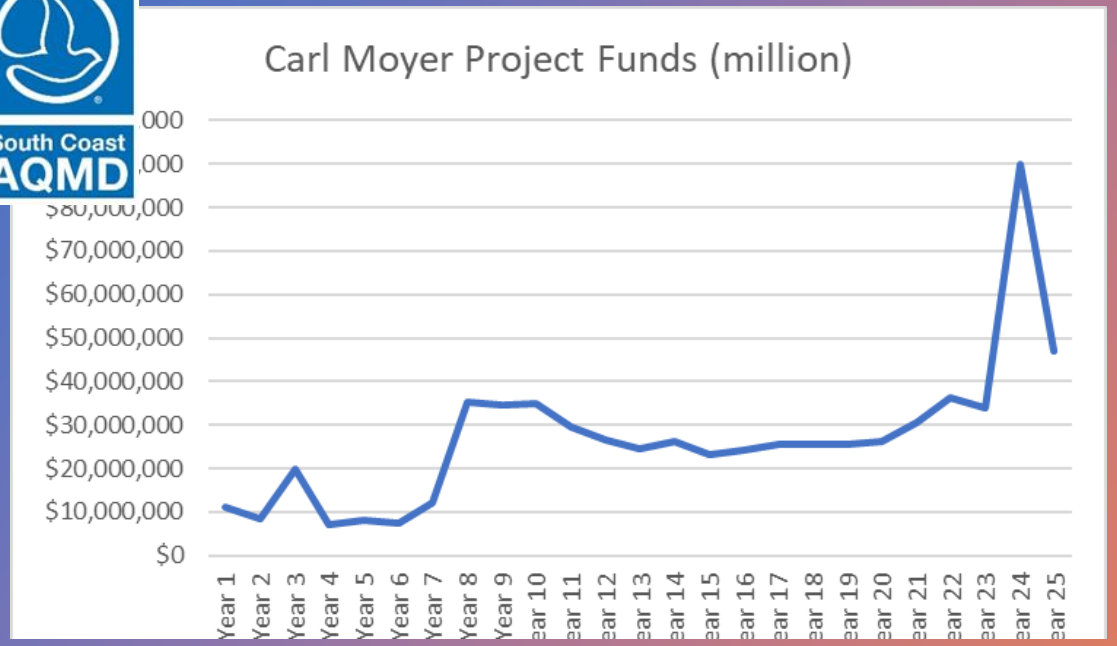


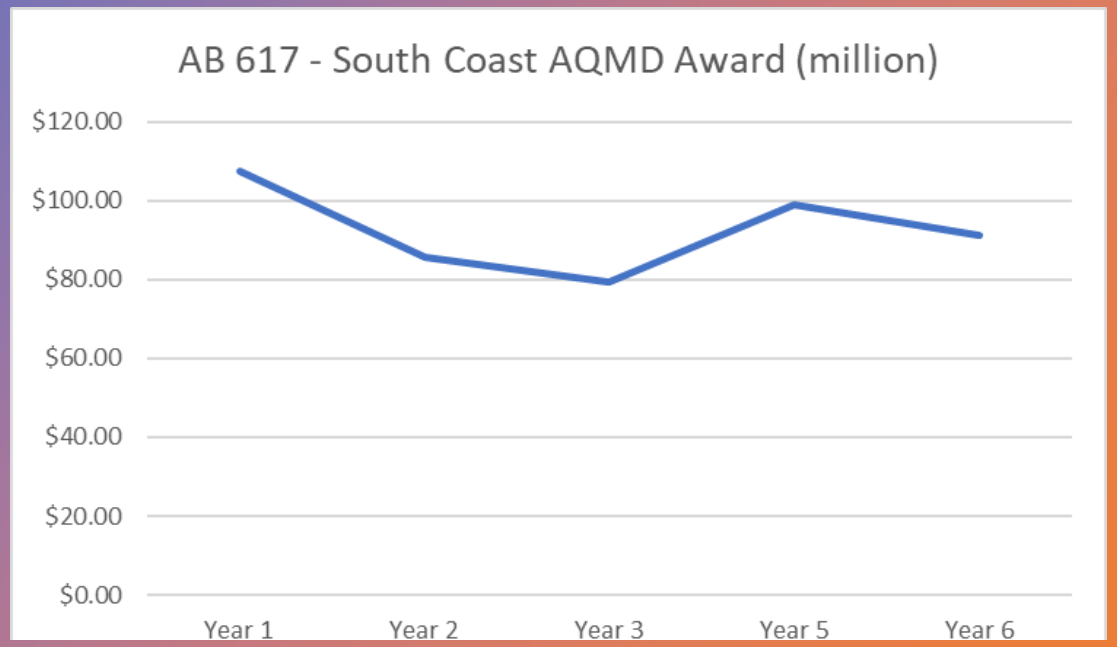
Grant Updates and Opportunities

Mei Wang

Assistant Deputy Executive Officer

South Coast AQMD





Technology Advancement Office
Incentive Funding Overview

- Carl Moyer (~$45M)
  - Established in 1998
  - Initial funding of $11M
  - AB1274 provided funding increase
- Community Air Protection Program ($190M)
- Clean Cars 4 All ($40M)
- FARMER ($700K)
- Prop 1B ($500M total)

Technology Demonstration Funding Sources

- Clean Fuels Program Fund (~$13M annually)
- CEC
- DOE
- EPA
- CARB
- DOT
- San Pedro Bay Ports Technology Advancement Program (TAP)
- MSRC
- Special funds

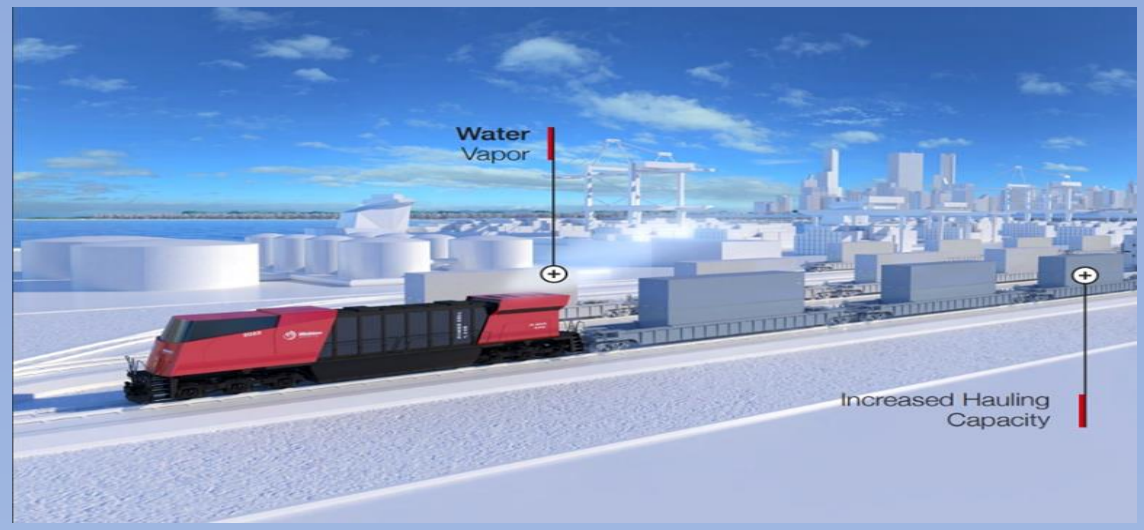
2022-2023 Awarded Demonstration Projects

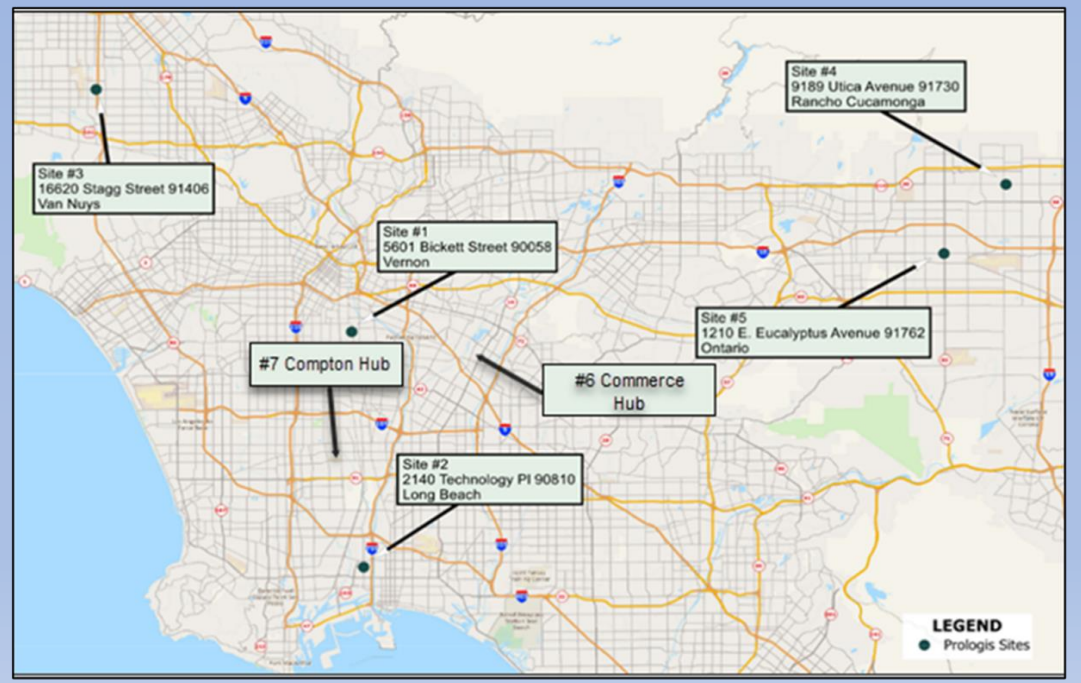
CalSTA- Port and Freight Infrastructure Program (PFIP) Grant

Freight Air Quality Solutions

Award: $76,250,003

- Hydrogen Fuel Cell Short Line Locomotive for Cargo Transport
  - Partner: Wabtec
  - Project cost: $42 million
  - Completion:2028
- 376 DCFC installation and 19 H2 dispensers
  - Partner: Prologis
  - Project cost: $195 million
  - Completion: 2025
  - Onsite generation and battery storage





2022-2023 Awarded Demonstration Projects

EPA Targeted Airshed Grants Program (TAG)

Awards: $16M

- Plug-in Hybrid Tugboat with Hydrogen Fuel Cell powered charging system
  - Partners: Crowley
  - Project cost: $43.5M
  - Completion:2025
- Commercializing Heavy-Duty Fuel Cell trucks
  - Partners: Daimler Trucks North America, Cummins Inc., Shell and Penske Truck Leasing
  - Project cost:$6.9M
  - Completion: 2026
- Battery Electric Asphalt Compactors
  - Partners: Volvo Technology of America
  - Project cost: $1.9M
  - Completion:2024

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2022-2023 Awarded Demonstration Projects

EPA Clean Air Initiative (CATI) Awards

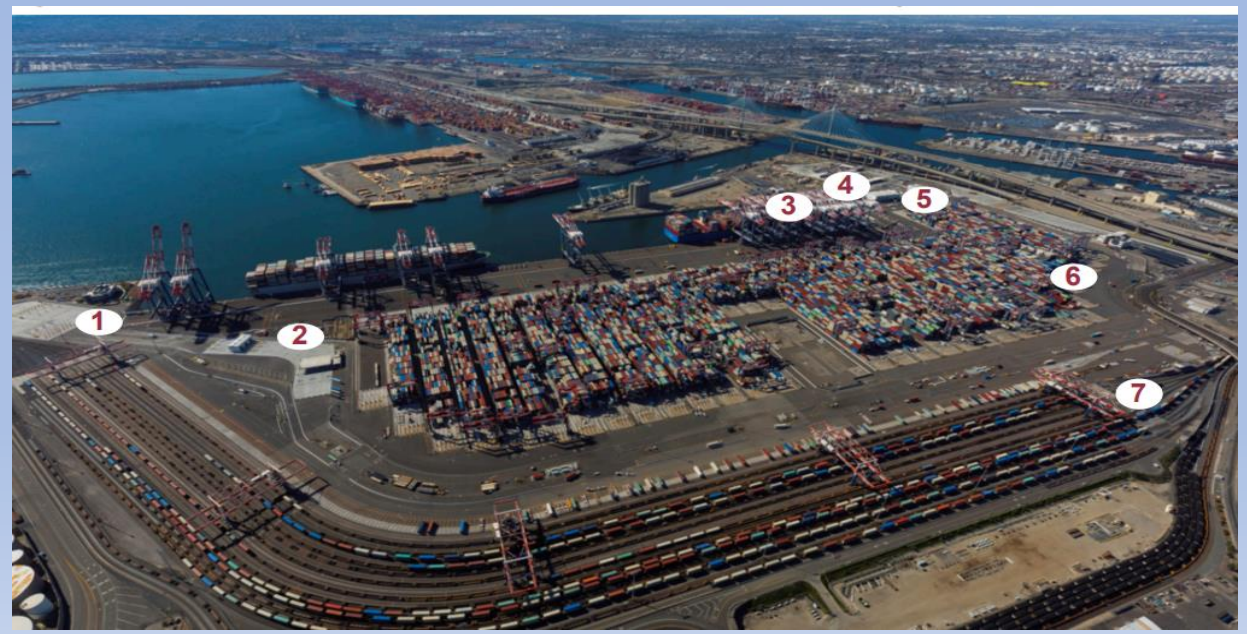
- Breathmobile Deployment
  - Partners: Arrowhead Regional Medical Center
  - Project cost: $1.2M
  - Completion: 2024

- ZE Power Take Off System for MD Work truck Demonstration
  - Partners: Odyne, LADWP, Edison
  - Project cost: $1.1M
  - Completion: 2024

2022-2023 Proposed Technology Demonstration Projects

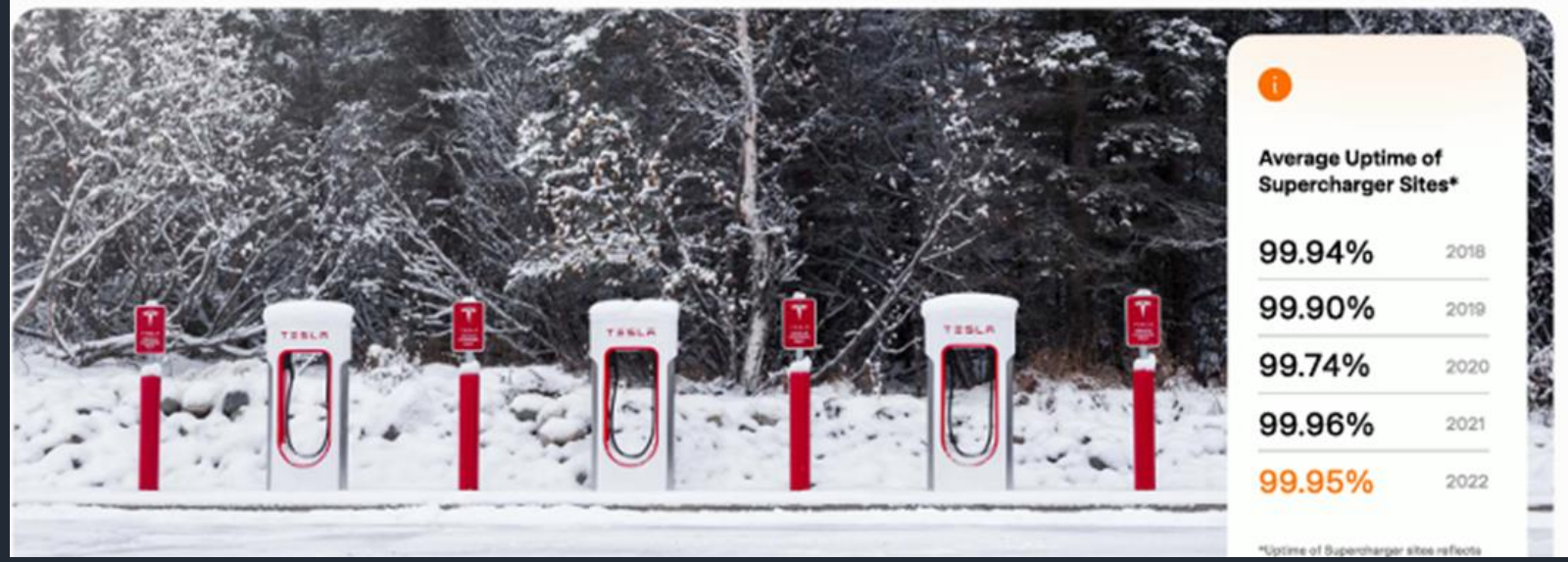
Port Infrastructure Development Program (PIDP) Maritime Administration

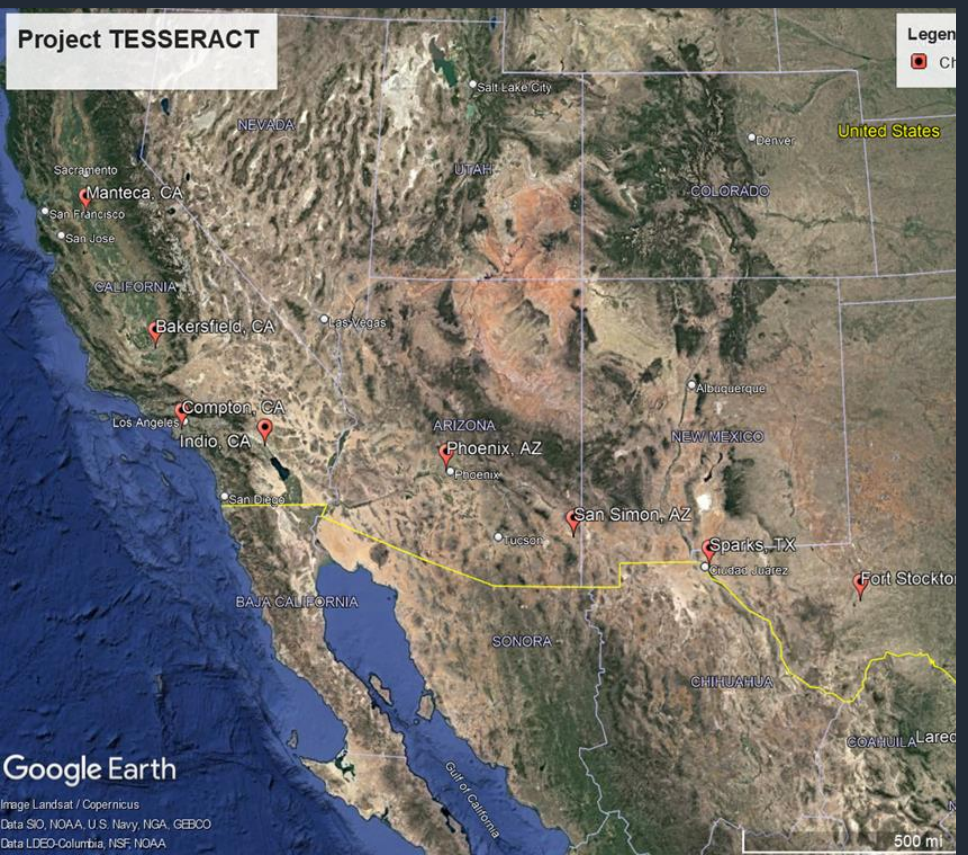
- Installation of electric charging units and electric infrastructure needed to complete the nation's first full zero-emission (ZE) terminal.
- Partner: Long Beach Container Terminal
- Cost: $85M (requested $68M)
- Completion: 2027



2022-2023 Proposed Technology Demonstration Projects

Charging and Fueling Infrastructure Grant (Federal Highway Administration)





- TESSERACT-Transport Electrification Supporting Semi Operating in AZ, CA and TX
- Installation of 72 750-kW DCFC and 36 250-kW CCS-1, BESS
- Partner: Tesla
- Cost: $127M (requested $97M)
- Completion: 2027

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2022-2023 Proposed Technology Demonstration Projects

Charging and Fueling Infrastructure Grant (Federal Highway Administration)

West Coast Truck Charging and Fueling Corridor Project

- Multistate project supports ZE truck deployment along the major freight centers across California, Oregon and Washington
- Partners: CEC, CalTrans, WA, OR, POLA, POLB, MSRC, City of LA

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Upcoming Grant Opportunities

Current Notices of Funding Opportunities:

- CARB Advanced Technology Demonstration and Pilot Projects (Due 10/12/23): $225M
- EPA DERA National Program (Due: 12/1/2023): $115M

Upcoming NOFOs Pending Release:

- FRA CRISI (Fall 2023)
- EPA Climate Pollution Reduction Implementation Grants (September 2023):$4.6B
- EPA Reduction of Air Pollution at Ports (2024):$3B
- EPA Clean heavy-Duty Vehicles (2024):$1B
- 2023 EPA Target Airshed Grant Program (NOFO likely 2024):$66M

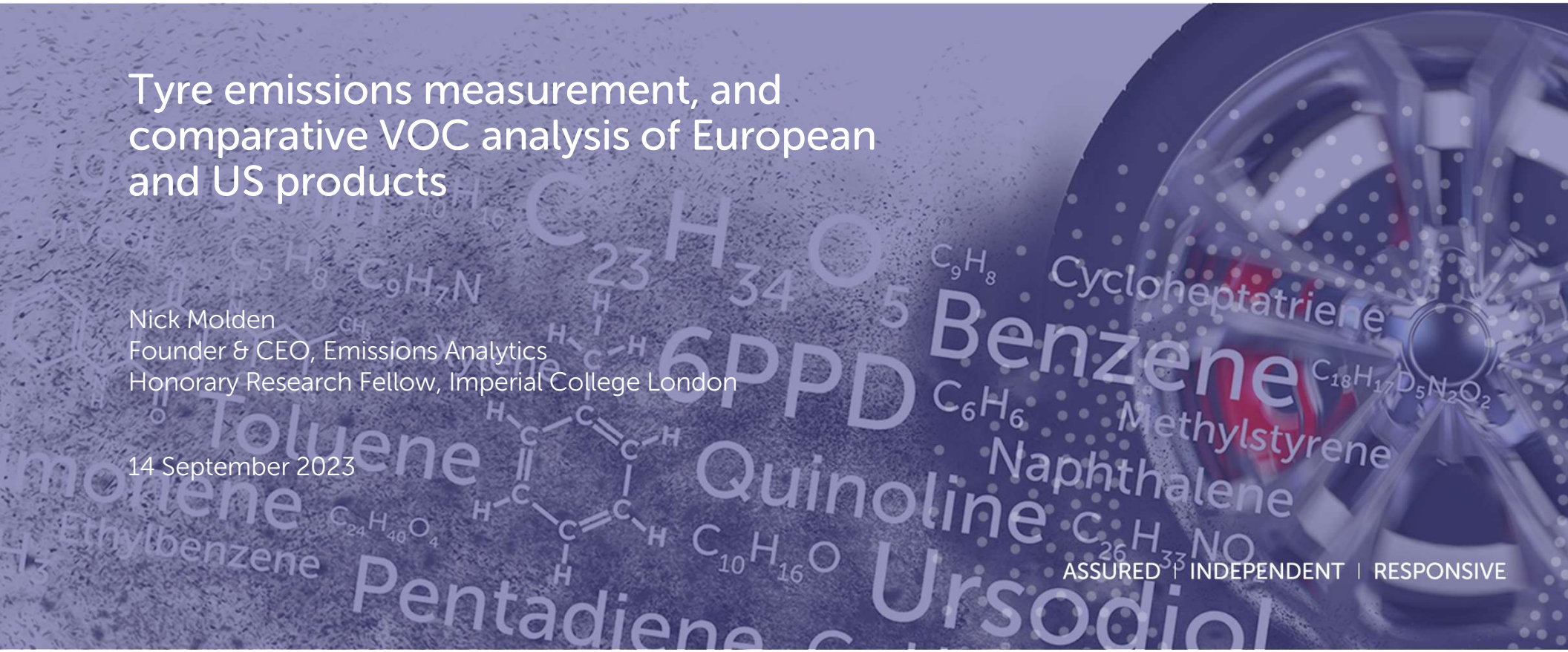
Questions

EMISSIONS ANALYTICS

Tyre emissions measurement, and comparative VOC analysis of European and US products

Nick Molden
Founder & CEO, Emissions Analytics
Honorary Research Fellow, Imperial College London

14 September 2023



Agenda

- How prevalent are tyre wear emissions?
- To what extent do they include micro plastics?
- What are their health and environmental effects?
- What is the chemical profile of tyres?
- How do European and US tyres compare?
- What are the options for reducing the impact?

The issue

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Omnipresence of tyre wear emissions

- 6 million tonnes of tyre wear globally per year
- Or 4 kg per car per year
- Excluding 1-2 billion end-of-life tyres per year
- Ultrafine particles (<100 nm) are airborne before eventually settling
- Fine particles settle on soil close to roadway
- Larger particles wash into the drainage system
- Multiple vectors for human inhalation or ingestion
- 135 ng of 6PPD and 6PPD-quinone in urine of average adult per day

Rapidly declining tailpipe emissions

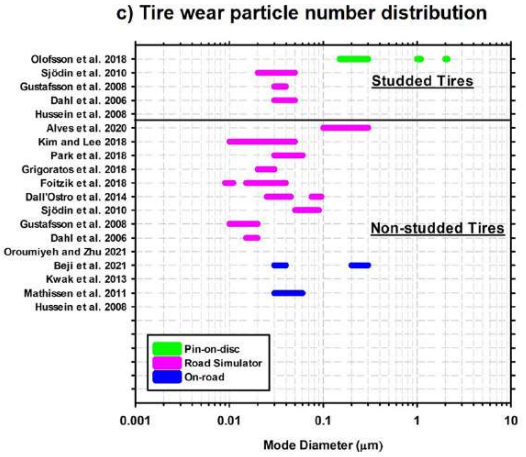
- 37 mg/km tyre wear is x8 maximum permissible tailpipe mass emissions
- 0.02 mg/km is actual, real-world tailpipe mass emissions from latest cars
- Tyres are x1,850 times more polluting on this measure

Ultrafine particles from tyres

- On-road test with ‘normal’ dynamics
- 11% of fine particle mass is below 2.5 µm diameter
- This mass accounts for almost 100% of particle number
- And ultrafines account for 92% by number
- Other potential source of ultrafines is from combustion, but influence from other vehicles eliminated
- Results borne out in academic literature

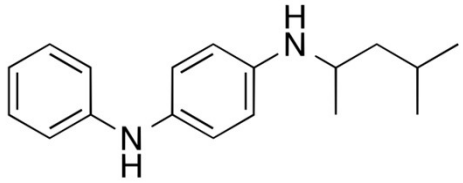
➢ Tyres are simultaneously a problem for air, soil and water

Particulate mass	mg/km
PM 10	36.5
PM 2.5	4.1
PM 2.5 proportion of PM 10	11%
Ultrafine proportion of PM 10	0%
Particulate number	**# x10^{11}/km**
Down to 23 nm	1.1
Down to 6 nm	14.5
Fine as proportion of PM 10	8%
Ultrafine as proportion of PM 10	92%

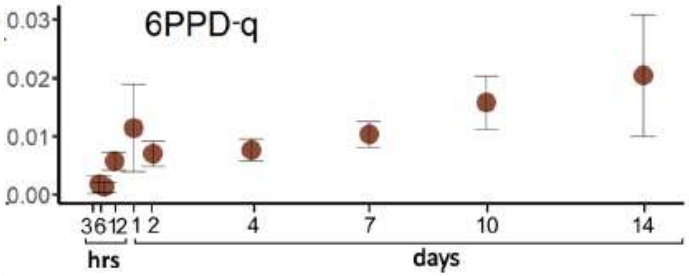


Derivative products

- Formation of 6PPD-quinone by oxidation of 6PPD preservative
- 6PPD-quinone killing coho salmon and trout in US
- Absorbed through roots of lettuce

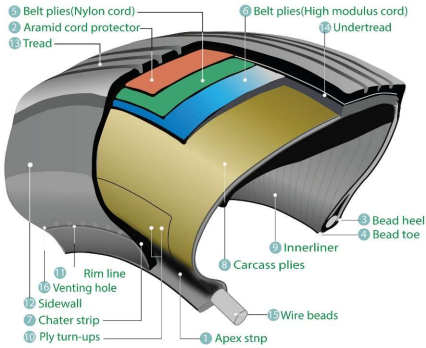


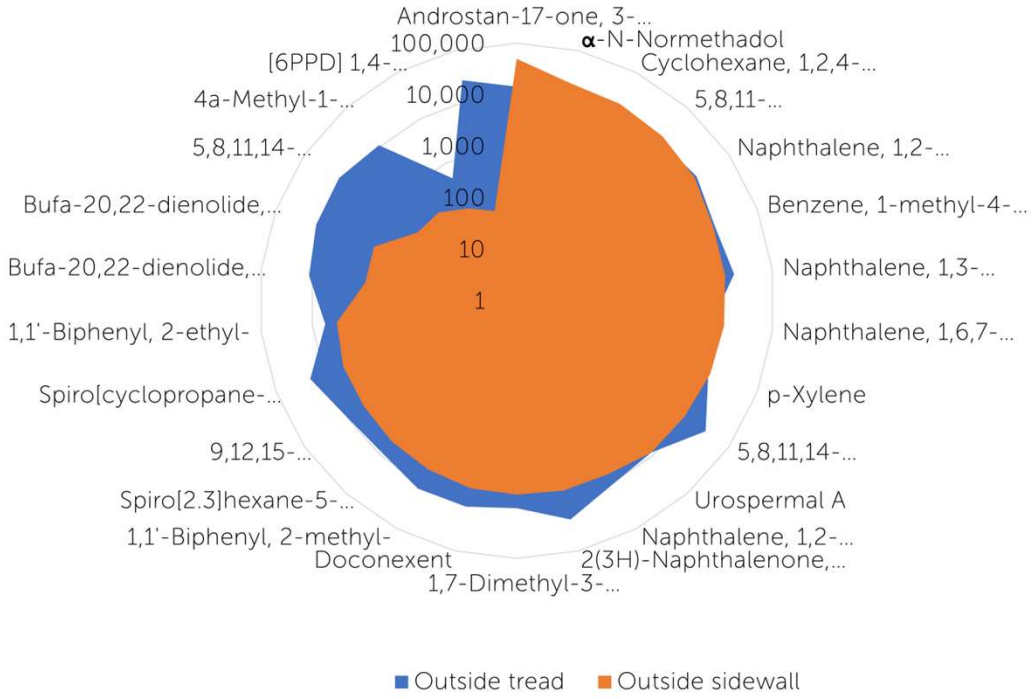
N-(1,3-dimethylbutyl)-N'-phenyl-p-phenylenediamine, aka 6PPD



Secondary pollutants

- Secondary organic aerosol formation from off-gassed VOCs reacting in air
- Mainly from tyre sidewall, which can be different chemical composition from tread
- SOA Yield of 4.01 μg/m^3 from toluene in recent research in Shanghai





BTAS brake and tyres analysis system

Experimental approach

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Concept

Tyre wear rate

x

Chemical speciation

x

Compound hazard

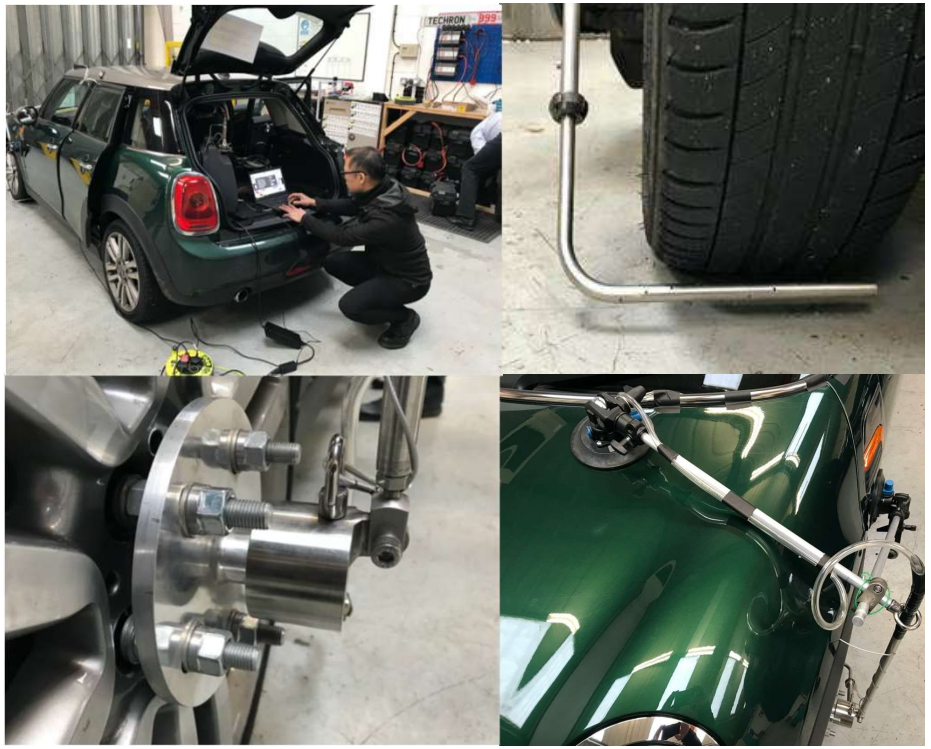
=

Potential environmental impact

On-vehicle sampling – principles

- Universal fitment across vehicles
- Fits to any and all wheels on a vehicle
- No vehicle modification required
- Articulates as the vehicle steers
- Safe and road-legal
- Can be coupled with any detector
- And collecting plates/receptacle
- Patent-pending

➢ Mass, number and physical collection



BTAS brake and tyres analysis system

Chemical fingerprinting

- Two-dimensional gas chromatography with mass spectrometry
- INSIGHT flow modulator from SepSolve Analytical for separation
- BENCH-TOF time-of flight mass spectrometer
- Multi-stage pyrolysis method

Pyrolysis sampling

- *Are the compounds measured really in the originally tyre?*
- *Does the high temperature of the pyrolysis lead to compounds breaking down?*

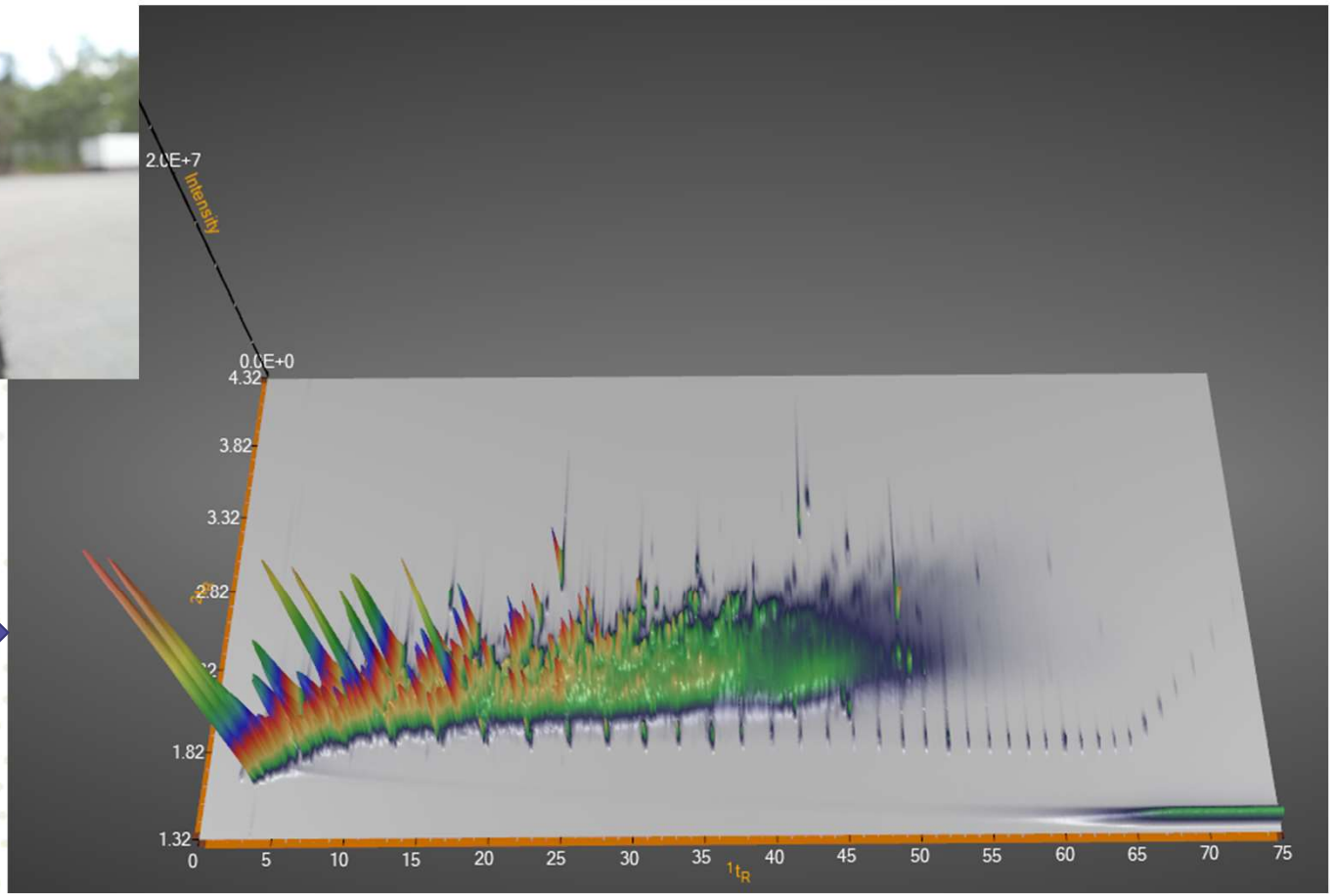
- Due to the very rapid heating and then flushing out of the hot zone, the pyrolysates are likely to remain unchanged, with secondary reactions and pyrolysate aggregation occurring rarely (Shin Tsuge, 2012) (Xiao-Ming Ma, 2014).
- The degradation process is useful for understanding the structure of the polymer but also for determining what smaller molecules could possibly be formed and for example, leach into the environment (Ladak, 2021) (Greta Biale, 2021).

Method development

- Objective to determine all compounds in tyre as sold to user
- Estimate potential to leach organic chemicals over time
- Quantification of measurement uncertainty – National Physical Laboratory, UK
- Required development of specialist spectral library
- Peer reviewed

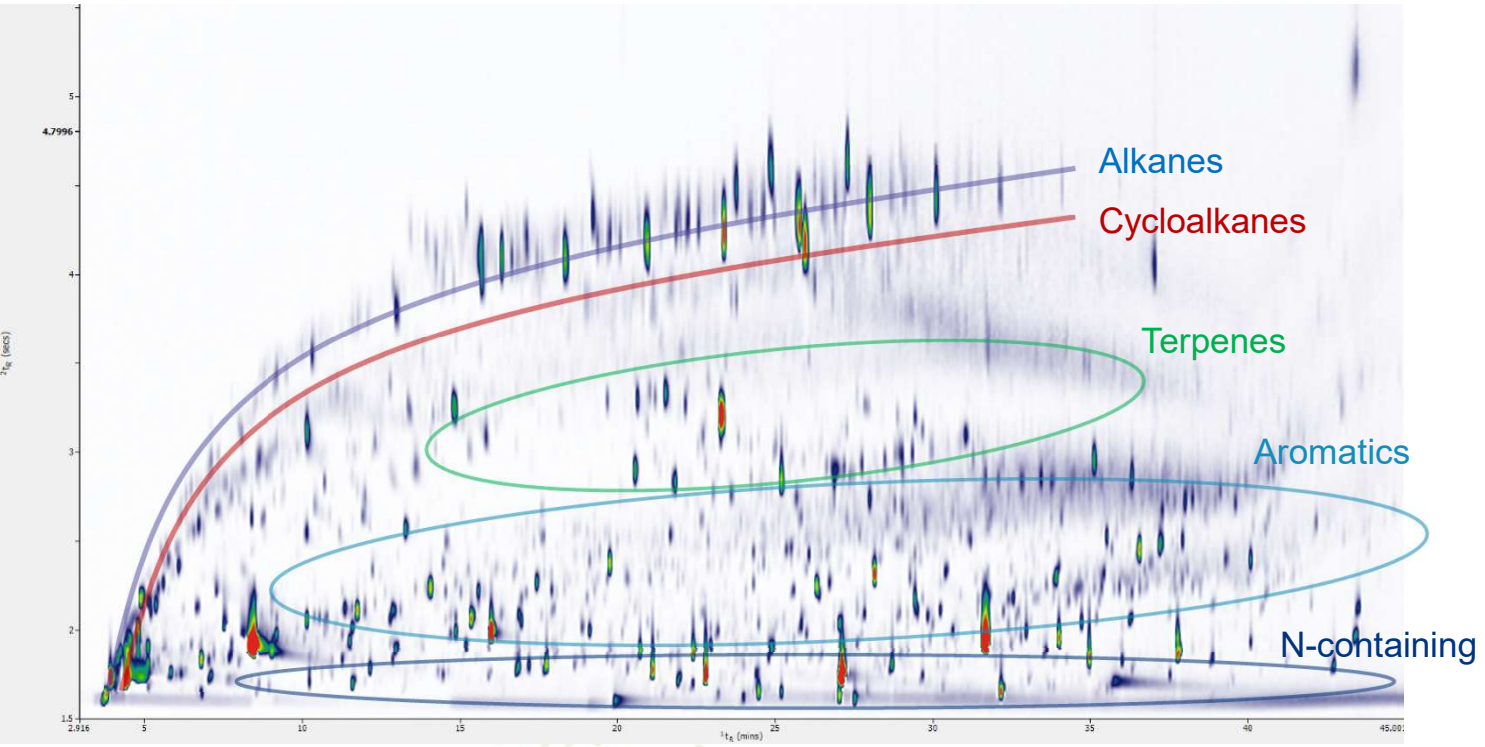
➢ Allow fair comparison between different tyres

Two-dimensional pyrolysis chromatogram



BTAS brake and tyres analysis system

Functional group classification



- Wide-ranging analytes identified

- Alkanes: lungs, liver, kidney, brain
- Cycloalkanes: headaches, dizziness
- Terpenes: aromas
- Aromatics: carcinogens
- N-containing: carcinogens

BTAS brake and tyres analysis system

Hazards

Hazard code	Description
H300	Fatal if swallowed
H301	Toxic if swallowed
H302	Harmful if swallowed
H303	May be harmful if swallowed
H304	May be fatal if swallowed and enters airways
H305	May be harmful if swallowed and enters airways

- Globally Harmonized System of Classification and Labelling of Chemicals (GHS) – United Nations' standardised system
- Compounds identified CAS Registry Number, unique identifier assigned by US Chemical Abstracts Service
- European Chemicals Agency database of manufacturer disclosures
- 'Hazard codes' describe different effects, from irritants to carcinogens
- Each compound can have multiple hazard codes
- Which can be weighted together using a severity index

$$\text{Overall toxicity factor} = \sum_{i=1}^{n} \text{Number of hazard codes}_i \times \text{Compound concentration in sample (µg/mg)}_i$$

Tyre wear results

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Comparative tyre wear results

- 18 different models of tyre
- Tested from new
- 90% motorway driving by distance
- Public highway
- Average total distance 3,300 miles

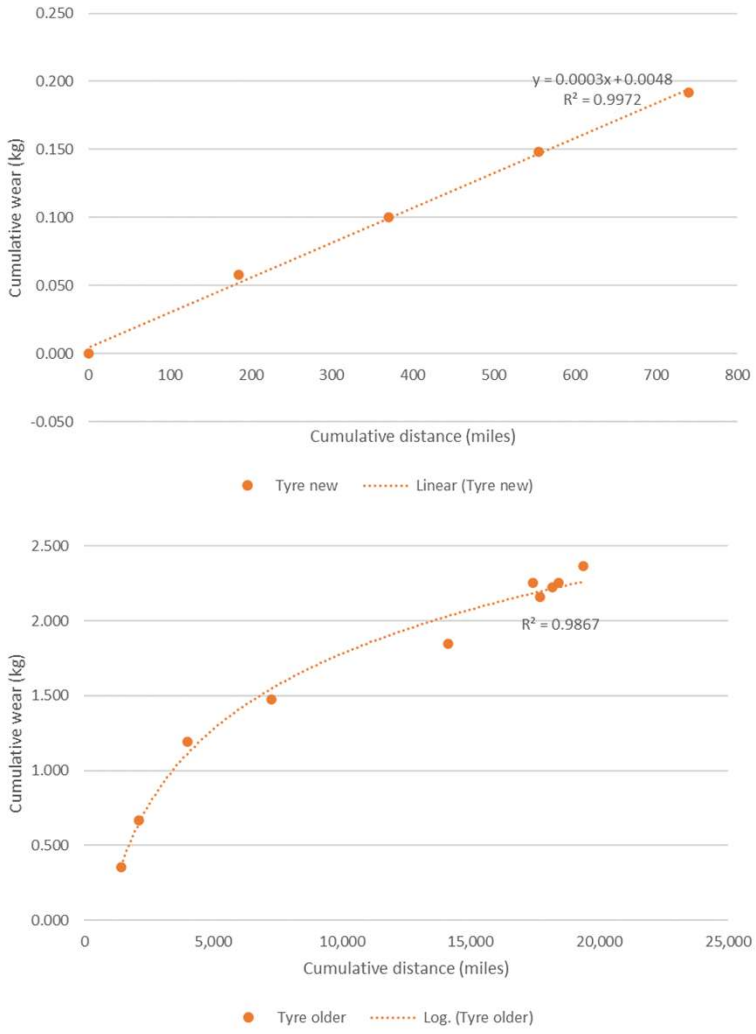
- 108 mg/mile mean

Tire #	Manufacturer	Wear rate (mg/km)
1	Continental	161
2	Michelin	61
3	Sumitomo	38
4	Firestone	73
5	Avon	45
6	Kumho	75
7	Yokohama	89
8	Goodyear	75
9	Apollo	61
10	Kumho	51
11	Michelin	81
12	Hifly	76
13	Kumho	17
14	Rotola	66
15	Taurus	70
16	Bridgestone	46
17	Nankang	87
18	Snow Road	44
	Average	**67**

BTAS brake and tyres analysis system

Longitudinal results

- Continental Contisport 6 tyres on Mercedes C-Class/unladen
- Tyres tested from new
- Wear rate linear up to ~1,000 km
- Then approximately logarithmic trend up to ~30,000 km
- Shape of cumulative wear differs between models



Regional differences

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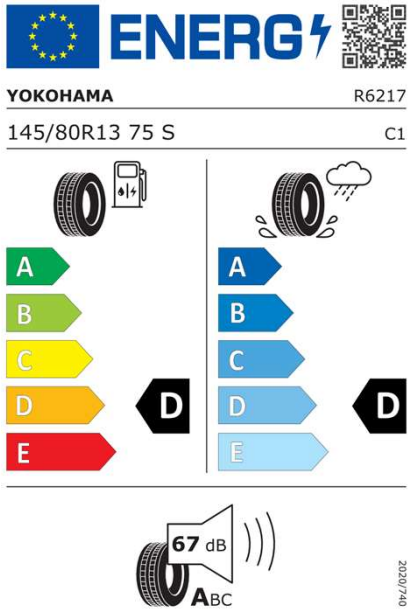
EQUA real-world test database

Regional labelling

- Official tyre labels exist in multiple regions
- Current focus on rolling resistance, grip, weather and noise in Europe
- Closest proxy is ‘tread wear rating’ in US
- Fuel economy is pre-eminent consideration in Europe
- Compared to durability in the US

➢ Differences likely to be seen in composition of tyres between regions



Comparison by target market – light duty

- 228 tyres analysed across Europe and North America
- Sourced from retail outlets
- Vent sprues from unused tyres
- Significantly lower aromatic content in US tyres, with lower toxicity potential
- Fewer alkanes in US tyres, but higher toxicity potential on average

	Europe	North America	Variance
Tyres analysed	185	43	
Average aromatics concentration (ng/mg)	226,021	94,181	-58%
Human toxicity potential	42	26	-38%
Marine toxicity potential	4	2	-37%
Average alkanes concentration (ng/mg)	123,907	70,354	-43%
Human toxicity potential	20	24	17%
Marine toxicity potential	3	3	-13%

BTAS brake and tyres analysis system

Comparison by target market – heavy duty

- 55 tyres analysed
- Sourced from retail and New York City authorities
- Less aromatics and alkanes in US tyres
- High marine toxicity potential from US tyres, but mixed effects on human health

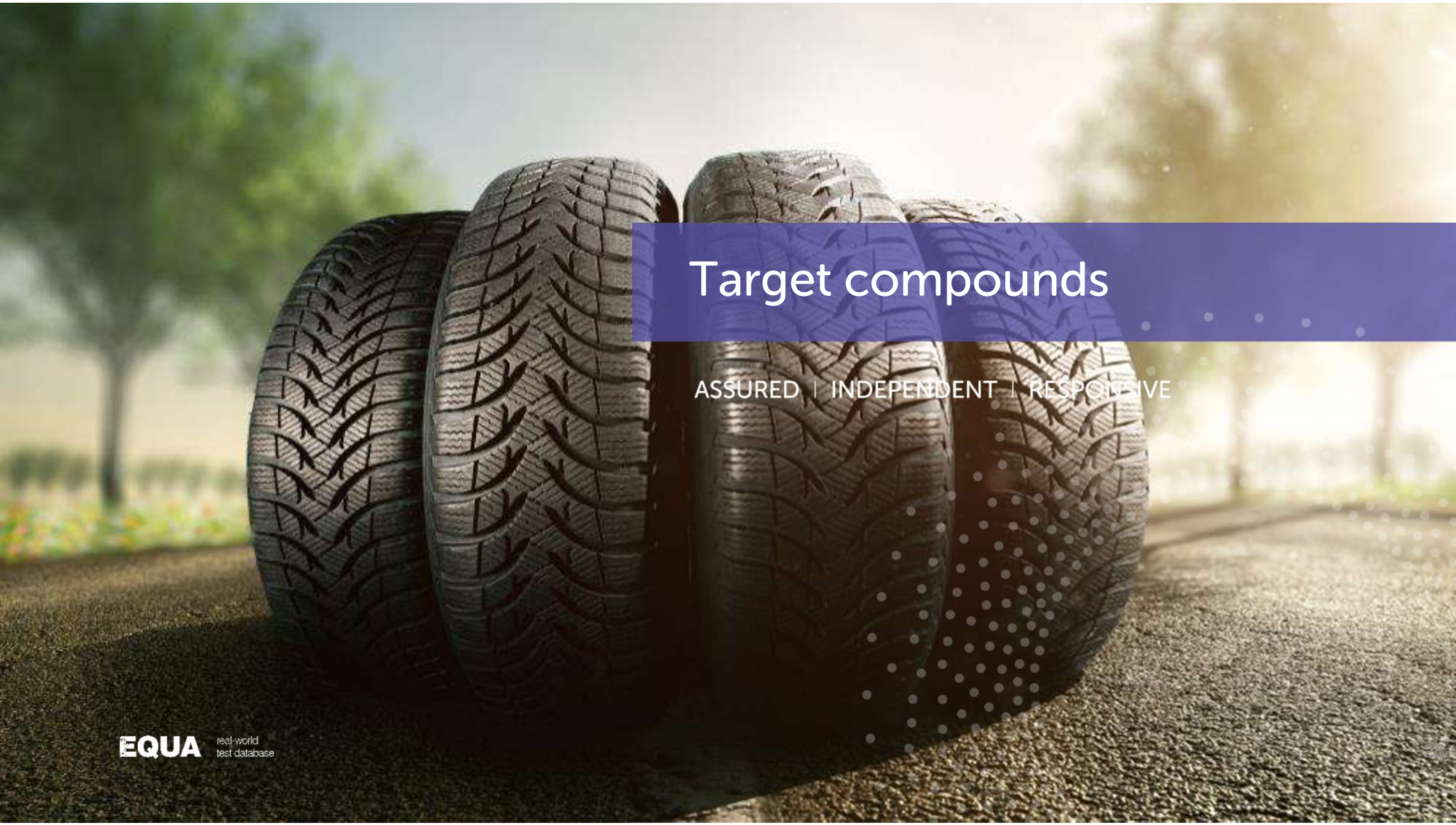
	Europe	North America	Variance
Tyres analysed	16	39	
Average aromatics concentration (ng/mg)	95,142	64,122	-33%
Human toxicity potential	26	21	-20%
Marine toxicity potential	2	2	14%
Average alkanes concentration (ng/mg)	133,963	100,328	-25%
Human toxicity potential	26	34	34%
Marine toxicity potential	4	4	13%

BTAS brake and tyres analysis system

Aromatics by manufacturer– light duty

- Segmenting by manufacturer to achieve closer to like-for-like comparison
- Compound data available from both regions for 7 OEs
- One-third less aromatics in US tyres, but varies

ng/mg	Europe	North America	Variance
Bridgestone	111,252	99,670	-10%
Continental	183,670	111,757	-39%
Dunlop	98,757	95,704	-3%
Goodyear	217,062	92,521	-57%
Hankook	111,974	90,577	-19%
Kumho	182,072	90,015	-51%
Michelin	235,297	108,862	-54%
Average	**162,869**	**98,444**	**-33%**


Target compounds
ASSURED | INDEPENDENT | RESPONSIVE
EQUA
real-world
test database

Compounds of concern – marine

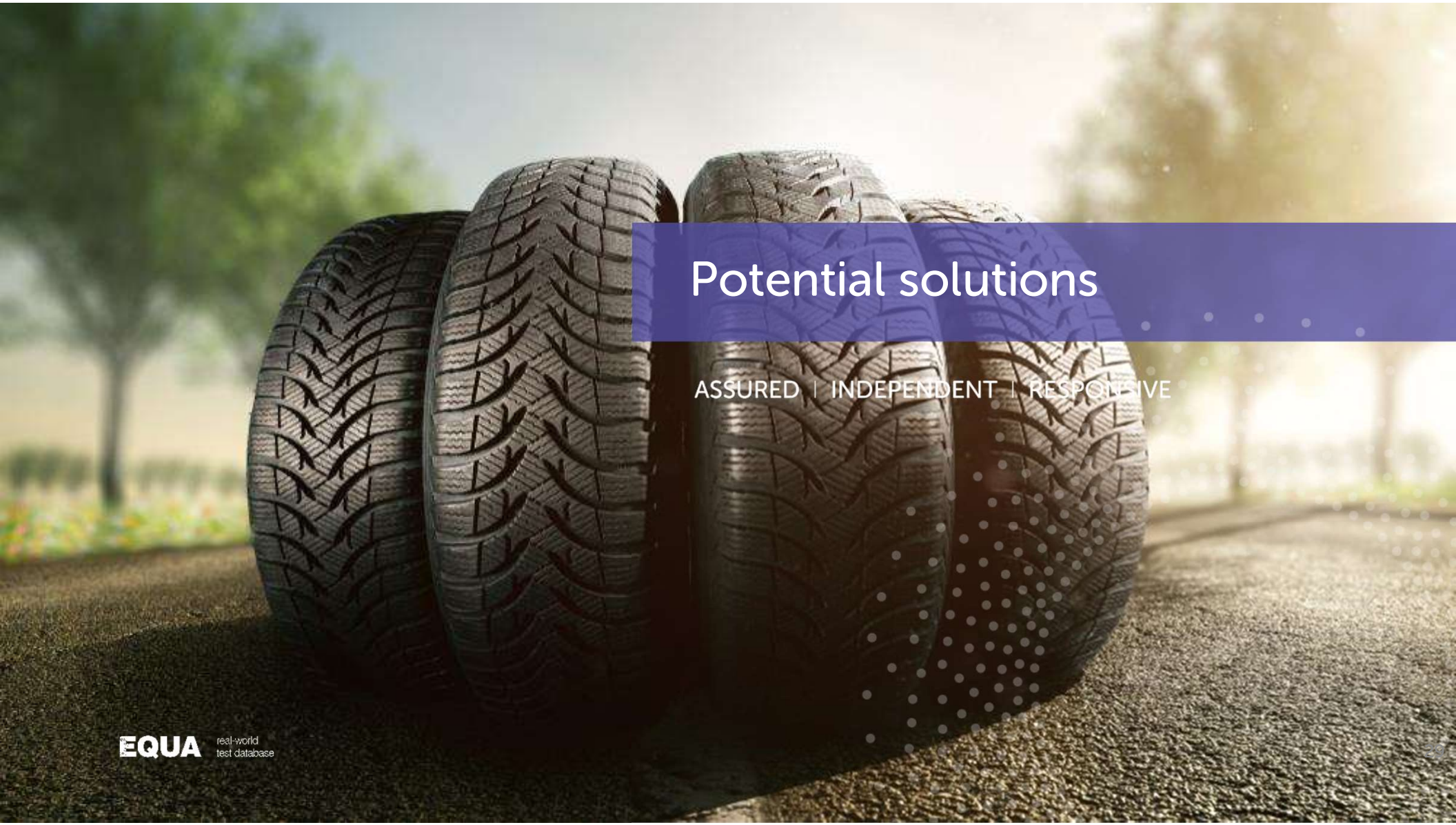
- Target compounds in tyres – sources including ChemSec SIN list, REACH, PEWS
- Average concentration of compound, where present in at least 10 European tyres
- Thousands of potential concerns can be seen at low concentrations
- 6PPD is not the only compound of concern for marine life

Compound name	Chemical formula	Europe average concentration (ng/mg)	American average concentration (ng/mg)	Potential effects - aquatic	Other potential effects - human
N-(1,3-dimethylbutyl)-N'-phenyl-p-phenylenediamine	$C_{18}H_{24}N_2$	531	513	Very toxic, long-lasting	Human fertility, skin irritation
Dimethylselenide	C_2H_6Se	305		Very toxic, long-lasting	Toxic if inhaled, swallowed; organ damage
Naphthalene	$C_{10}H_8$	229	117	Very toxic, long-lasting	Harmful if swallowed; suspected carcinogen
Fluorene	$C_{13}H_{10}$	152	140	Very toxic, long-lasting	
1,2-dihydro-2,2,4-trimethylquinoline	$C_{12}H_{15}N$	148	53	Toxic, long-lasting	Harmful if swallowed
N-isopropyl-N'-phenyl-p-phenylenediamine [IPPD]	$C_{15}H_{18}N_2$	101		Very toxic, long-lasting	Harmful if swallowed; skin irritation
Chrysene [CHR]	$C_{18}H_{12}$	100		Very toxic, long-lasting	Potential carcinogen; suspected genetic effects
Retene [RET]	$C_{18}H_{18}$	29	1,083	Very toxic, long-lasting	

Compounds of concern – human

- Pattern of compounds of concern very different between Europe and America

Compound name	Chemical formula	Europe average concentration (ng/mg)	American average concentration (ng/mg)	Potential effects - human	Other potential effects - aquatic
Benzene, 1,3-dimethyl-	C_8H_{10}	2,352		May be fatal if swallowed or inhaled; serious eye, respiratory irritation	Harmful, long-lasting
p-Xylene	C_8H_{10}	2,142	210	May be fatal if swallowed or inhaled; serious eye, respiratory irritation	Harmful, long-lasting
Benzene	C_6H_6	1,077	171	May be fatal if swallowed or inhaled; organ damage; potential carcinogen; genetic effects; serious eye irritation	
Indene	C_9H_8	850	166	May be fatal if swallowed or inhaled; serious eye, skin irritation; suspected carcinogen	Toxic, long-lasting
Styrene	C_8H_8	681	30	May be fatal if swallowed or inhaled; eye, skin irritation; potential carcinogen	Harmful, long-lasting
Ethylbenzene	C_8H_{10}	269	520	Potential carcinogen; genetic effects; harmful if swallowed	Harmful, long-lasting
Acetonitrile cyanomethane	C_2H_3N	248	14	Toxic if swallowed, inhaled or skin contact; skin and eye damage; potential carcinogen	Toxic, long-lasting
Benzothiazole [BTZ]	C_7H_5NS	222	130	Toxic if swallowed, inhaled or skin contact; eye damage; organic damage	
Benzothiazole, 2-phenyl-	$C_{13}H_9NS$	77	197	Serious eye irritation	
2-(methylthio)benzothiazole [2-MTBT]	$C_8H_7NS_2$	33	97	Serious eye, skin and respiratory irritation	


Potential solutions
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EQUA
real-world
test database

Reduce wear rates

- Almost a factor of x10 from the slowest to fastest wearing models
- 28% reduction would be achieved by eliminating fastest wearing half of the market
- Need to consider trade-offs with safety, noise and efficiency
- Proposed Euro 7 vehicle certification includes placeholder for tyre wear limits
- Future introduction would put downward pressure on wear rates
- But with potential trade-off with increased toxicity

Reduce potential toxicity

- Opportunity to remove the highest potential toxicity products
- Any scoring system would need to be validated against toxicological experiments
- Chemical disclosure could be extended, building on ECHA work
- Specific, high-toxicity chemicals could be banned
- Manufacturers could be forced to consider alternatives – as in California
- Limit values could be set on target chemicals – as REACH already does
- Consumer labelling to influence demand

Next steps

- Automatic target screening
- Tracking and benchmarking latest formulations – especially “green” tyres
- Fingerprinting environmental samples – quantifying proportion of tyre material
- Optimising on-road sample collection
- Toxicological studies – underway with five universities

Tyre target lists

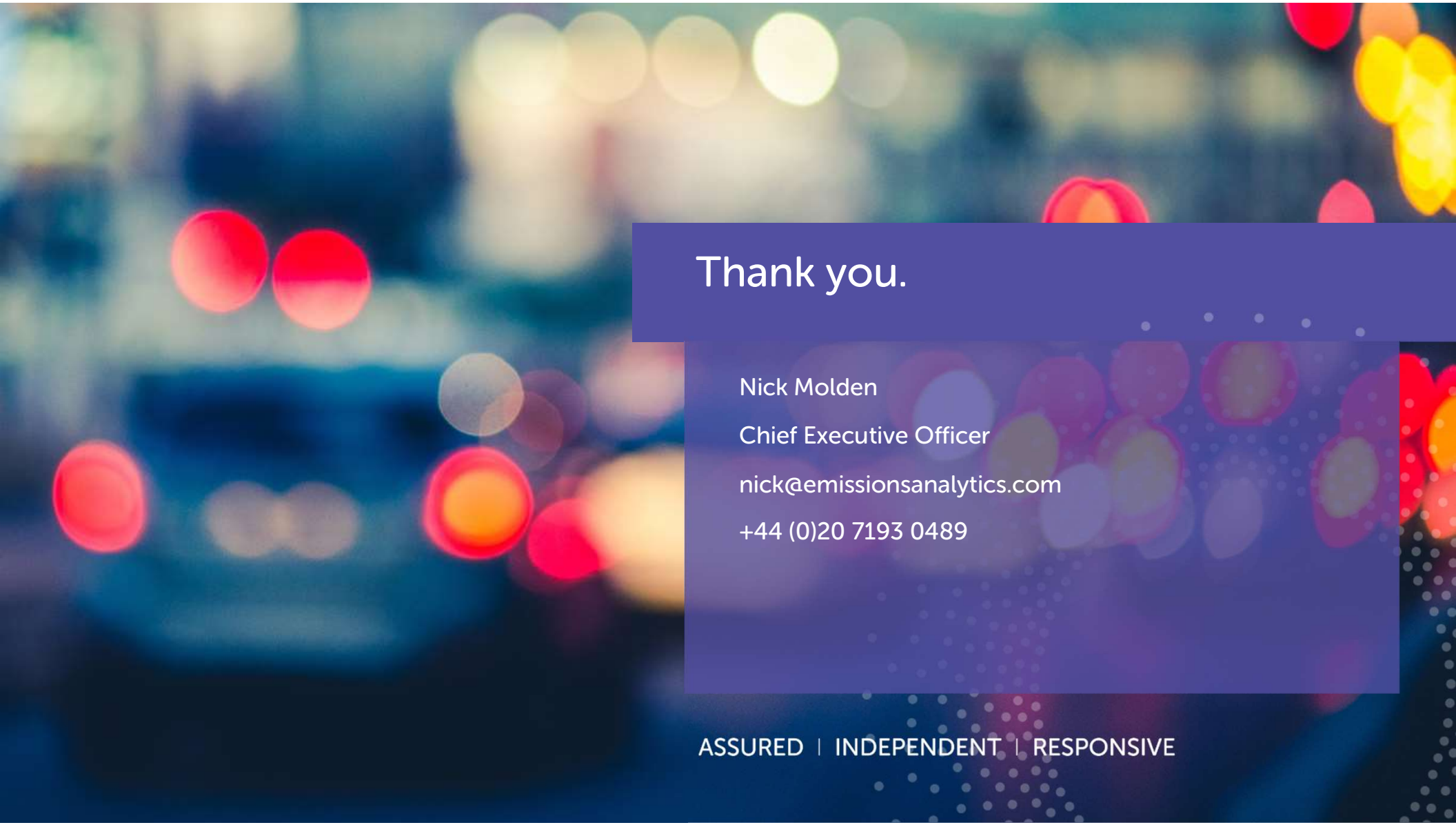
Target list	Concentration per tyre			Substances found per tyre
	Min	Avg	Max	Avg
	µg/mg	µg/mg	µg/mg	# (% of list)
Weighted average for all lists ?		*18.928*		*19 (7.13%)*
CalSAFER	3.827	34.877	110.296	29 (0.88%)
ChemSec SIN	0.032	4.808	56.798	8 (0.54%)
Emissions Analytics Toxicity	56.052	151.782	333.464	172 (4.61%)
EPA Hazardous Air Pollutants	0.435	22.566	84.113	10 (4.98%)
GADSL	0.123	13.665	83.932	13 (0.22%)
NORMAN TIRECHEM	0.018	0.839	3.866	2 (11.37%)
PEWS	0.038	2.165	37.163	4 (2.04%)
REACH	0.002	0.112	1.658	1 (13.39%)
TIP TRWP Markers	0.001	3.066	23.349	2 (58.08%)

Summary

- Tyre wear emissions are all around and inside us
- Encompassing larger and smaller particles, but tyres also off-gas VOCs
- Aromatics and alkanes are on average much lower in American tyres
- Likely to be deliberate to match market preferences
- Heavy duty tyres are lower in aromatics
- Averages hide large variances between tyre models

➢ Significant work still to do to improve on-vehicle collection, fingerprinting, environmental sampling and quantification

BTAS brake and tyres analysis system



Thank you.

Nick Molden

Chief Executive Officer

nick@emissionsanalytics.com

+44 (0)20 7193 0489

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Assured
Emissions testing in real-world conditions brings challenges that experience anticipates and expertise overcomes. We deliver.

Independent
Objectivity and candour are the driving forces in all our work, so you know the facts.

Responsive
We're fast on our feet so we can conduct emissions testing when and where we're needed.

EMISSIONS ANALYTICS

Our Belief

When it comes to the pursuit for improved air quality, we believe in the power of clarity, transparency and integrity. With real-world data we can meet emissions challenges – instilling trust and confidence in our industry partners and public.

It's with our commitment and independence we are able to make a significant contribution toward positive change and to achieve enduring results.

EMISSIONS ANALYTICS

Blending Consumer-Grade Air Quality Sensor Data with Regulatory Monitoring Data to Help Reduce Exposure to Poor Air Quality

Scott A. Epstein, Ph.D.
Program Supervisor

Nico Schulte, Ph.D.
Air Quality Specialist

Air Quality Assessment
Planning, Rule Development and Implementation
South Coast Air Quality Management District

Outline

- How real-time air quality is reported to the public
- Treatment of consumer-grade sensors
- Blending of regulatory monitoring data, sensor data, and model data
- How accurate is the AQI map?
- Ongoing improvements to the AQI Map

South Coast AQMD

Schulte, N., Li, X., Ghosh, J.K., Fine, P.M., Epstein, S.A. **Responsive High-Resolution Air Quality Index Mapping Using Model, Regulatory Monitor, and Sensor Data in Real-Time**, 2020, *Environmental Research Letters,* **15** 1040a7

Air Quality Index (AQI)

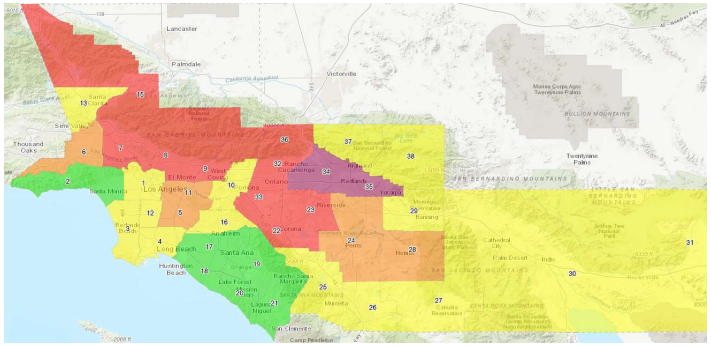
Daily AQI Color	Levels of Concern	Values of Index	Health Recommendations
Green	Good	0 to 50	Air quality is satisfactory, and air pollution poses little or no risk.
Yellow	Moderate	51 to 100	Air quality is acceptable; unusually sensitive people should consider limiting prolonged outdoor exertion.
Orange	Unhealthy for Sensitive Groups	101 to 150	Sensitive groups should limit prolonged or heavy outdoor exertion
Red	Unhealthy	151 to 200	Some members of the public may experience health effects; sensitive groups should avoid prolonged time outdoors.
Purple	Very Unhealthy	201 to 300	Health alert: Sensitive groups should avoid all outdoor physical activity. Everyone else should avoid prolonged or heavy outdoor activity.
Maroon	Hazardous	301 and higher	Health warning of emergency conditions: everyone is more likely to be affected. Everyone should avoid all physical activity outdoors.

South Coast AQMD

Sensitive groups are people with heart disease, pregnant women, children and older adults, people with lung disease, such as asthma

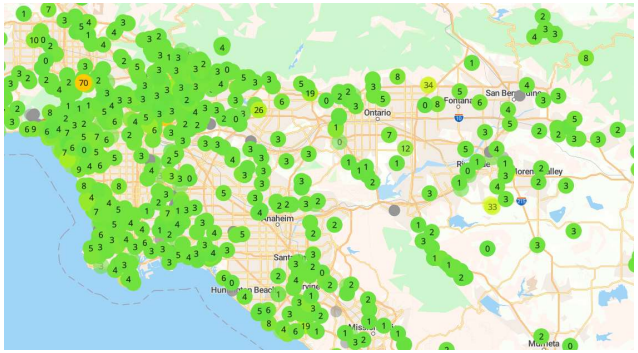
Methods of Displaying Real-Time Air Quality Data

South Coast AQMD "Proxy Method"



AirNow

PurpleAir



Limitations identified:

- Location of monitor that is driving an area's current AQI is unclear
- Distance-weighted interpolation doesn't account for complex terrain
- Public often looks at multiple maps to understand current air quality (PurpleAir map) and does not interpret consumer-grade sensor data appropriately
- Resolution is too large to accurately represent localized events (i.e. "Proxy")
- For maps showing point-data, some locations may have AQI values that do not consider measurements from all relevant pollutants

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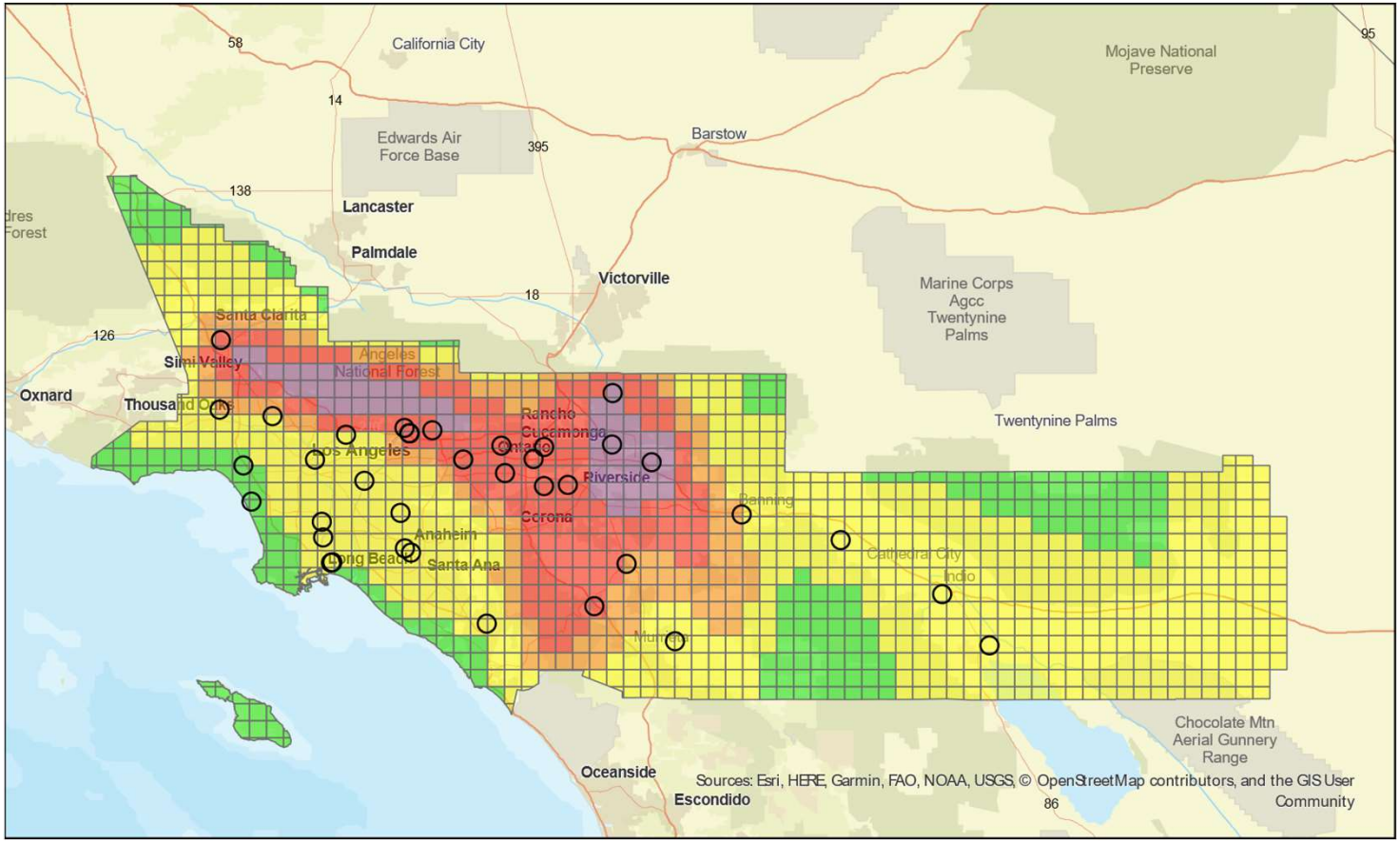
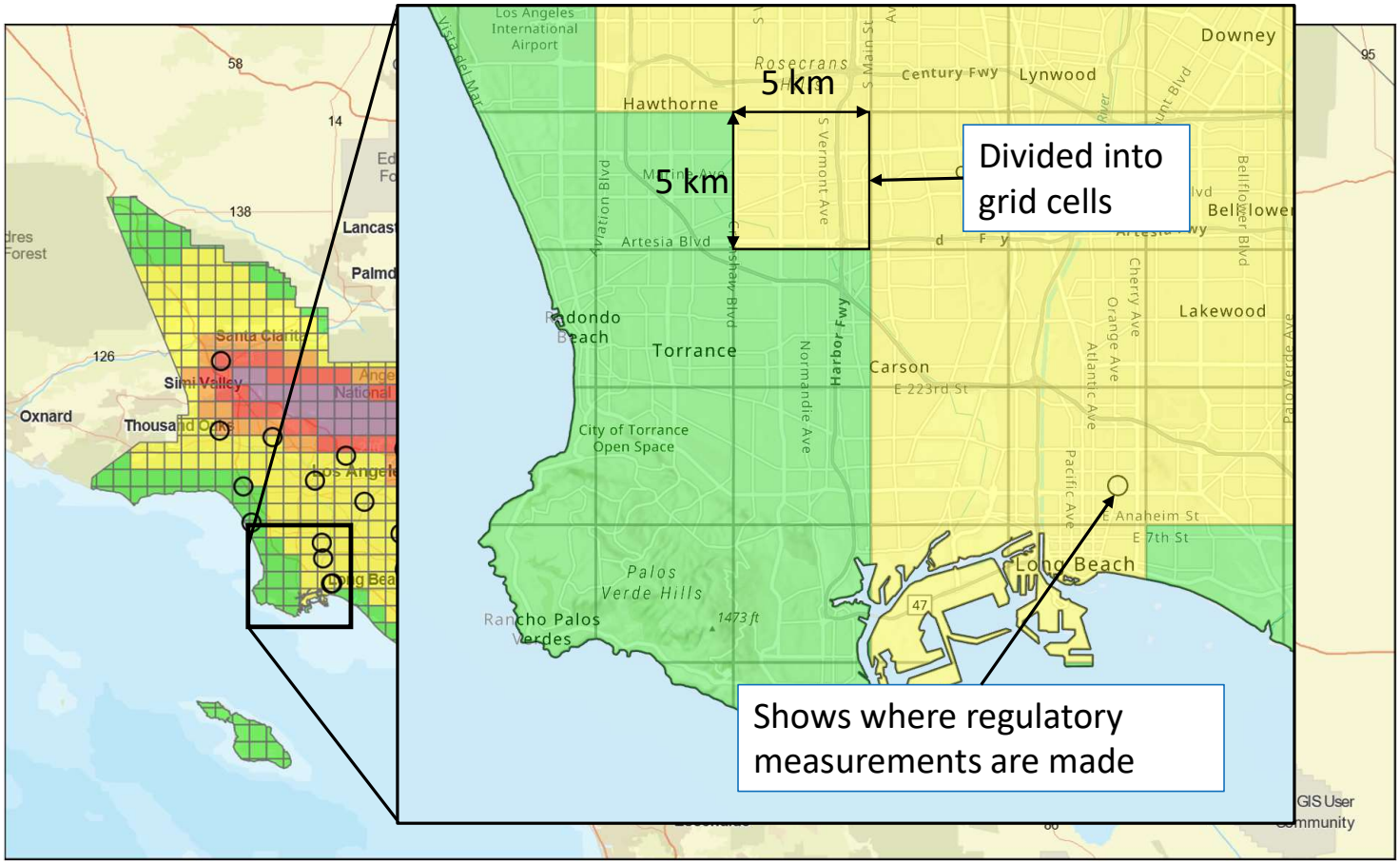
Real-Time AQI Map (www.aqmd.gov/aqimap)



South Coast AQMD

Real-Time AQI Map (www.aqmd.gov/aqimap)

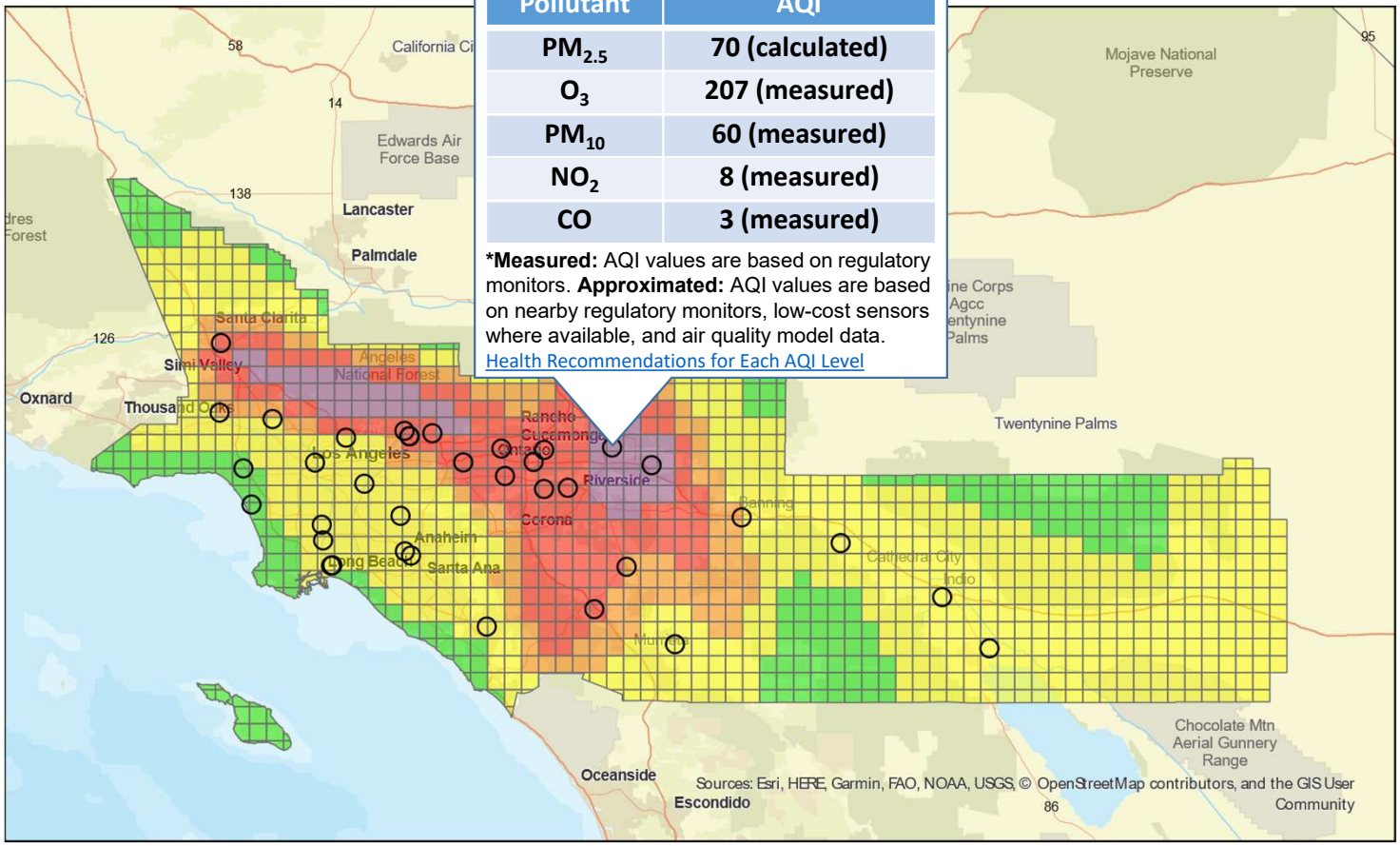


Real-Time AQI M d.gov/aqimap)

San Bernardino
AQI: 207
AQI Category: Very Unhealthy
Dominant Pollutant: Ozone | Updated: 4 PM

Pollutant	AQI
$PM_{2.5}$	70 (calculated)
O_3	207 (measured)
PM_{10}	60 (measured)
NO_2	8 (measured)
CO	3 (measured)

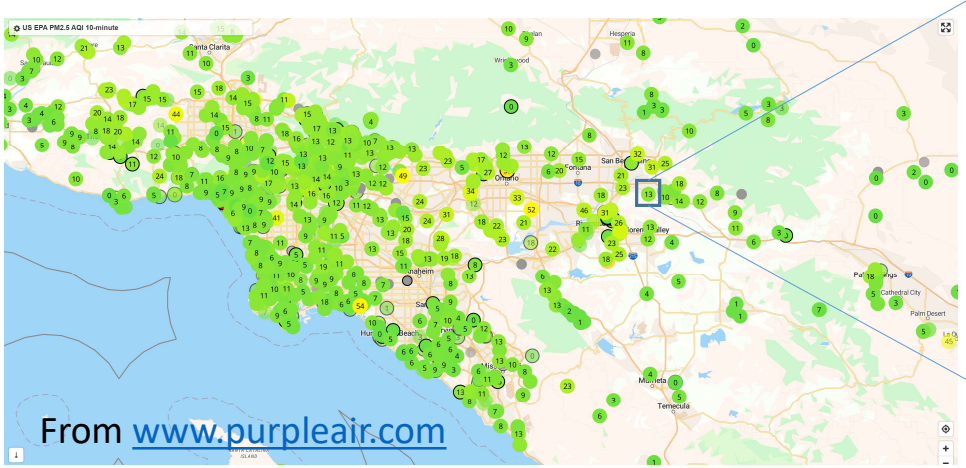
***Measured:** AQI values are based on regulatory monitors. **Approximated:** AQI values are based on nearby regulatory monitors, low-cost sensors where available, and air quality model data.
Health Recommendations for Each AQI Level



South Coast AQMD

Consumer-Grade Sensors

- About 700 PurpleAir PM2.5 sensors in 2021; Great spatial coverage
- **South Coast AQMD AQI Map** uses sensor data to fill in gaps between monitor measurements



PurpleAir Low-Cost sensor

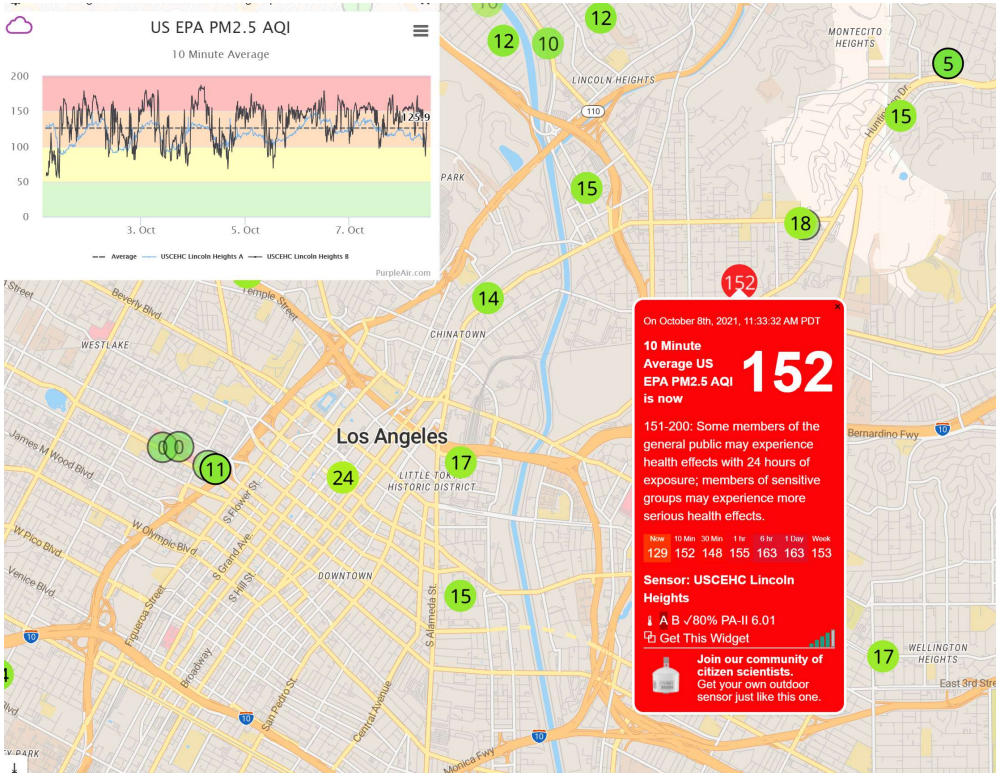
Other types of sensors are also being deployed (aeroqual AQY) and will be integrated after testing
The AQI map also uses model data

Interpreting Consumer-Grade Sensor Data

- Sensor data should be:
  - Representative (place sensor away from local pollution sources)
  - Calibrated/corrected (often based on colocation with regulatory monitors)
  - Reliable (remove broken sensors)
  - Averaged (1-hour averages for NowCast AQI)

- **South Coast AQMD AQI map handles these issues**

Example: This sensor is broken



From www.purpleair.com

Treatment of Consumer-Grade Sensor PM2.5 Data

1) Quality Control PurpleAir data

By comparing the simultaneous measurements from the two channels within each sensor and applying statistical criteria

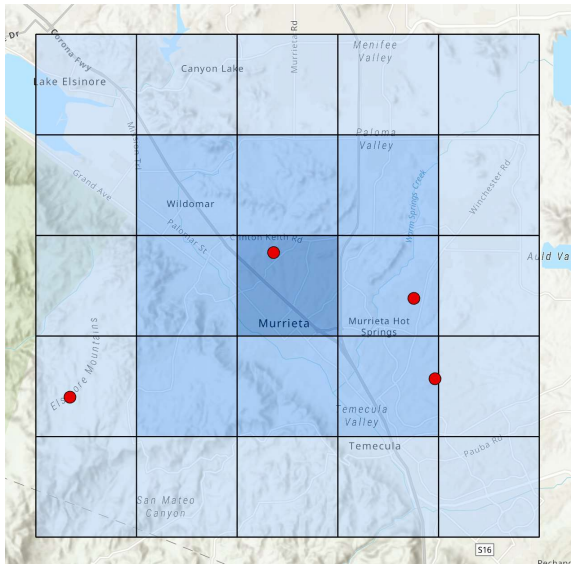
https://notunhealthy.com

2) Calibrate PurpleAir data

Using collocated reference monitor data and correction for relative humidity

https://www.aqmd.gov/aq-spec/

3) Combine sensors to estimate average concentration in grid cell

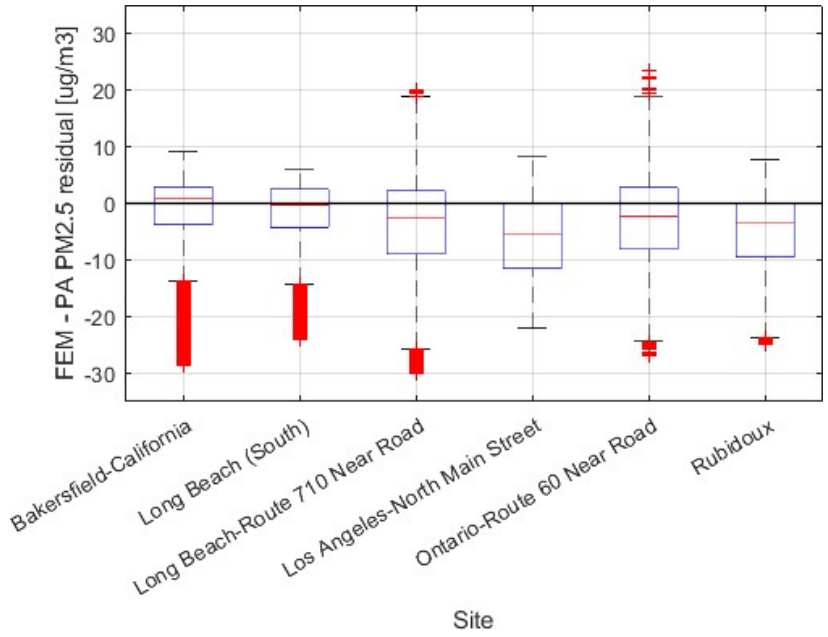


To mitigate potential bias caused by hyperlocal sensors, we average sensors in similar geographical areas

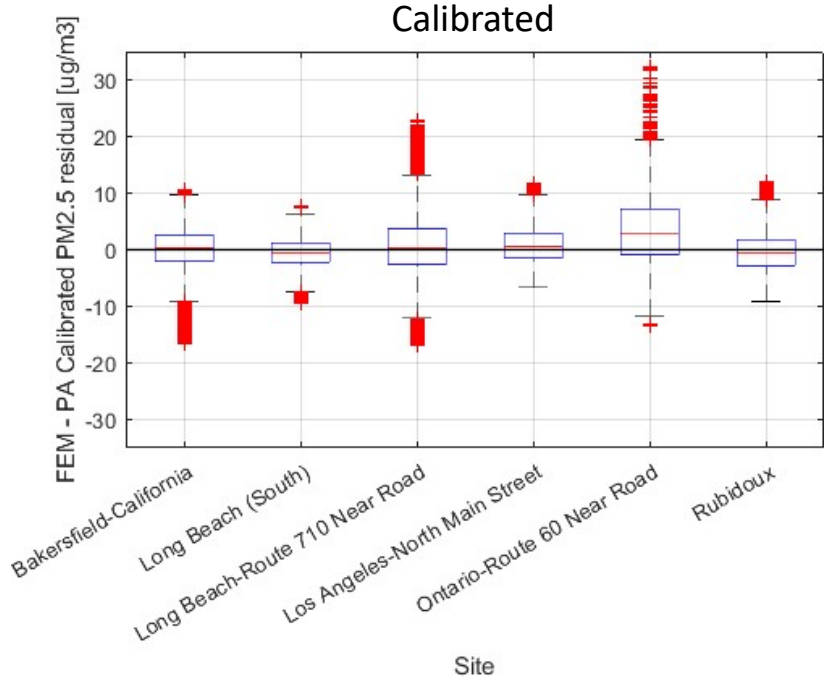
South Coast AQMD

Sensor Calibration Performance

Not calibrated



Calibrated

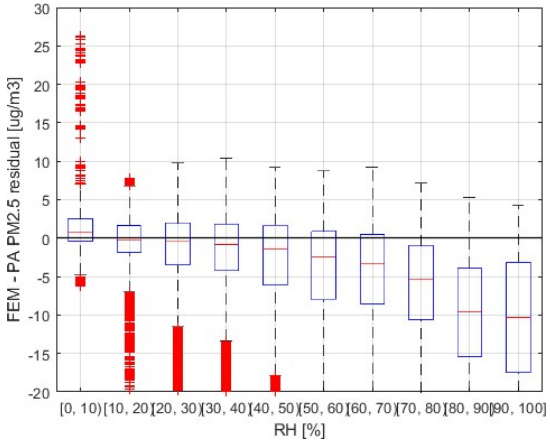


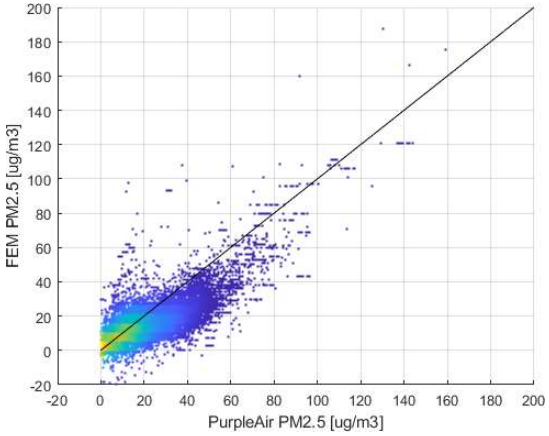
645,000 hourly data points (Purple Air with collocated FEM) are used to derive a calibration equation

Calibration equations adapted from: Malings et al, 2019. Aerosol Science & Technology

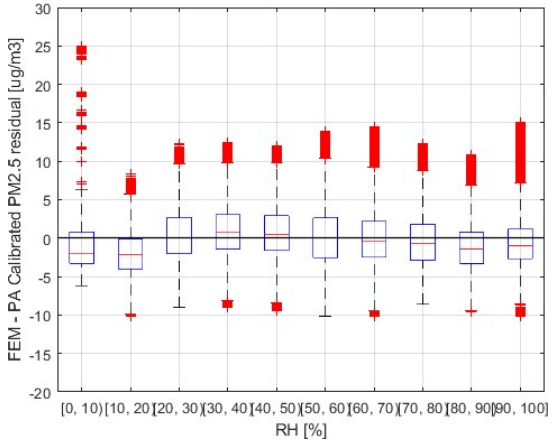
Sensor Calibration Performance

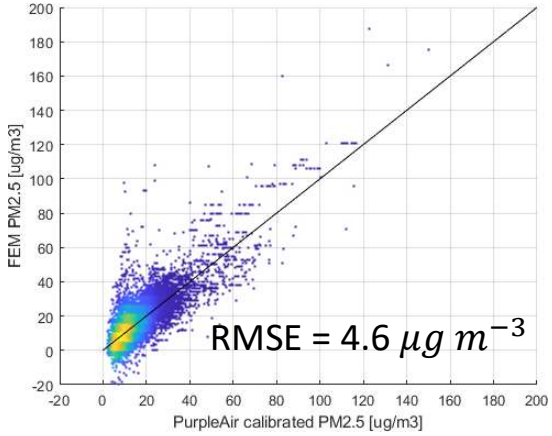
Not Calibrated





Calibrated

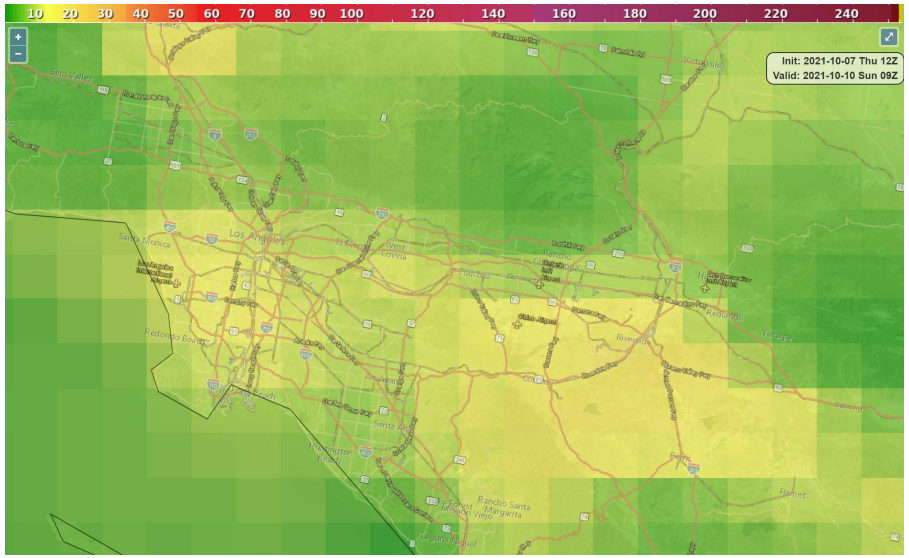




South Coast AQMD

AQI Map Also Uses Model Data

- National Air Quality Forecast Capability
  - Community Multi-scale Air Quality model with Global Forecast System meteorology
  - National Emission Inventory 2016 (NEI)
  - Kalman Filter Analog bias correction
  - 6z/12z daily runs
  - PM2.5 and Ozone
  - Conducted for entire U.S.



From https://digital.mdl.nws.noaa.gov/airquality

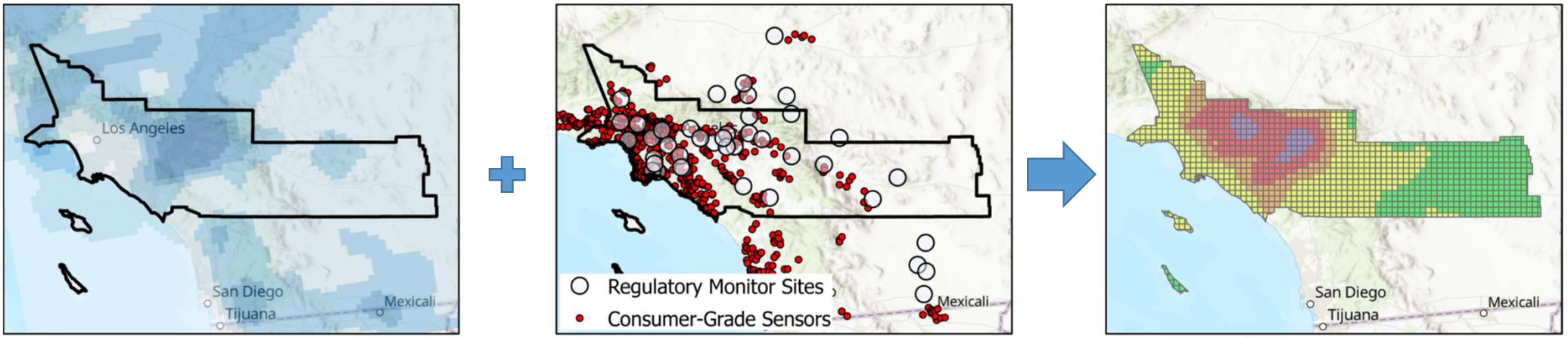
South Coast AQMD

How the AQI Map Works

Gridded Model Data

Monitor and Consumer-Grade Sensor Data

Gridded AQI

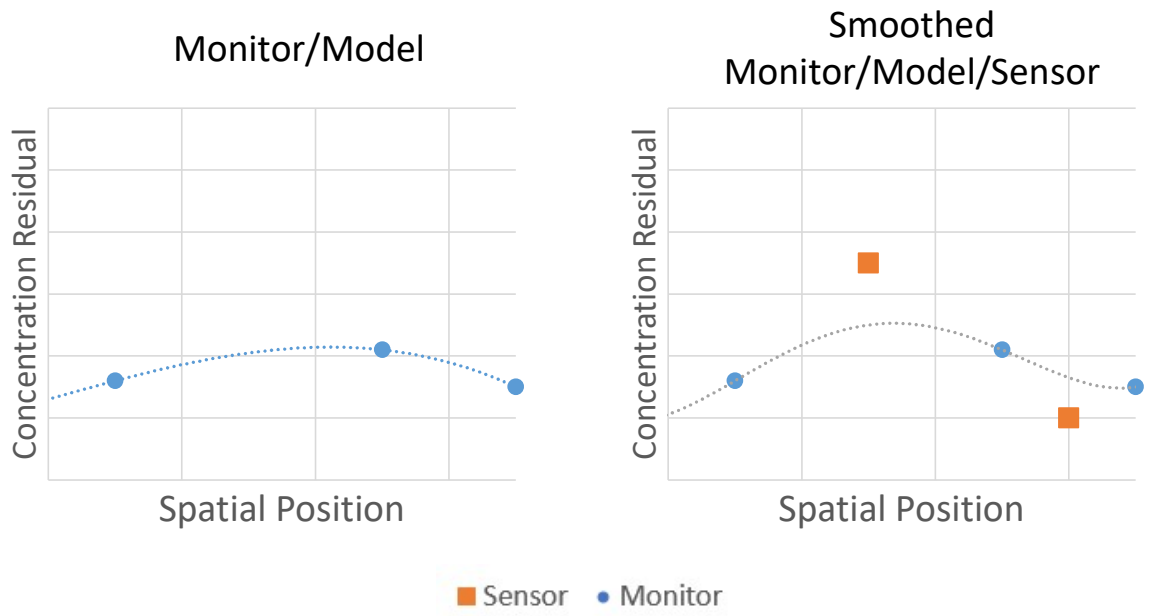


Loma Linda University, UC Riverside, County of Riverside, California State Parks, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, Esri, USGS

Pollutant	Method	Far from monitors	Near monitors
$PM_{2.5}$	Fill in gaps between monitors using model and consumer-grade sensor data	Models and consumer-grade sensor data drive concentration	Monitor data drives concentration
O_3	Fill in gaps between monitors using model	Models drive concentration	
PM_{10}, NO_2, CO	Natural neighbor interpolation	Monitor data drives concentration	

South Coast AQMD

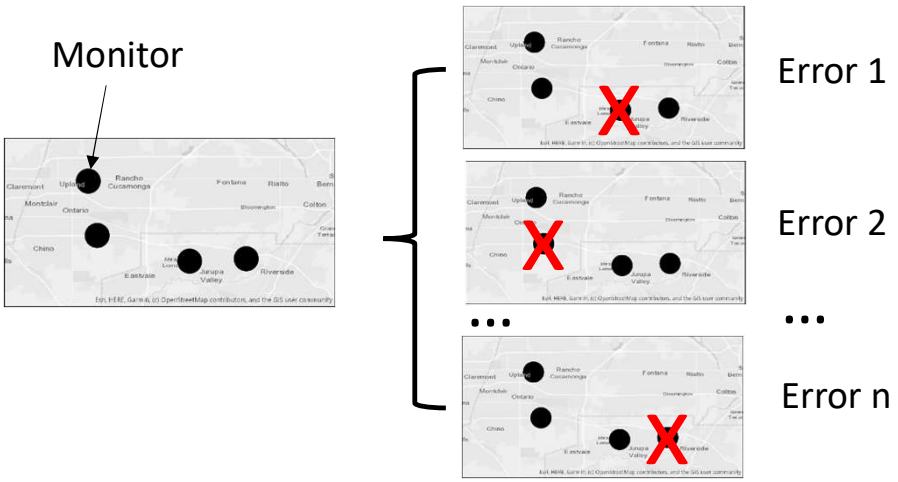
How the AQI Map Blends Monitor/Model/Sensor Data



Concentration "surface" is fixed to regulatory monitors. Between monitors, model and consumer-grade sensor data modifies the concentration surface based on their relative uncertainties.

Evaluating Performance Compared to Other Methods

Leave one out cross validation holds out one monitor at a time to estimate error



Root Mean Square Error (all pollutants)

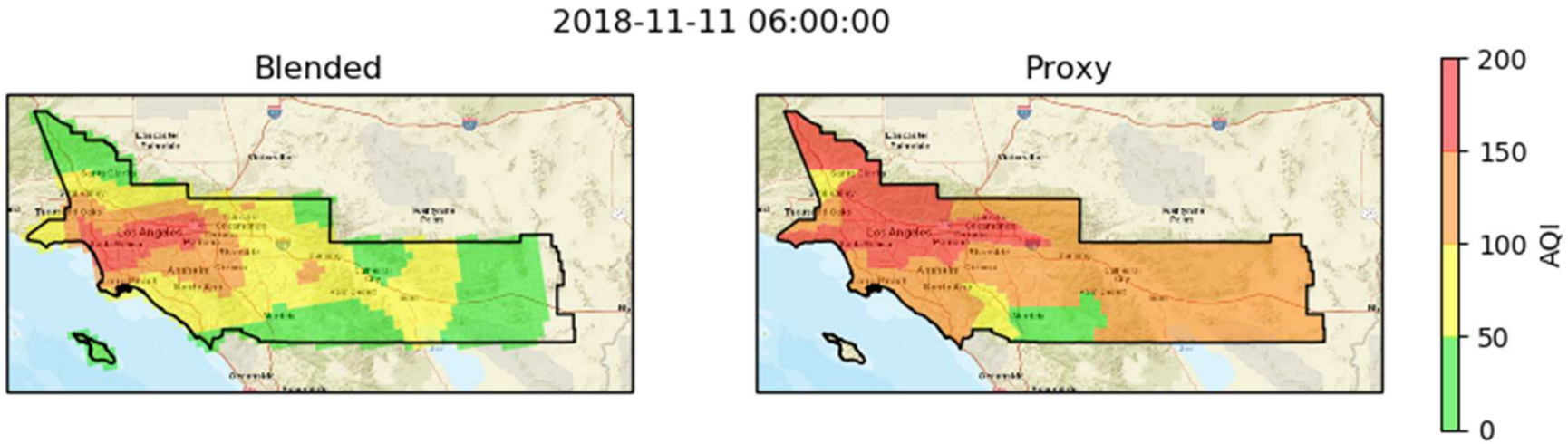
Pollutant	Proxy	Inverse Distance Weighting	South Coast AQMD AQI Map
$PM_{2.5}$ [µg m^{-3}]	7.6	7.73	5.94
O_3 [ppb]	10.2	8.75	7.12
PM_{10} [µg m^{-3}]	34.7	36.1	33.6
CO [ppm]	0.171	0.191	0.163
NO_2 [ppb]	7.57	6.94	6.22

IDW – Inverse distance weighting as used by AirNow maps

- South Coast AQMD AQI map has lower errors than Proxy and IDW for all pollutants used in AQI calculation
- Additional assessment conducted for PM2.5 data with independent data sets

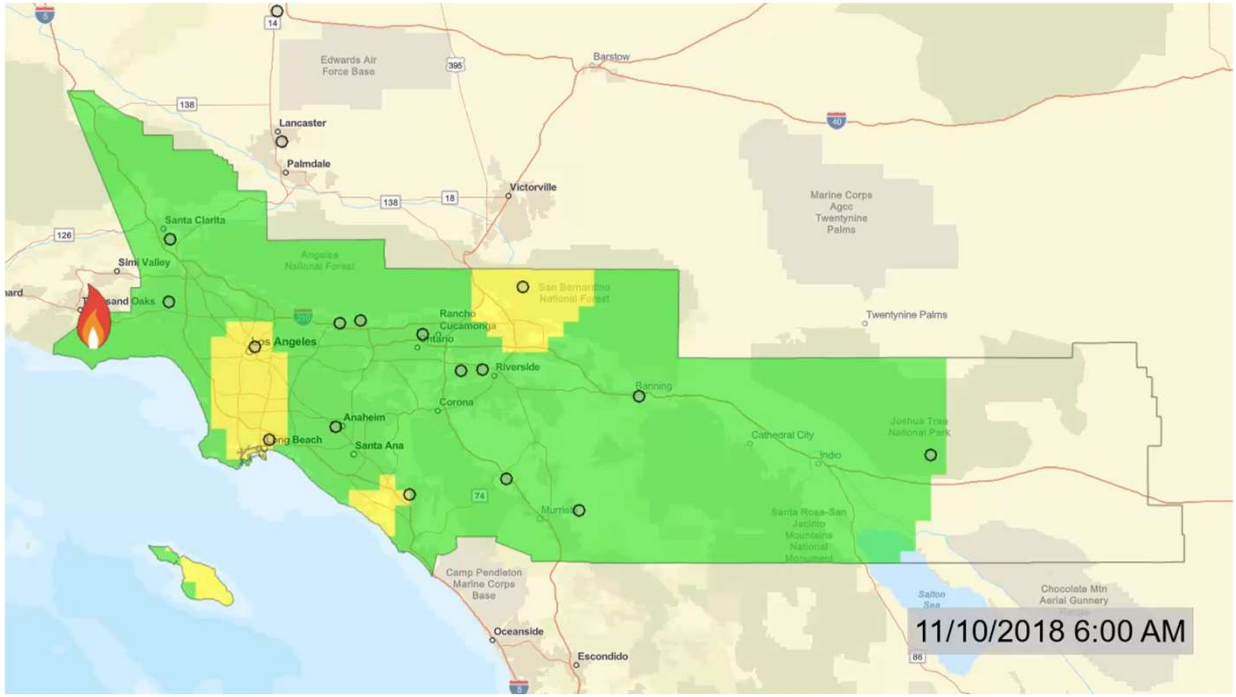
Additional Advantages of Blended Map During Wildfires

- Integration of PurpleAir and NOAA model data helps capture localized smoke plumes that are between regulatory monitors
- Higher resolution blended map better represents wildfire plumes
- Blended map automatically integrates temporary e-BAM monitoring data



South Coast AQMD

Map Performance Excels During Wildfires



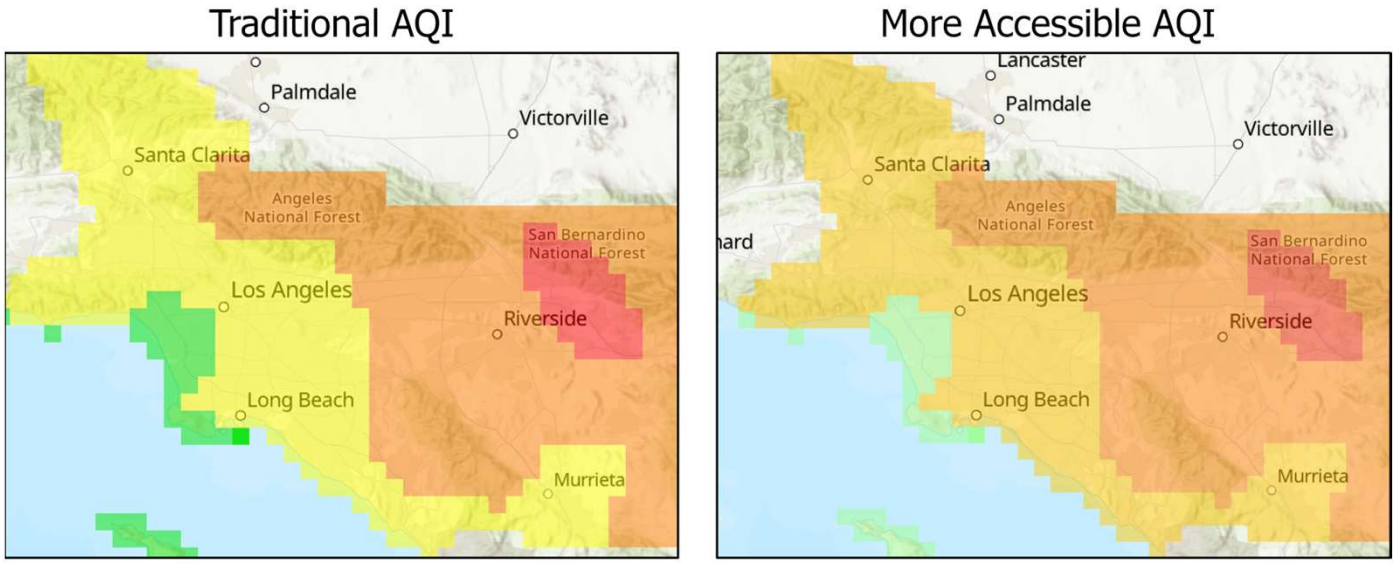
$PM_{2.5}$ RMSE [$\mu g\ m^{-3}$] on fire days

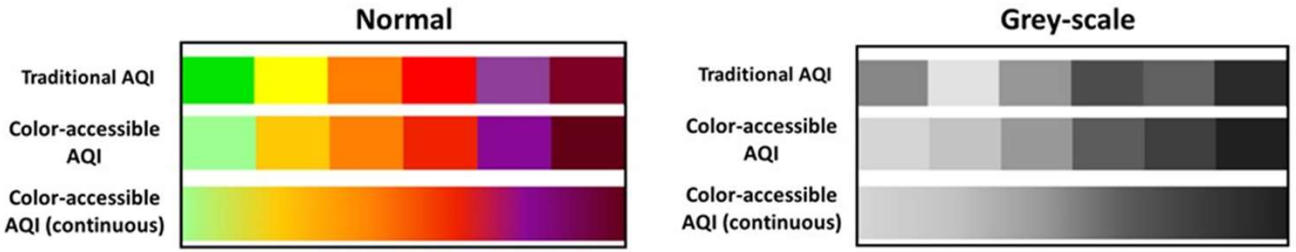
Method	Proxy	Inverse Distance Weighting	South Coast AQMD AQI Map
Leave One Out Cross Validation	7.04	6.62	6.01
Gravimetric validation dataset	5.68	4.39	3.35
North Hollywood validation dataset	19.2	16.8	9.15

Proxy and Inverse Distance Weighting are other methods that have been used to make AQI maps

South Coast AQMD

More Accessible AQI Colors





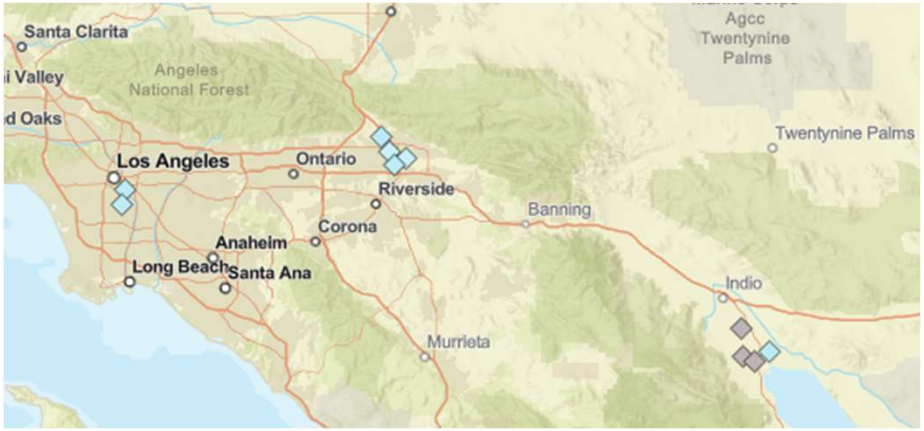
- Available as option in current AQI map and on EPA Fire and Smoke Map
- Modified colors improve accessibility for people with eight types of colorblindness
- Color lightness changes uniformly with AQI
- Can be used for continuous color scale

South Coast AQMD

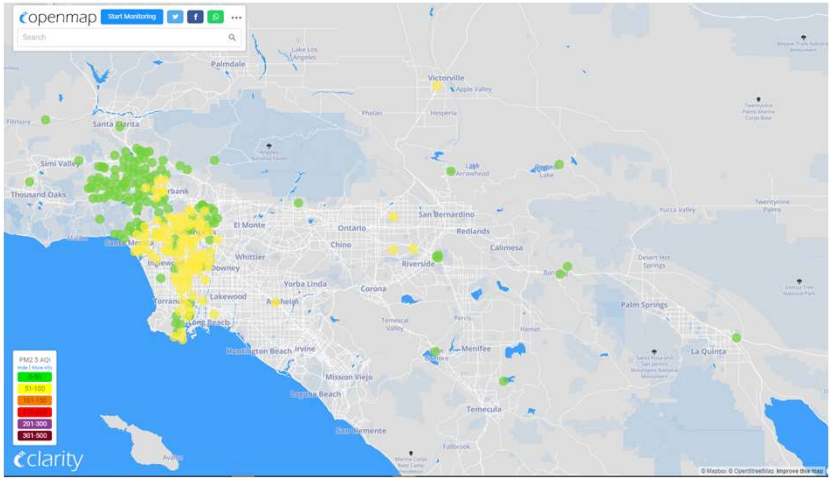
Ongoing Improvements to AQI Map

- Adding data from more types of Consumer-Grade sensors
  - Aeroqual AQY 1: PM2.5, NO2, Ozone
  - Clarity Node-S: PM2.5, NO2, Ozone (optional)
- Improving code (increase responsiveness and reduce data outages)

Aeroqual AQY



Clarity Open Data



Conclusions

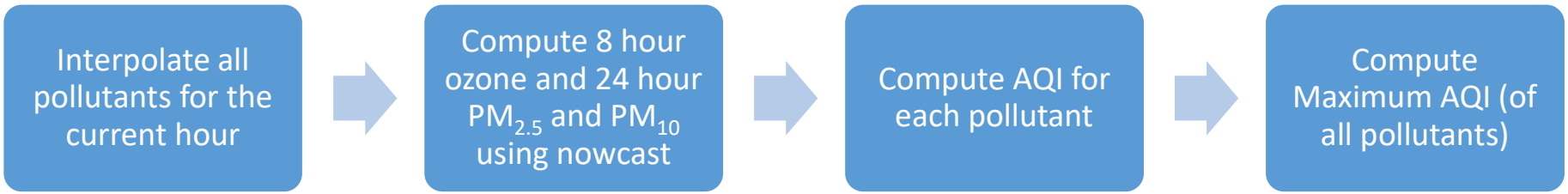
This slide was edited after initial posting.

- AQI map has high level of accuracy and avoids common public misunderstandings of real-time sensor readings
- Air Quality sensors are an important tool to supplement regulatory measurements in the AQI map
- Currently looking for additional locations to site PurpleAir and Aeroqual AQY sensors to fill data gaps in the map
- Data displayed on South Coast AQMD homepage and mobile app (www.aqmd.gov/mobileapp)
  - App can push notifications during periods of poor air quality

South Coast AQMD

Backup Slides

Process to Generate AQI Values



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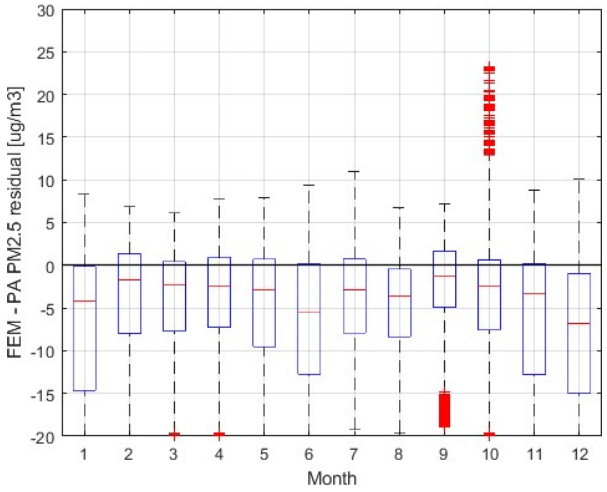
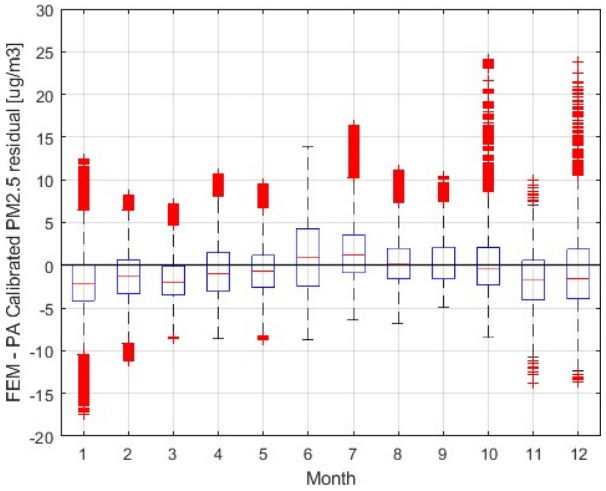
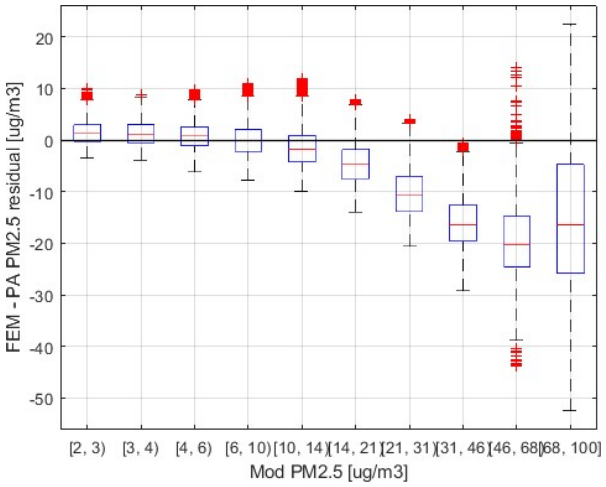
PurpleAir Calibration

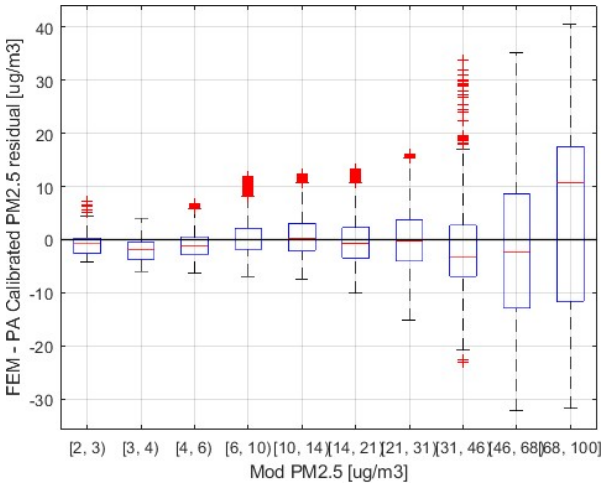
Not calibrated



Calibrated







South Coast AQMD

Sensor Blending Method

- Quality control, calibrate, and smooth (average in grid cell) the PurpleAir data

- Residual Kriging interpolation with modifications
  - PurpleAir data is included as observations in addition to monitor data
  - Data is assigned a measurement uncertainty that is used to give more weight to the more accurate monitor data

- Measurement Uncertainty
  - PurpleAir uncertainty is the sum of two components: the RMSE of the collocation curve fit[1] and the standard error of the average in the grid cell[2]
  - Monitor data has zero uncertainty

[1] As 1 standard deviation

[2] Standard error is estimated based on the average concentration when the number of sensors is small

South Coast AQMD

Additional Evaluation of PM2.5 Performance with Monitoring Data from Independent Data Sets

- 24-hour Average Gravimetric Data (June 30, 2018 – March 31, 2020)
  - ➢ Performed analysis at 11 sites that do not have collocated continuous PM2.5 monitors
- North Hollywood Hourly PM2.5 (Oct 11, 2019 – March 31, 2020)
- Mission Viejo Hourly PM2.5 (Oct 29, 2019 – March 31, 2020)

$PM_{2.5}$ Root Mean Square Error [$\mu g\ m^{-3}$]

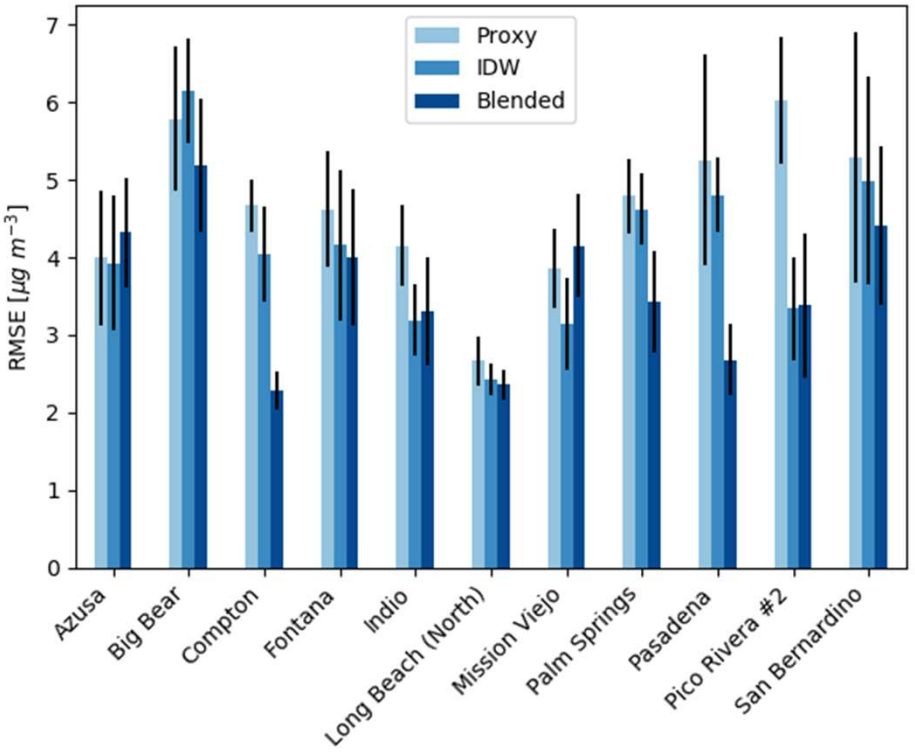
Method	Proxy	IDW	Blended
Gravimetric	4.64	4.07	3.59
North Hollywood	8.91	9.07	7.51
Mission Viejo	8.83	7.31	8.87

South Coast AQMD

Gravimetric, North Hollywood, and Mission Viejo monitor data are not used by interpolation or by NOAA model

Using Gravimetric Monitor Data to Evaluate Performance

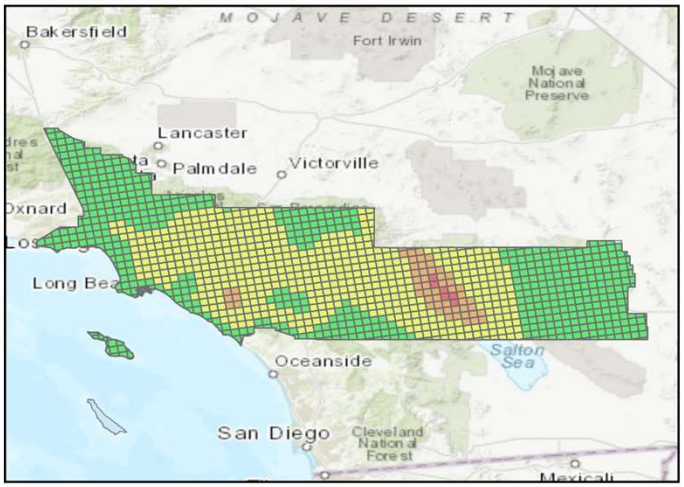
- 24-hour PM2.5 average of blended map predictions are compared to gravimetric measurements at stations without collocated continuous instruments
- Performance is somewhat station dependent
- Blended map has lower average RMSE than Proxy and IDW



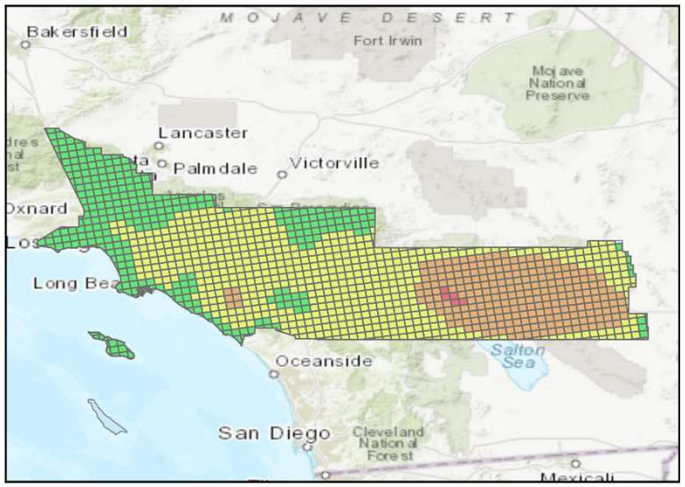
South Coast AQMD

Including PM_{10} Measurements from Surrounding Areas Produces More Realistic AQI

With Surrounding Area PM10



Without Surrounding Area PM10



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

South Coast AQMD

Challenges in Deploying Heavy-Duty Charging Infrastructure

Sam Cao

Cleans Fuels Advisory Group

September 14 2023

https://www.jetsiproject.com/

JETSI – Schneider Was Successful but Still Faced Challenges

- Part of the Joint Electric Truck Scaling Initiative (JETSI):
  - Up to 92 Class 8 Battery Electric Trucks
  - 16 dual-corded 350 kW chargers

"Schneider Battery-Electric Truck Ribbon Cutting Event"
https://www.jetsiproject.com/

JETSI – Schneider Project Timeline

- 2021:
  - April/June: Project awarded and approved
  - October: SCE Charge Ready Transport agreement executed
- 2022:
  - June: EVSE equipment ordered
  - August: construction permit submittal
- 2023:
  - January: 1st BET delivered
  - February: Construction commenced
  - May: Site energized
  - August: Commissioning complete
- Challenges: Limited grid capacity, charging equipment UL certification, construction permitting, cost increases

Photo shared with permission from DTNA

https://www.bv.com/projects/electrifying-commercial-freight-delivery-for-schneider-national

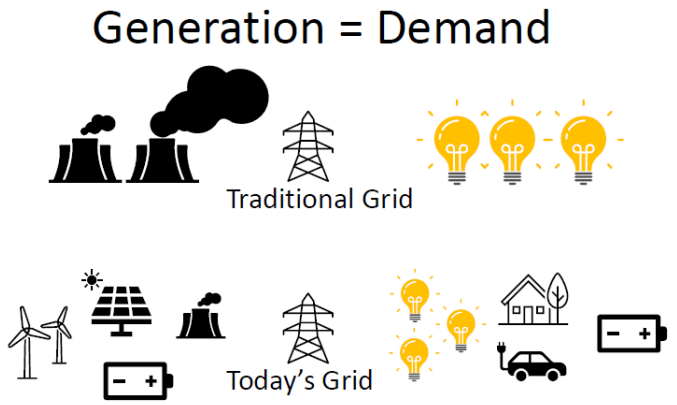
Installed chargers at Fleet A waiting to be energized, shared with permission from fleet

Skid mounted temporary 50kW chargers at Fleet C, shared with permission from DTNA

Other BET Deployment Infrastructure Challenges

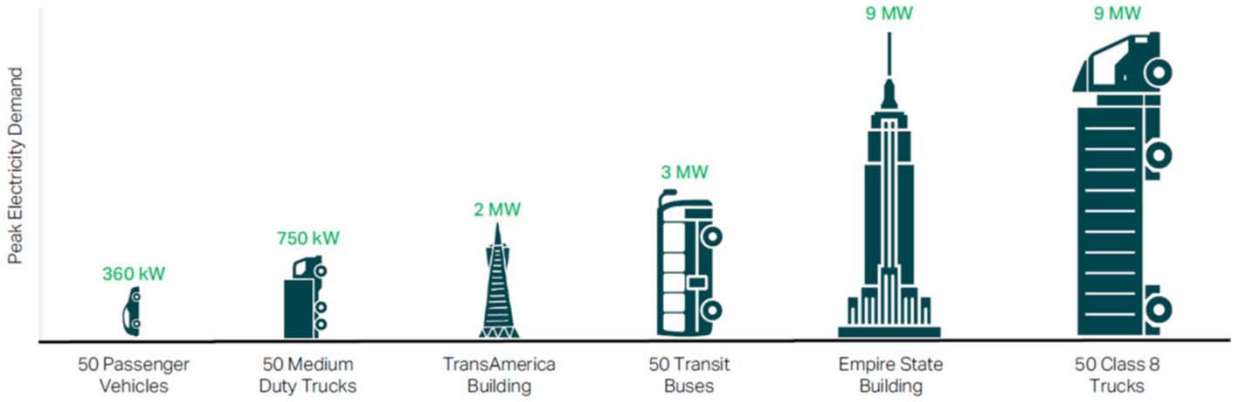
- Fleet A: 50 BETs, 19 350 kW chargers, 1 MW solar and 4 MWh battery storage
  - Also part of JETSI project
  - Change of site electrical service classification doubles EVSE equipment and installation costs
  - DER – non-offsetting demand
  - Resolutions: utility provided temporary power to energize 10 chargers by Nov 2023, remaining chargers will be installed but not energized until summer of 2024
- Fleet B: 8 BETs, 7 240 kW chargers
  - Limited grid capacity, UL certification, and fleet plan changes
  - Resolutions: utility provided temporary power and energized a 240 kW charger to support 5 BETs
- Fleet C: 15 BETs, 15 180 kW chargers
  - Delay in local construction permitting, since 2/2023
  - Resolutions: 5 temporary chargers (~50kw) to support 15 BETs

Upgrading the Grid for Transportation will Take Time



California Is Electrifying: Learn About the CA Grid and the Scope of the Effort Required. A. Katzenstein, Presentation to 2023 OSAR conference, March 2023

- Generation must be met by demand
- Full fleet electrification will need new generation
- Chargers needed by 2030: 114,500 for MDV/HDV and 1.01M for LDV*

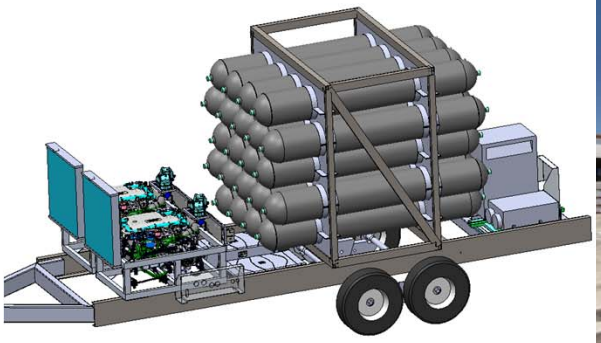


*CEC AB 2127 report

Driving EV Adoption -Program Recommendations for the Next Generation of EV Charging Deployment, Peter Olmsted & Renee Samson, FreeWire Technologies, White Paper, April 2022

Innovative Infrastructure Solutions Needed

- Challenges ahead in meeting regulatory requirements
- Take away: permanent infrastructure takes time
  - Distribution grid not built to support transportation
  - Permitting/UL requirements can also delay
- ZE truck deliveries likely occur before permanent infrastructure is ready
- Innovative charging solutions needed:
  - Portable chargers and grid support using batteries and/or clean onsite generation



“We all want to avoid temporary charging”

B. Stevens, Daimler Trucks North America, “BEV Beachhead”, presentation at the Clean Fuels Program Advisory Group Retreat, Feb 2023

HYLIION®

OVERVIEW PRESENTATION

COMPANY OVERVIEW

250+
EMPLOYEES

AUSTIN, TX
150k sq. ft. HQ

HYLN
NYSE

$354M
AVAILABLE CAPITAL
as of Q2 2023

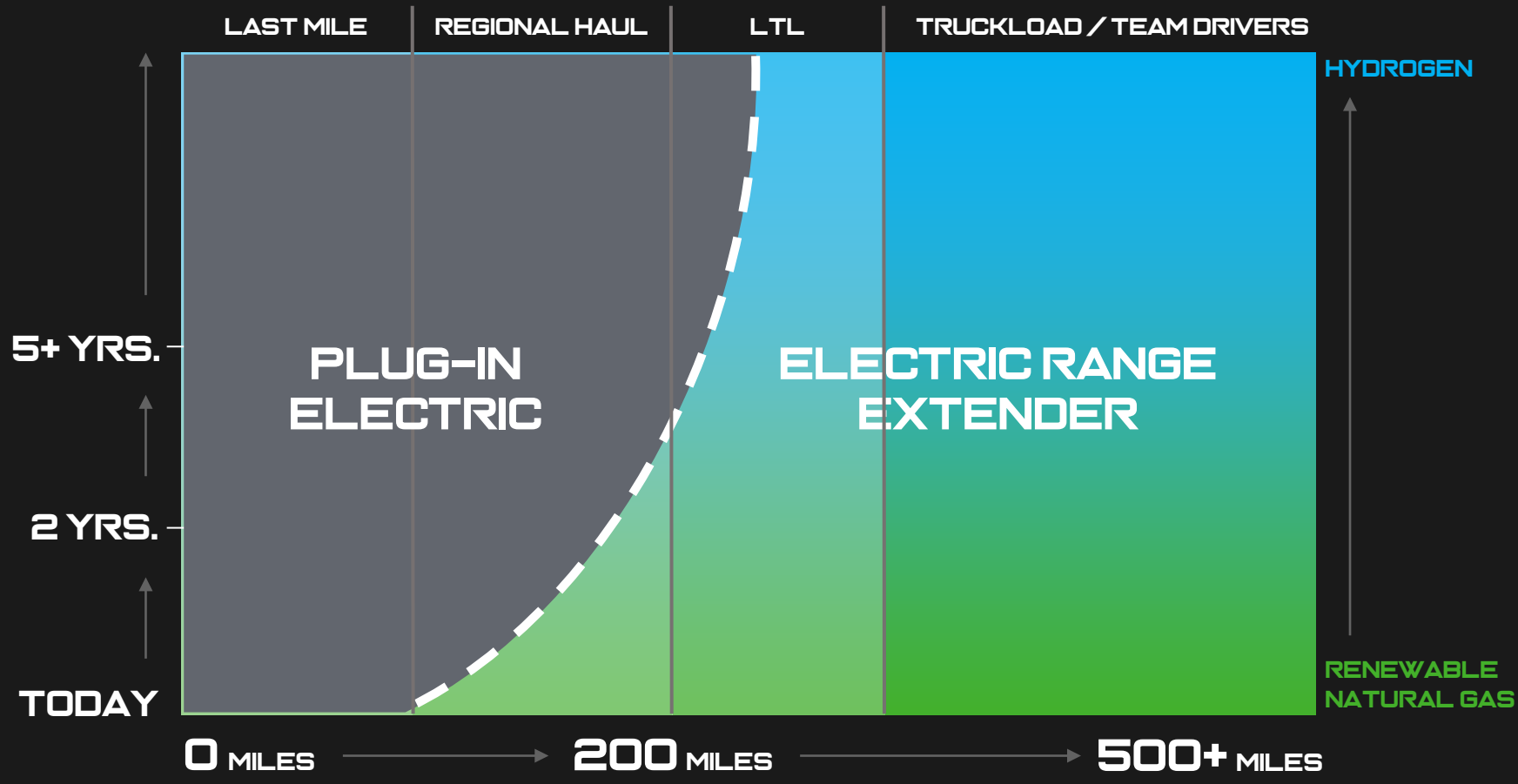
ELECTRIC POWERTRAINS

ELECTRICITY GENERATION

- Reduce Carbon Emissions
- Reduce Cost of Operation
- Leverage Existing Infrastructure

POWERTRAIN EVOLUTION

2 ELECTRIC SOLUTIONS = PLUG-IN ELECTRIC | ELECTRIC RANGE EXTENDER



HYLIION PRODUCT PORTFOLIO

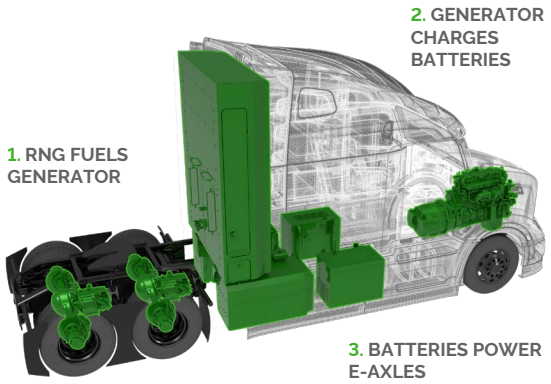
- HYPERTRUCK™ FUEL CELL
- HYPERTRUCK™ KARNO
- HYPERTRUCK™ ERX

POWERTRAIN PRODUCT PORTFOLIO

HYPERTRUCK™ ERX

Product currently in-production

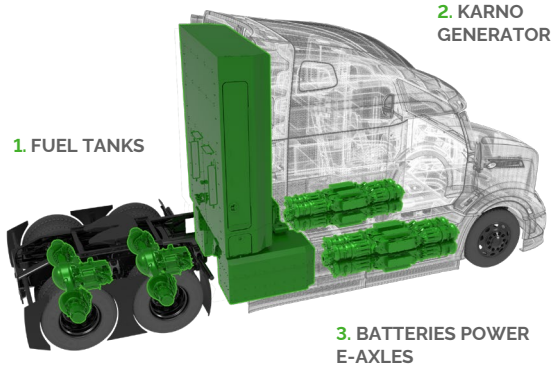
Fully Electric Powertrain Solution



HYPERTRUCK™ FUEL AGNOSTIC

Through partnership with KARNO

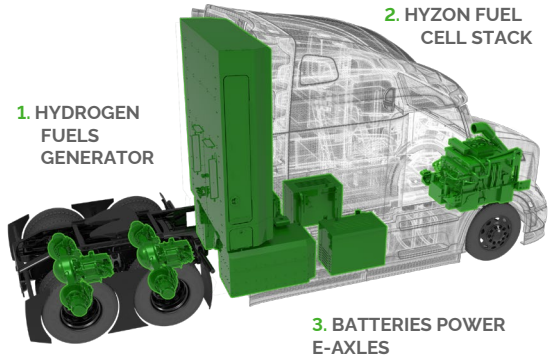
Fuel-Agnostic Linear Generator



HYPERTRUCK™ FUEL CELL

Development capabilities

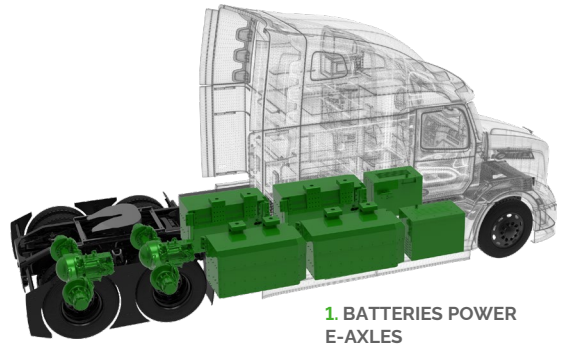
Groundbreaking Powertrain Solution With Hydrogen Fuel Cell Technology



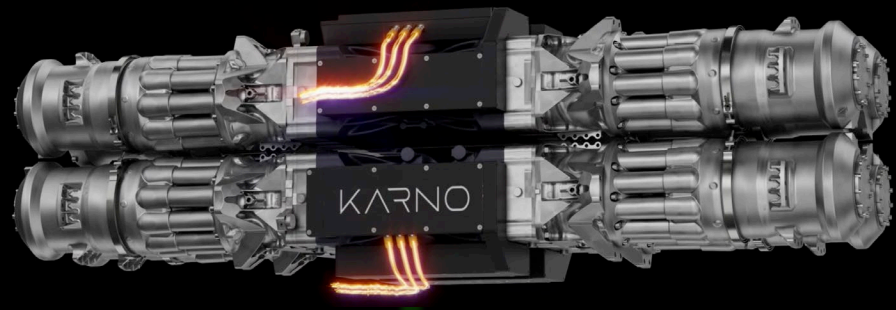
HYPERTRUCK™ BATTERY ELECTRIC

Development capabilities

Platform can easily be transitioned into a BEV vehicle



KARNO GENERATOR[1]



HYPERTRUCK™ KARNO

On-Highway | Off-Highway | Vocational
Drayage | Medium-Duty

KARNO™
STATIONARY POWER

EV-Chargers | Data Centers | Industrial |
Commercial Properties | Neighborhoods

SCALABLE POWER

Stack systems to scale from 150 kW to 5 MW+ power output

FUEL AGNOSTIC

Over 20 compatible fuel types

INCREASED EFFICIENCY

Expected 20%+ increase in efficiency over todays leading generators

REDUCED EMISSIONS

Hydrogen capable and ultra-low emissions on conventional fuels

[1]KARNO advantages are preliminary modeling results

KARNO | POWER DENSE AND MODULAR

KARNO STATIONARY UNIT

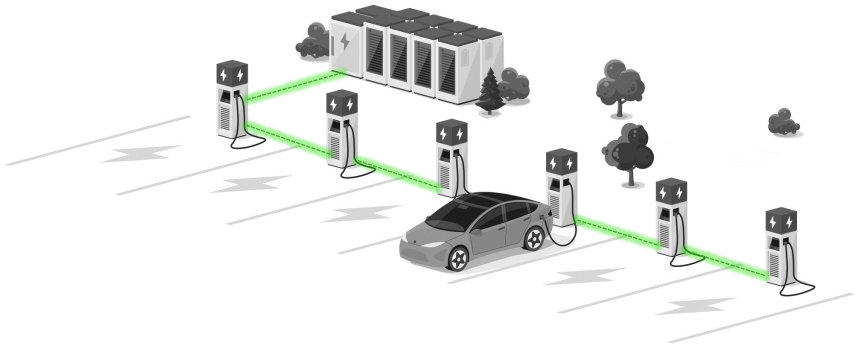
200 KW per module

~1MW of KARNO Powergen in a standard 10ft container[1], 2MW in a 20ft container[2]

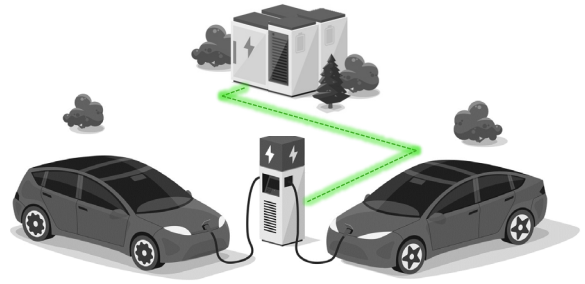
5-10X smaller footprint vs. other generators

1 Dimensions of a standard 10 ft container (10'x8'x8.5')
2 Dimensions of a standard 20 ft container (20'x8'x8.5')

SITE SETUP



Power Block



Power-Matched

KARNO BENEFITS TO STATIONARY POWER

LOW EMISSIONS FLEXIBILITY

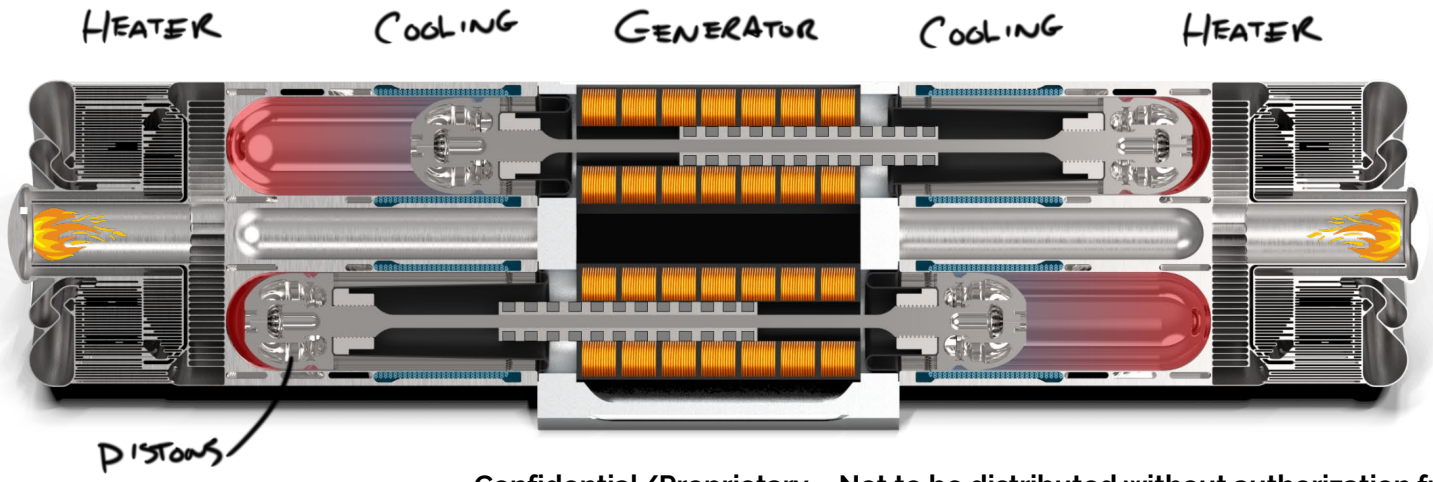
- Fuel agnostic
- Low emissions

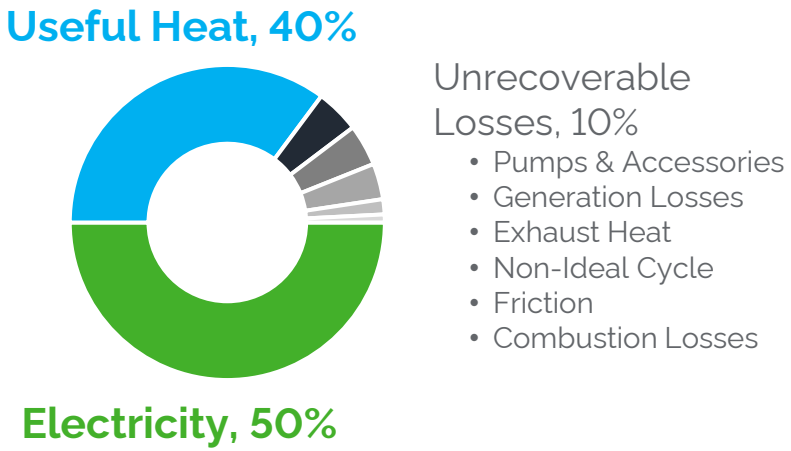
ADVANTAGED ECONOMICS

- High efficiency
- Low levelized cost of electricity (LCOE)

EASY TO IMPLEMENT

- Power dense + Modular
- Low maintenance + Quiet





ADDITIVE MANUFACTURING

- Enables USA based cost competitive manufacturing
- Printing capacity can scale as volumes scale
- Proven technology; GE produces machines for aviation, healthcare & automotive

FUEL AGNOSTIC AND REDUCED EMISSIONS

HYDROGEN

GASEOUS HYDROGEN

LIQUID HYDROGEN

NATURAL GAS

RENEWABLE NATURAL GAS

COMPRESSED NATURAL GAS

LIQUIFIED NATURAL GAS

CONVENTIONAL FUEL

DIESEL

GASOLINE

KEROSENE

JET FUEL (JP8)

ALTERNATIVE FUEL

PROPANE

AMMONIA

DIMETHYL ETHER

+ OTHERS

EMISSIONS STANDARDS

The KARNO™ generator is expected to comply with all current and foreseeable emissions standards, specifically from CARB and EPA, even when utilizing conventional fuels.[1]

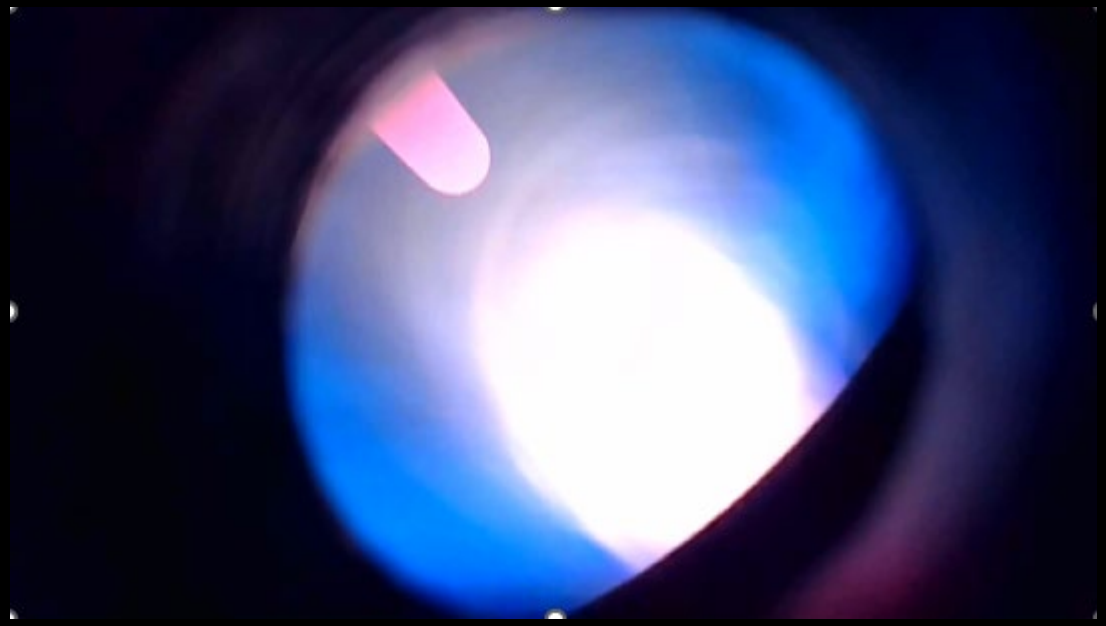
HYDROGEN CAPABLE

The KARNO™ generator is expected to operate on Hydrogen at efficiency levels that even surpass most of today's leading fuel cell solutions.[1]

[1]Preliminary modeling results

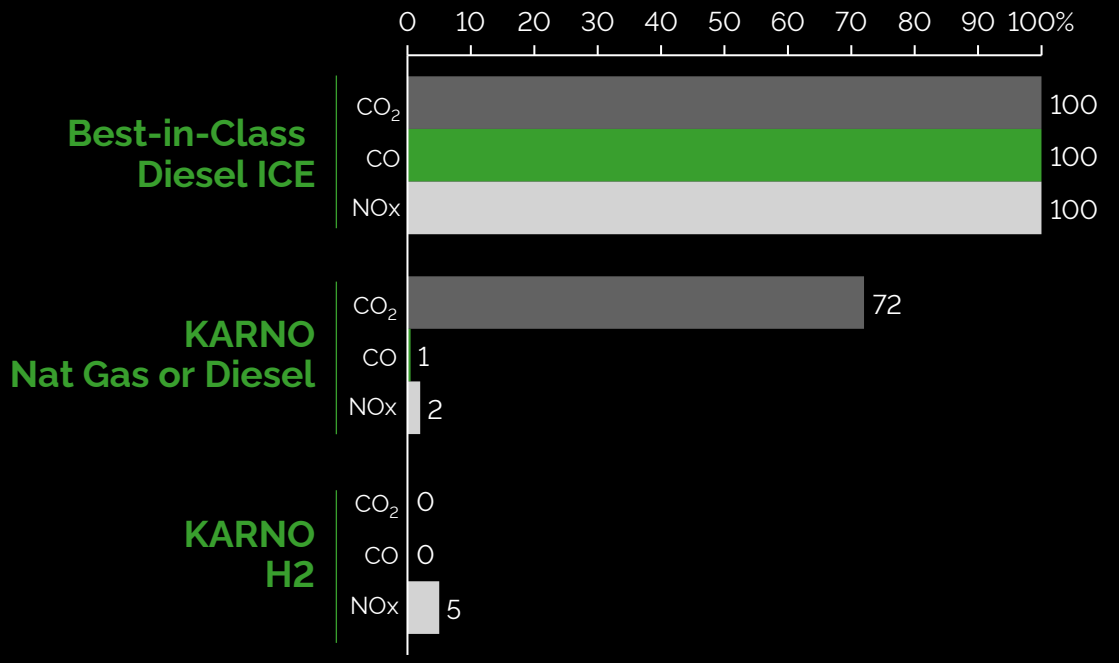
KARNO DESIGN DRIVES A STEP-CHANGE IN UNTREATED EMISSIONS

KARNO builds on decades of multi-fuel, swirl stabilized combustion system



- Flameless oxidation
- Lean burn throughout the cycle
- Long resonance time

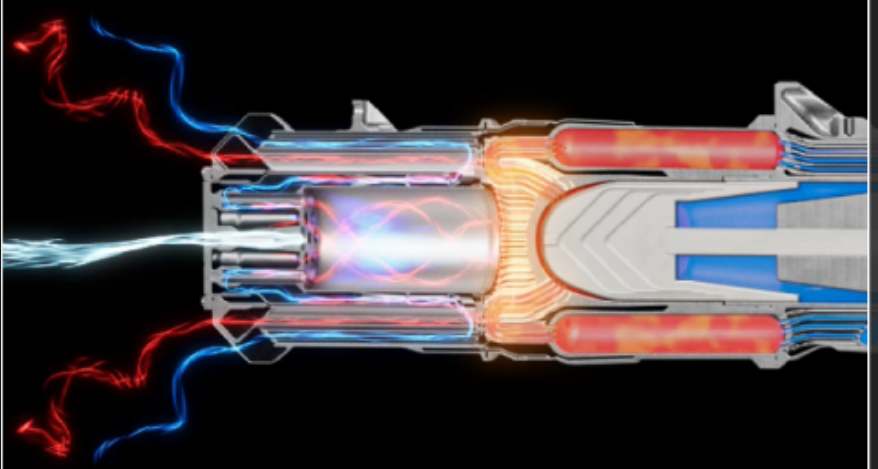
KARNO untreated emissions vs. diesel ICE

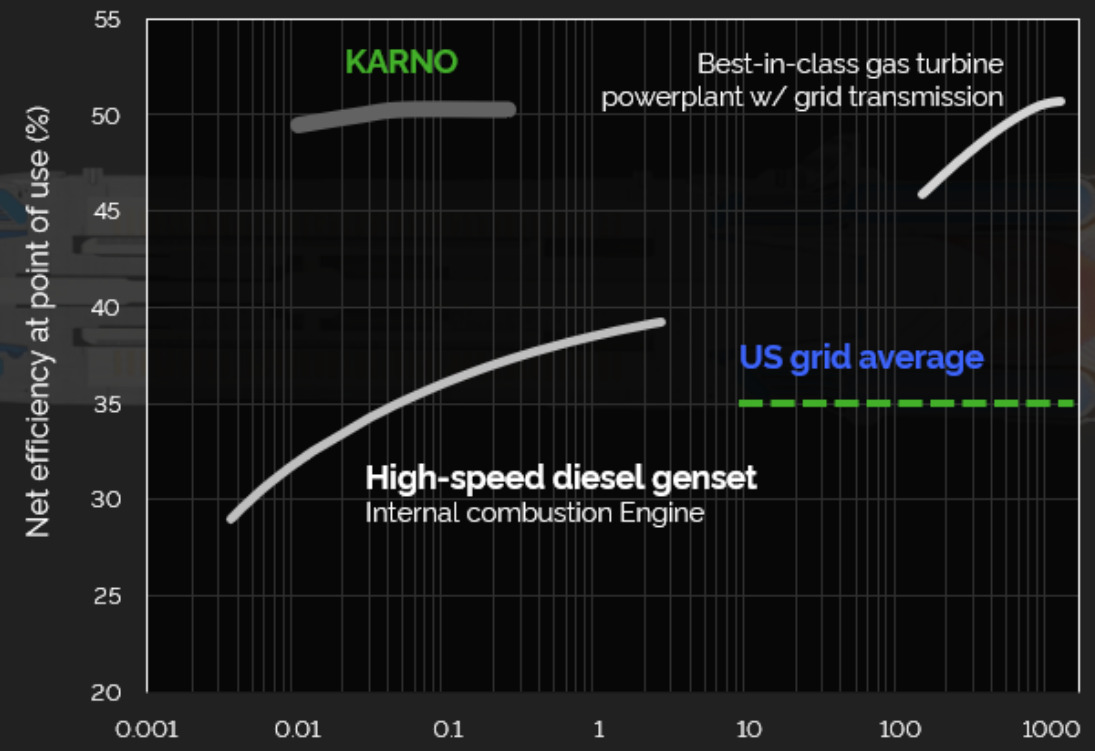


Emissions (%) of baseline Diesel ICE

KARNO power unit emits no unburned hydrocarbons (UHCs / PICs) due to ultra-lean pre-mixed oxidation

High Efficiency + Low Cost Of Electricity



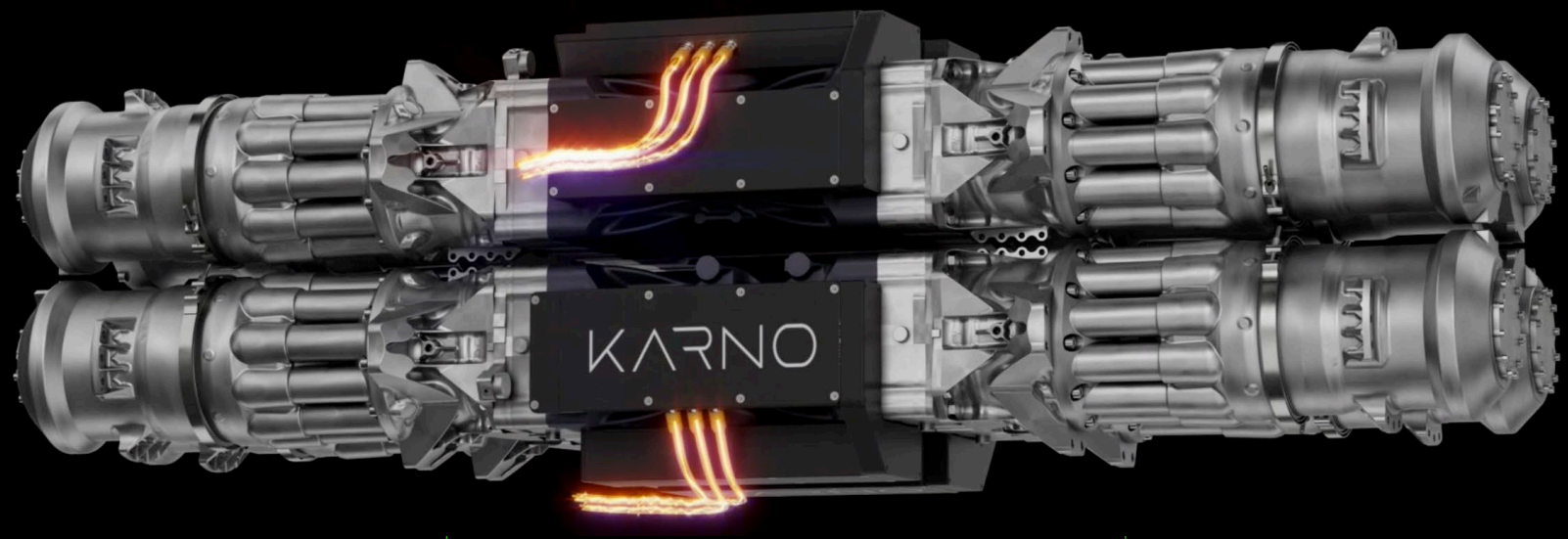


KARNO has +15-20% improvement over similar power output systems

KARNO performs at utility scale efficiency but in scalable, modular size

DESIGNED FOR LOW MAINTENANCE, QUIET OPERATION

10+ YEARS[1] | **$0 ROUTINE COST[1]** | **<65 dBA @ 6 FT[1]**



LONG LIFESPAN

- LOW FRICTION
- SEALED SYSTEM

NO SCHEDULED MAINTENANCE

- NO OIL/LUBRICATION
- NO WEAR PARTS

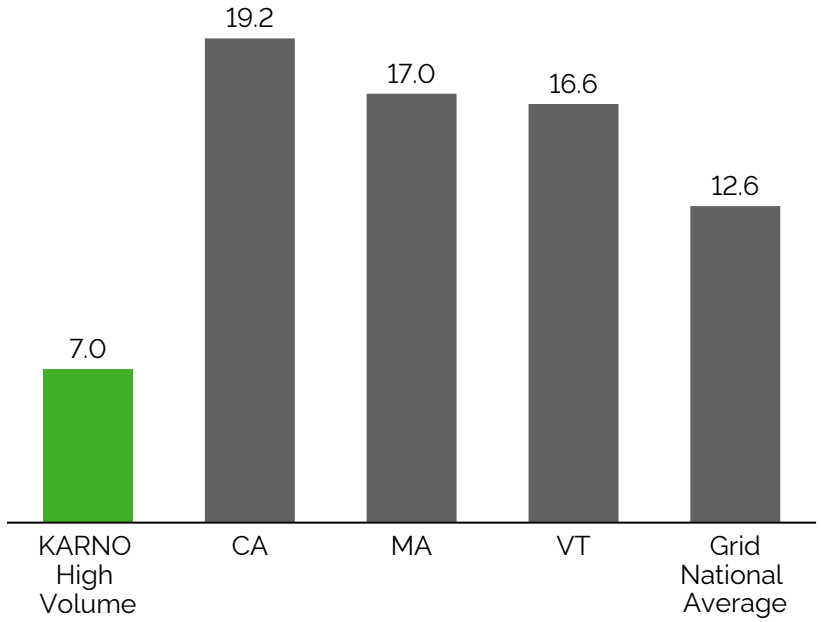
LOW NOISE

- NO HP COMBUSTION
- LOW VIBRATION

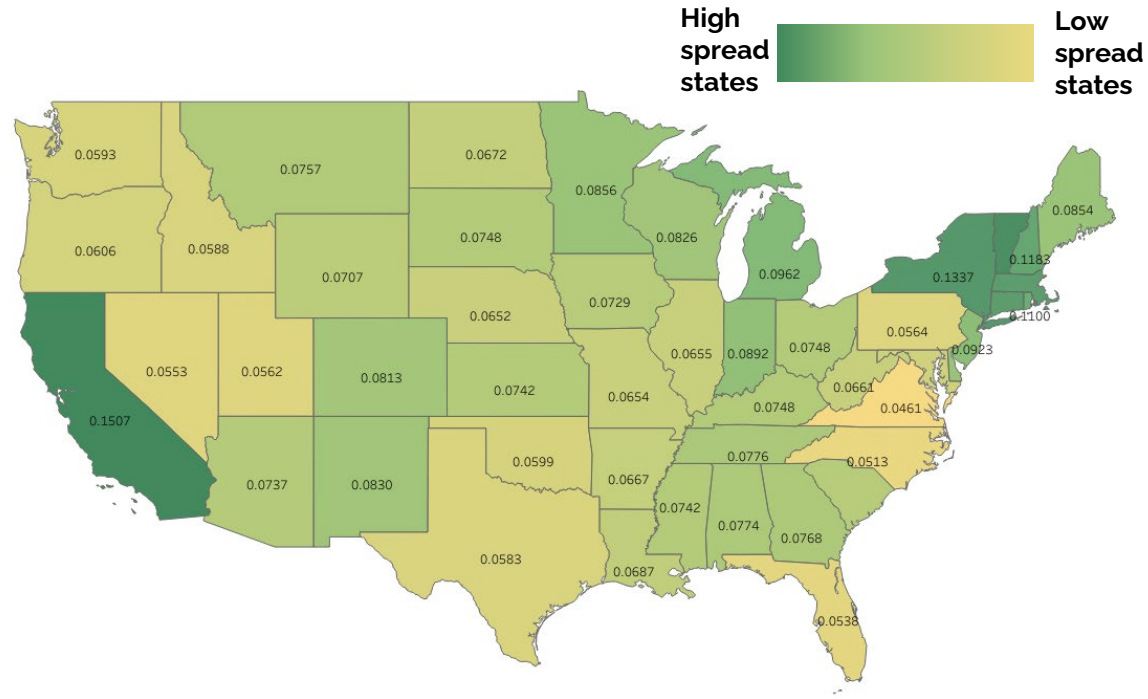
[1]Preliminary modeling results

LOWER COST OF ELECTRICITY VS. THE GRID

Levelized Cost of Electricity (LCOE) vs grid costs (cents/kWh)



Commercial electricity vs. commercial natural gas rates by state ($/kWh)



KARNO LCOE expected to be 20-50% lower than the grid given reduced capital and site development needs

Targeting states with high CNG-electricity spread can enable higher upside using KARNO

Source: EIA.gov, Commercial electricity (2021), commercial natural gas (2021), Contiguous US states only; Hyliion analysis

THANK YOU

HYLIION®

KAIZEN Clean Energy

Kaizen Clean Energy

Renewable Power
Anytime, Anywhere

September 2023

EXECUTIVE SUMMARY

Hydrogen Based Distributed Generation

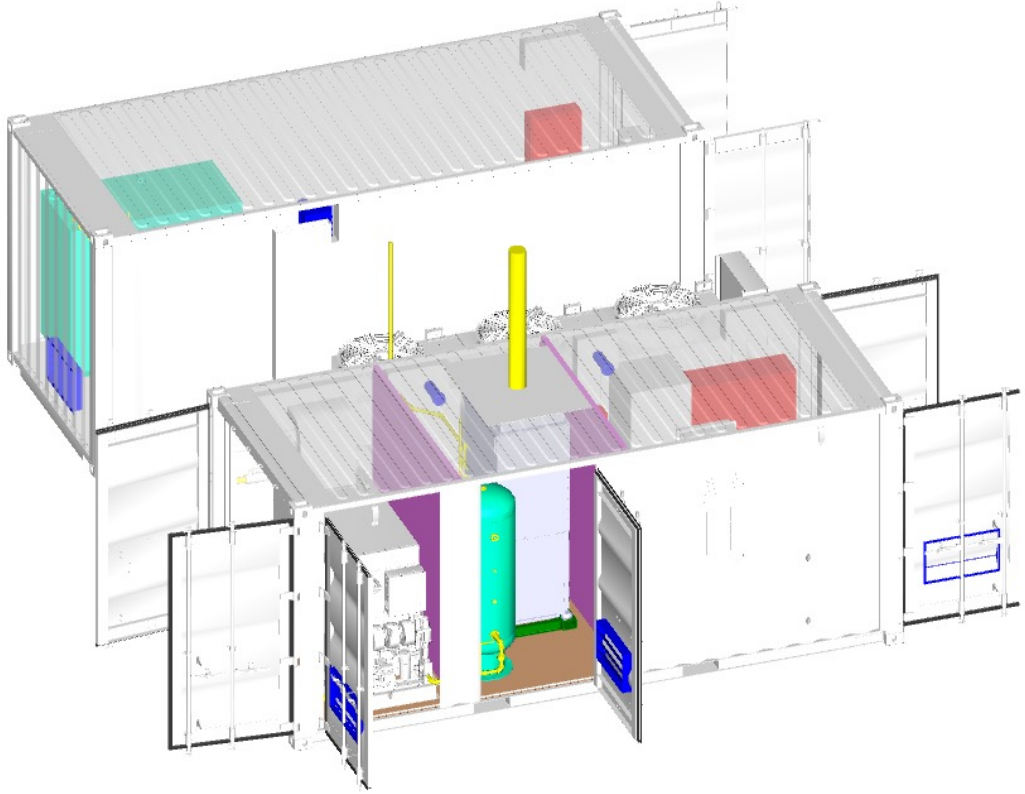
- EV charging
- Diesel generator replacement
- H2 fueling

Methanol as Hydrogen Carrier

- H2 produced on-site, on demand

Benefits

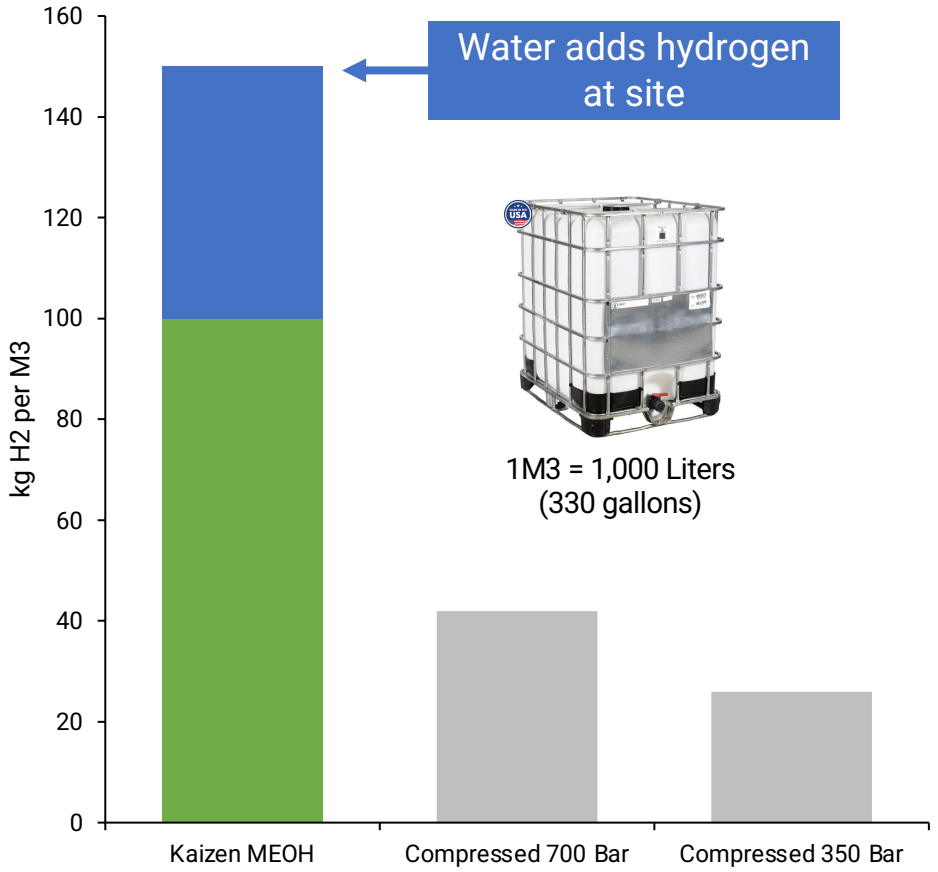
- Lower OPEX
- Flexible (moveable / scalable / energy security)
- **No local emissions (No NOx, SOx or particulates)**



Movable & scalable systems to displace diesel.

METHANOL AS A HYDROGEN CARRIER

- Lowest cost H2 carrier
  - Densest carrier of H2
  - Liquid: cheap and easy to transport and store
- Safe
  - Flammability and combustibility like diesel
  - Water soluble
  - Liquid, not gas
- Readily available
  - Globally produced
  - Extensive distribution system
  - Green methanol sources growing

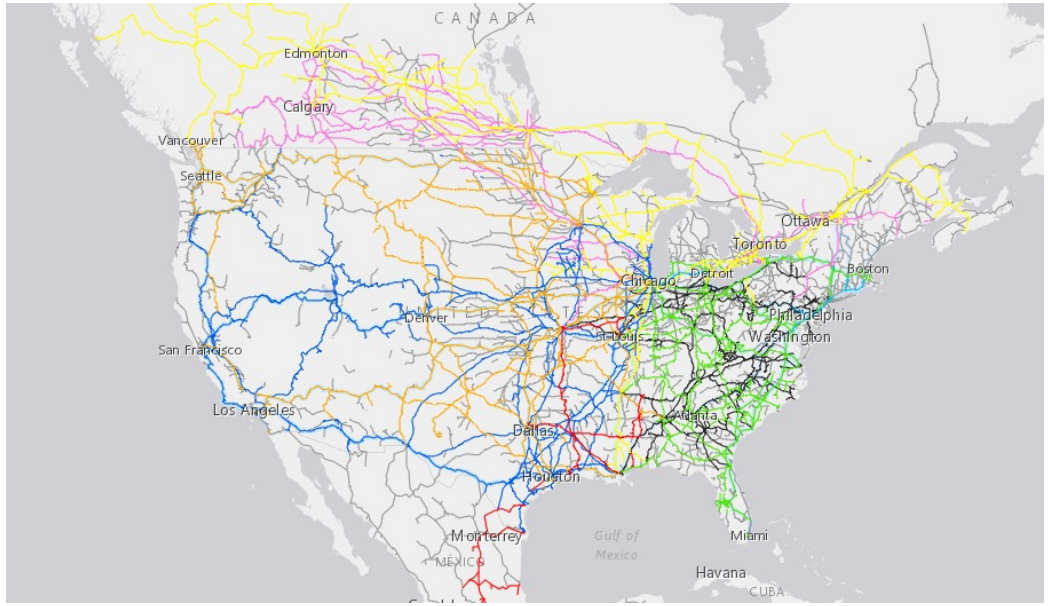


Methanol has more H2 by volume than other H2 carriers when using steam methanol reforming

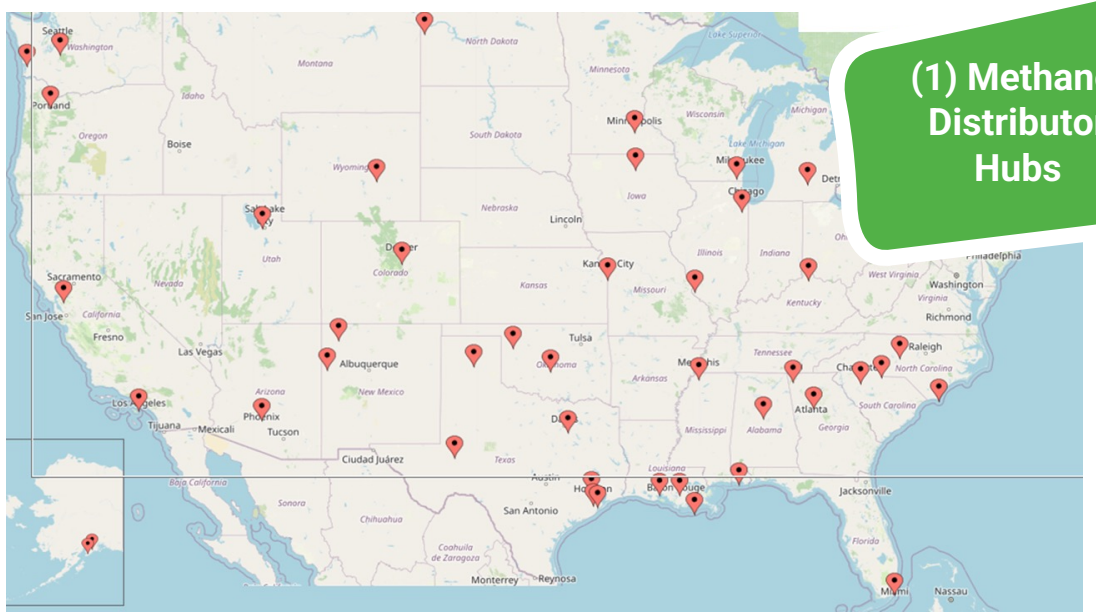
Methanol is the lowest cost and safest carrier of H2.

Source: Methanol Institute & Argonne National Laboratory

DISTRIBUTION & METHANOL HUBS



Leverages Rail Network

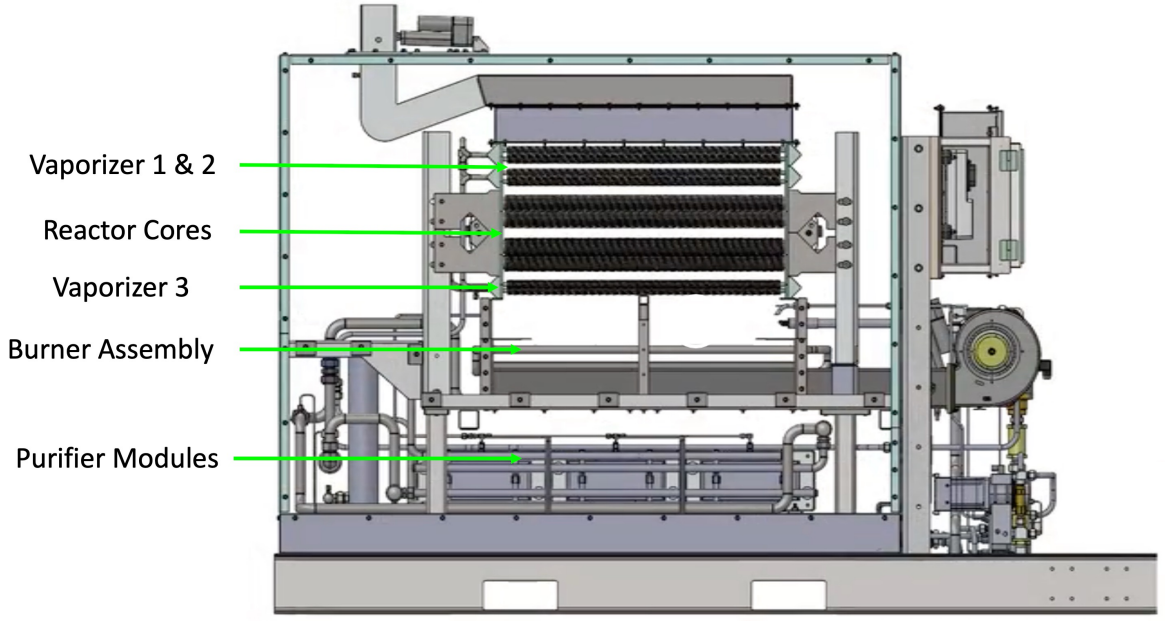


Existing MEOH Hubs

Methanol leverages existing distribution networks on rail, road, and shipping.

KCE REFORMER

- 230kg/day capacity
  - On-site, on demand production
- High efficiency
  - Lower operating temperature (400C)
  - > 80% efficiency
- Small footprint
  - 3’ x 4’ x 6’ dimensions
- Proven technology
  - ~250 H2 generators have been deployed
  - 20 + year operating history
  - Licensed from Element 1



Components of an 1,800 sLm H2 Generator

KCE’s H2 generators: compact, efficient, proven.

KCE150 EV CHARGING / MICROGRID

- **Scalable**: 150kW EV charging / microgrid scalable to MWs for primary power
- **Environmentally friendly**: No NOx, SOx or particulates. Carbon emissions of 0-45 gCO2e/MJ.
- **No permanent infrastructure**: The units are containerized and transportable.
- **Unmatched energy density**: a 20’ container provides 3.6MWh of energy per day. A 20’ fuel tank contains 48MWh of energy on-site.

KCE150

Performance	
Base Power Output	150kW
Peak Power Output	750kW
Output Voltage	AC 480v, 3-phase
Demand Response	Immediate
Operating Conditions	-40F to 120F

Emissions	
CO2	0-95 gCO2e/MJ
Nitrogen Oxides (NOx)	0 ppm
Sulfur Oxides (SOx)	0 ppm
Particulates (PM)	0 ppm
Noise	70dB (6’)

KCE 150 – 150kW base load with 750kW peaking.

UNITS IN SERVICE

Element 1

- 150kW EV Charging unit
- Demonstration in Bend OR in October

Extreme E

- 150kW DC to DC Microgrid unit
- Next race Sep 8/9 in Sardinia on Fox Sports

Products in service producing AC and DC power.

EXTREME E – A SHOWCASE FOR KAIZEN'S SOLUTION

Off-grid, transportable, zero emissions

POWER PRODUCTION CURVES

Sample multi-hour run of fuel cell & reformer.

POWER PRODUCTION CURVES

60kW long run test on left & 50-75kW tests on right.

APPLICATIONS

Application	Drivers	Current Target Market
EV charging	Advanced Clean Fleets Grid constraints	Fleets
Diesel generator replacement	NOx emissions Off-grid	Off-road vehicles Events Movie studios
H2 fueling	Innovative Clean Transit	Municipal transit agencies

TAKEAWAYS

- Lowest cost H2
- No local emissions
- Scalable
- Transportable
- Unmatched energy security
- Small footprint and spacing requirements

Questions / System Overview

Vehicle Electrification Technologies in the Heavy-Duty Sector

Seungbum Ha

Cleans Fuels Advisory Group Retreat

September 14, 2023

Heavy-Duty Battery Electric Truck Project

2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023

100mi

150mi

200mi

Early Demo
Tier 2 manufacturer developed EV technology

ZECT I
Battery Electric /CNG Hybrid
$13.3M($1.2M)

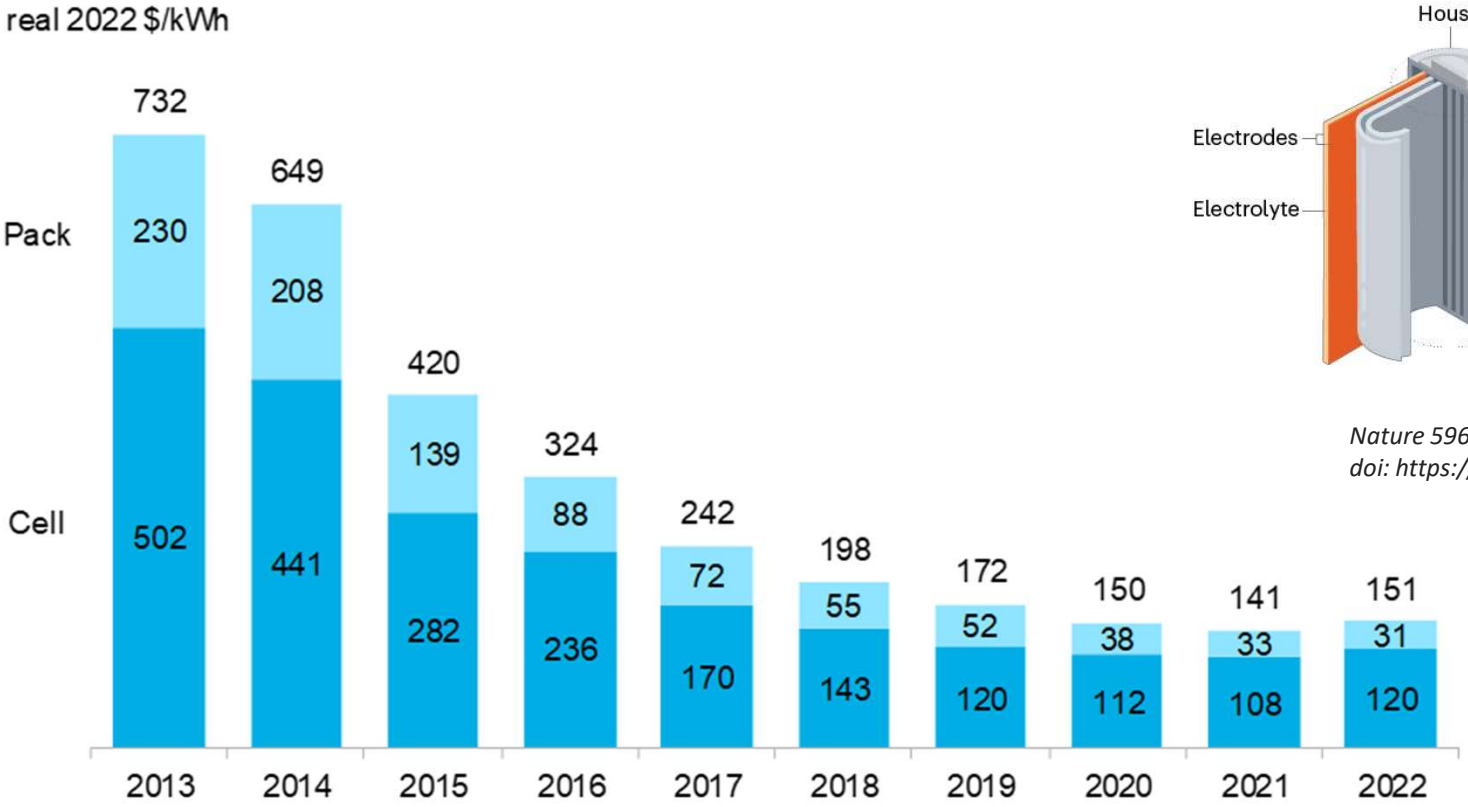
GGRF
Battery Electric /Hybrid
$40M($6M)

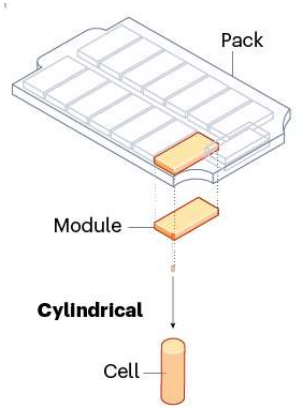
Daimler **Volvo**
Battery Electric
$31M($13M) **$90.4M($4M)**

CARB/CEC Pilot
Battery Electric
$70.4M($5.6M)

** $ Total Project Cost(SCAQMD Cost-share)*

Lithium-ion Battery – 10-year pricing history





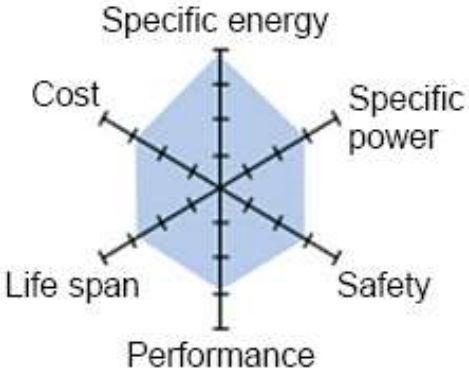
Nature 596, 336-339 (2021)
doi: https://doi.org/10.1038/d41586-021-02222-1

Bloomberg New Energy Finance above

https://about.bnef.com/blog/lithium-ion-battery-pack-prices-rise-for-first-time-to-an-average-of-151-kwh/

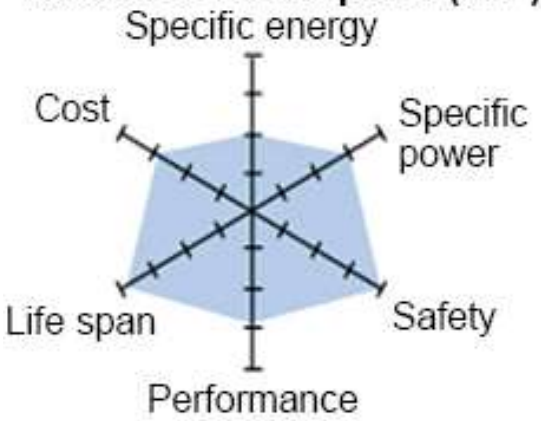
Lithium-ion Battery – Chemistry

Lithium-Nickel-Manganese-Cobalt (NMC)



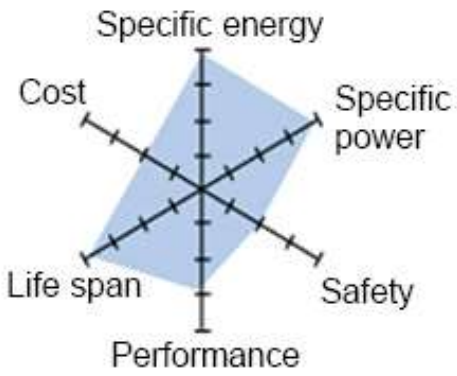
- High specific energy
- Good for EV application
- Relatively shorter life cycle

Lithium-Iron Phosphate (LFP)



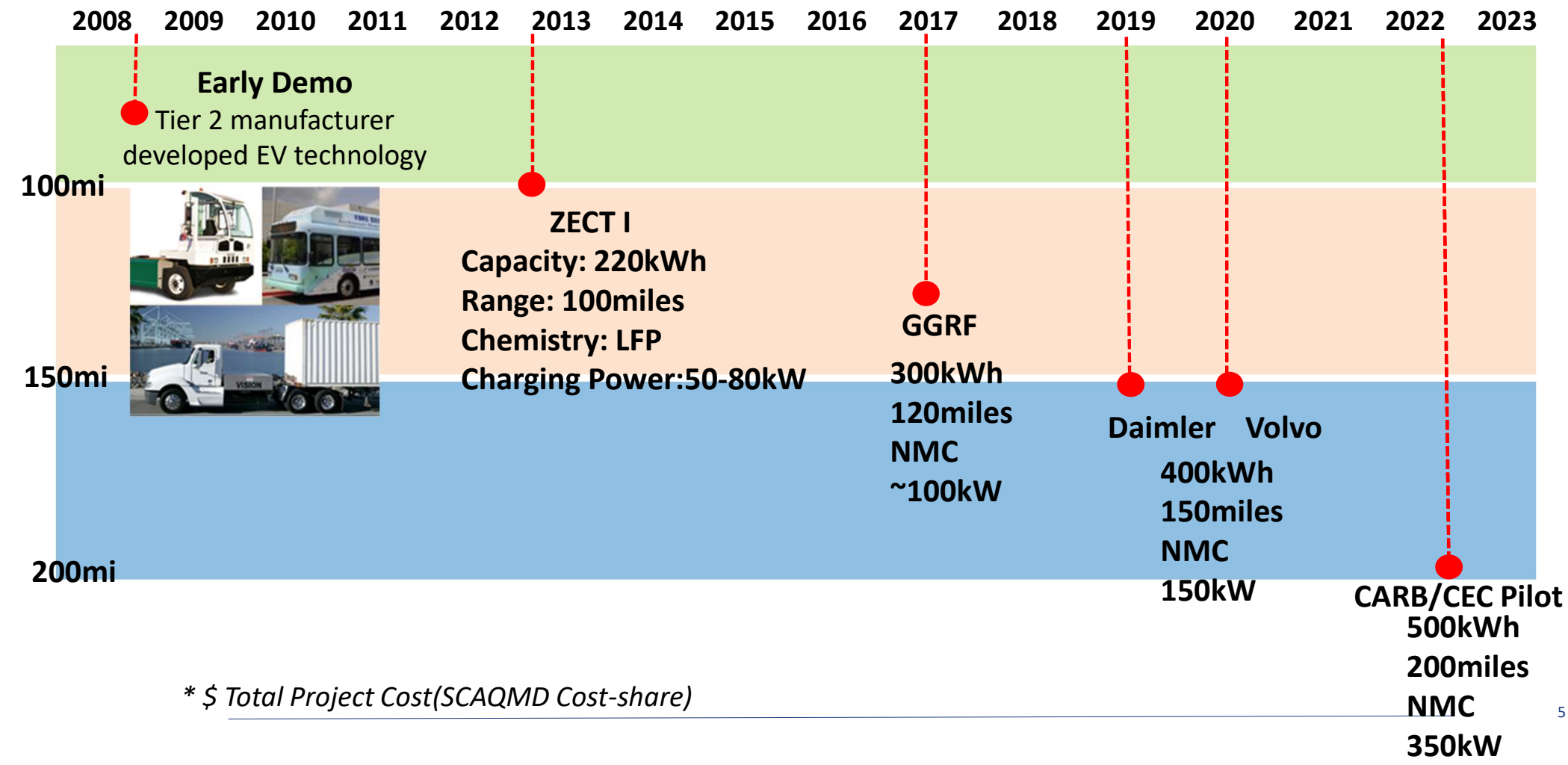
- Long life cycle
- Good thermal stability
- Enhanced safety
- Low energy density
- Poor performance at low temperatures

Lithium-Nickel-Cobalt-Aluminium (NCA)



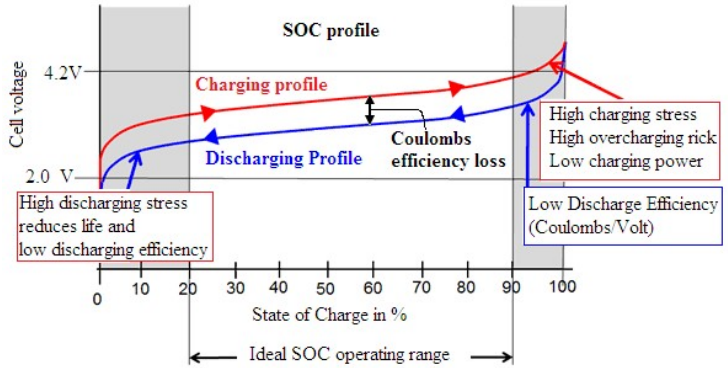
- High specific energy
- Good specific power
- Long life span
- Expensive
- Thermal instability

Heavy-Duty Battery Electric Truck Project

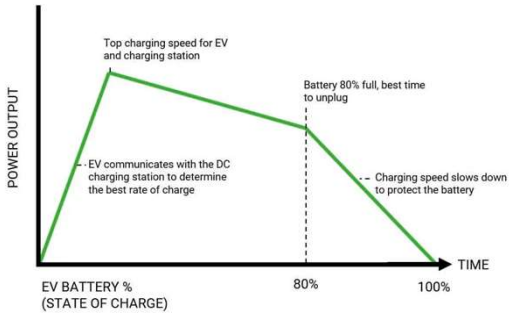


** $ Total Project Cost(SCAQMD Cost-share)*

Charging Duration – Still a Challenge…



Bharatiraja, C. & Padmanaban, Sanjeevikumar & Siano, Pierluigi & Ramesh, K. & Selvaraj, Raghu. (2017), Energies. 10. 10.3390/en10030377.

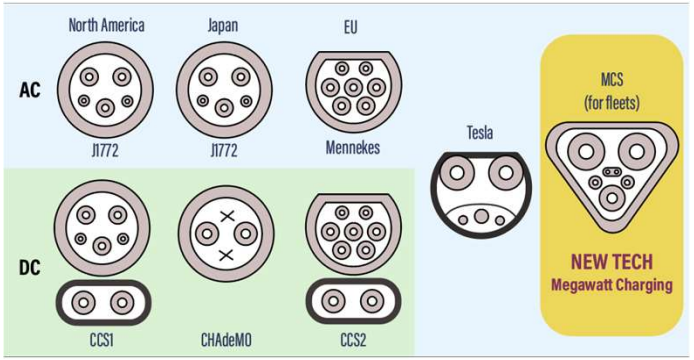


https://www.power-sonic.com/blog/the-ultimate-guide-to-dc-fast-charging/

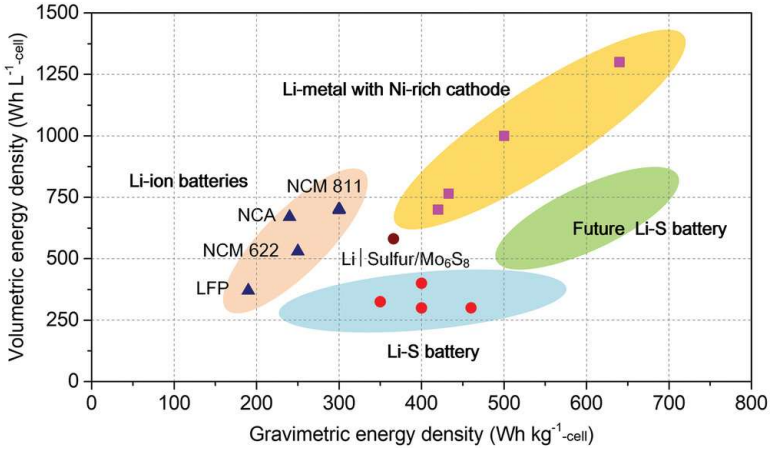
Megawatt Charging System(MCS)

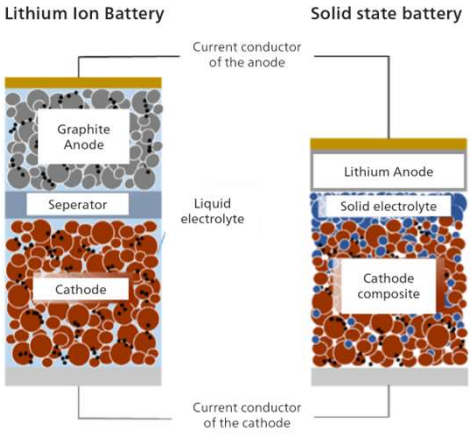
Charging rate	Charging hours*	Miles/min charging
150kW	2 hours	1miles/min
350kW	50mins	2.3miles/min
1MW	18mins	6.7miles/min

*Charging 20-80% of SoC

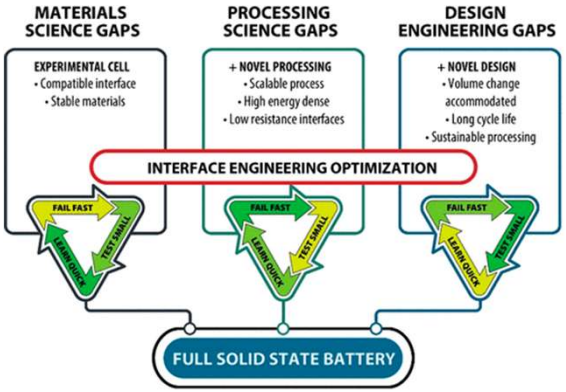


Energy Density and Safety – Still a challenge…





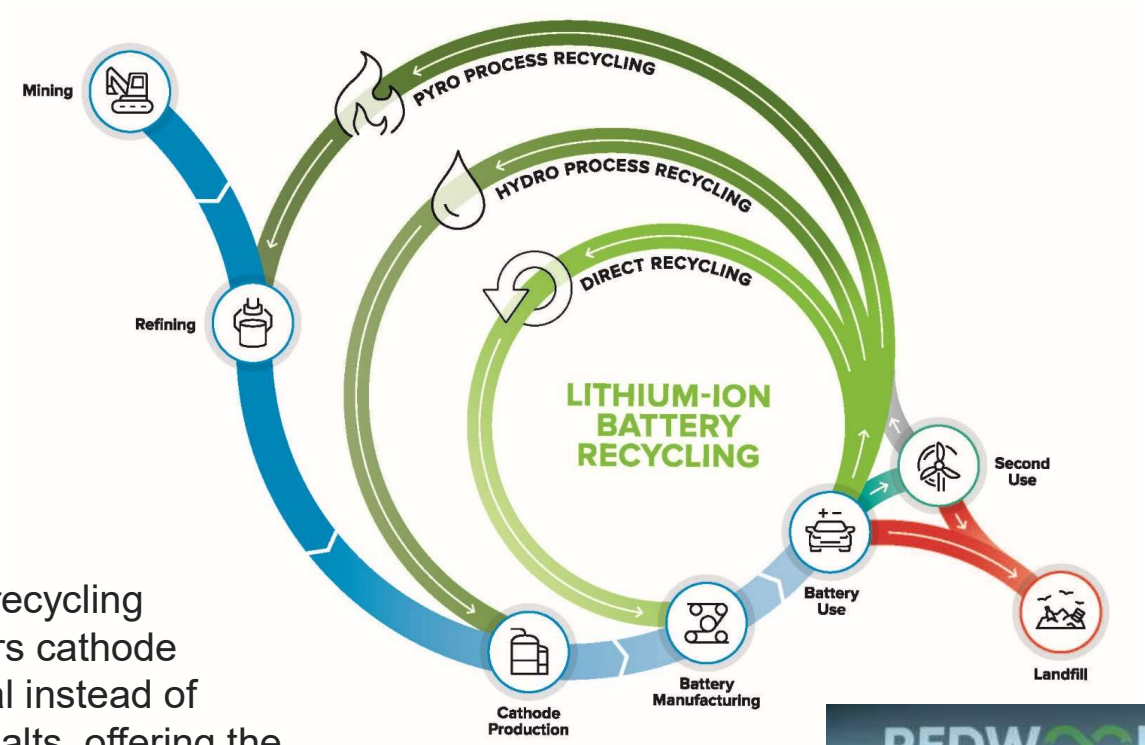
- Higher energy density
- Faster charging
- Improved safety
- Improved performance in extreme temperatures

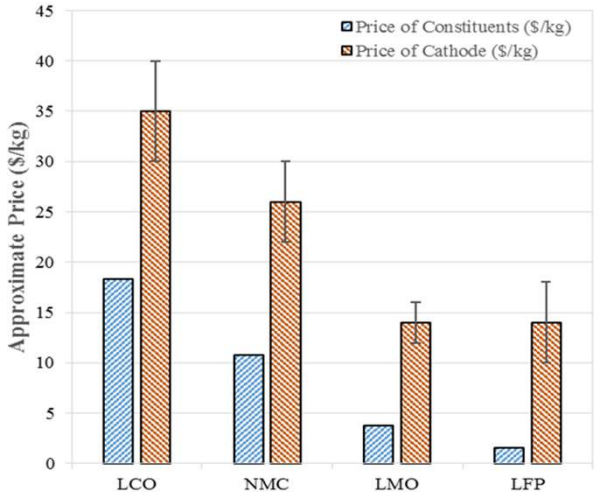


https://www.raylase.de/en/applications/Battery-Production-electric-mobility/solid-state-batteries-1.html

https://pubs.acs.org/doi/10.1021/acsenergylett.1c00445

Lithium-ion Battery – Recycling





https://www.anl.gov/topic/recell

Direct recycling recovers cathode material instead of metal salts, offering the most potential for cost effectiveness

range

Bringing trailers to life

South Coast AQMD | Sept. 14, 2023

Mission

Make towing cleaner, safer, and better for drivers, today.

Team

Our team has an action-biased culture marked by integrity, humility, competence, and passion for the mission and the systems we design.

We are building real products here, and are looking for doers to join us.

We are creators, makers, and doers.

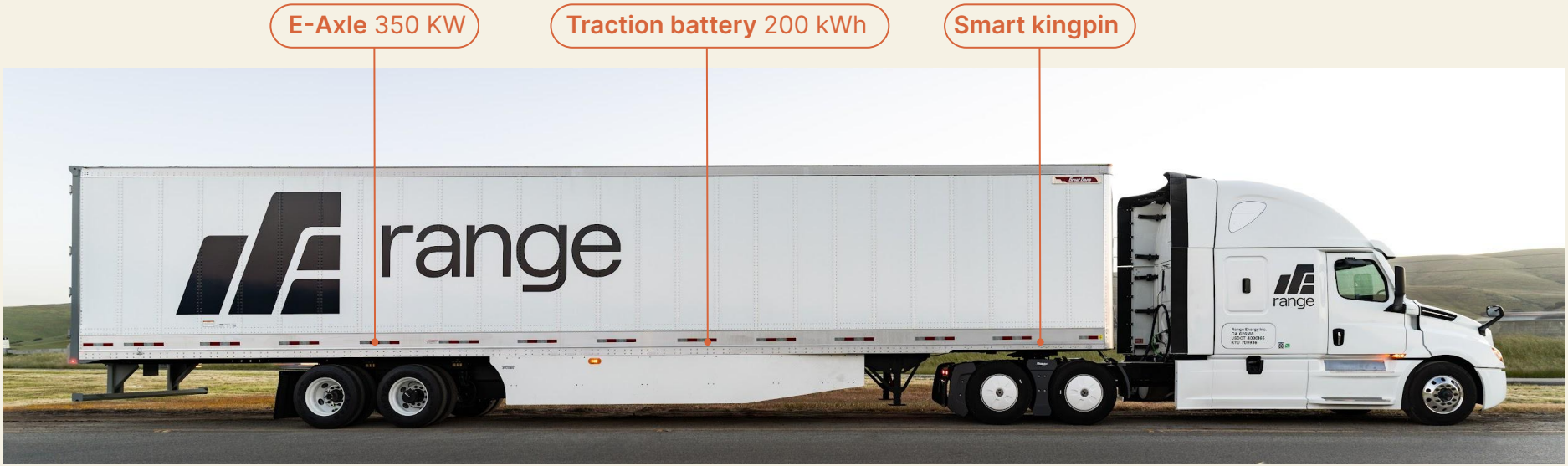
Ali Javidan
Founder/CEO

Google NIO Bloomenergy RW Molekule Walmart Caltrans RTX Freightliner SRI International amazon

AIRBUS Honda Universal Hydrogen Meggitt Zoox Tesla Dräxlmaier Lucid XOS Archer NGT Rivian

Helping meet your environmental goals

Range RA-01 Trailer



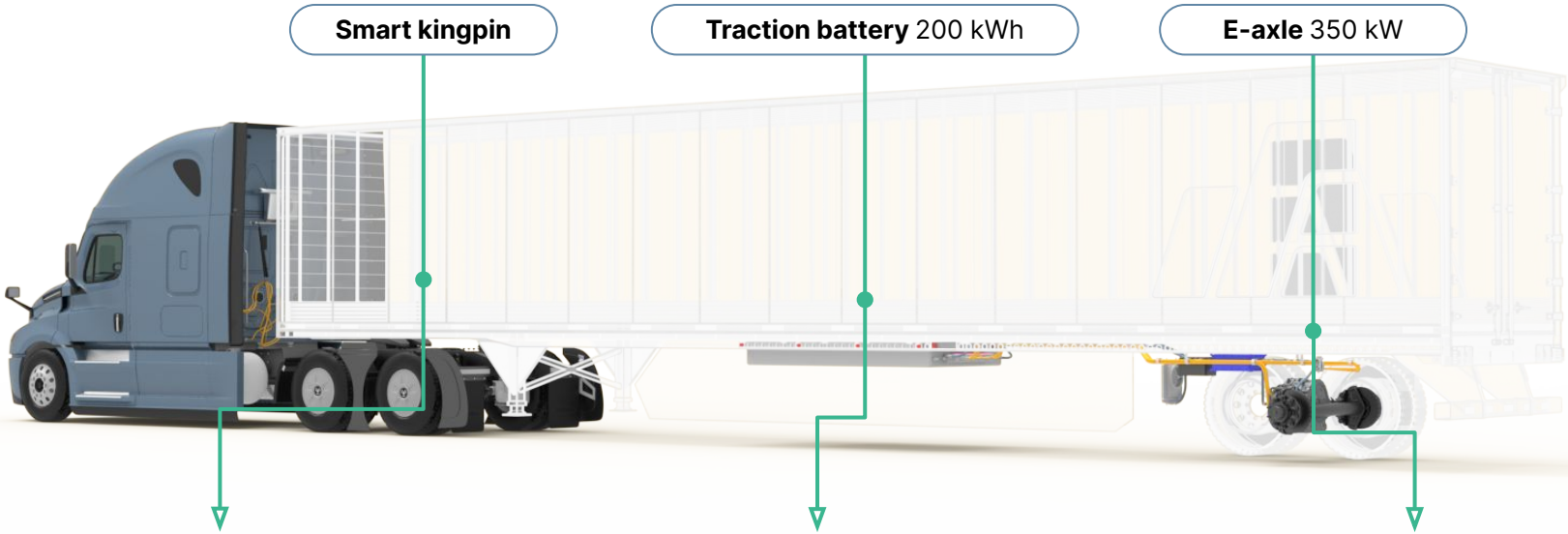
Lower diesel emissions by 30-40%

No changes needed to your fleet

Unlimited range in mild-hybrid mode

20,000+ miles on the road.

How our system works

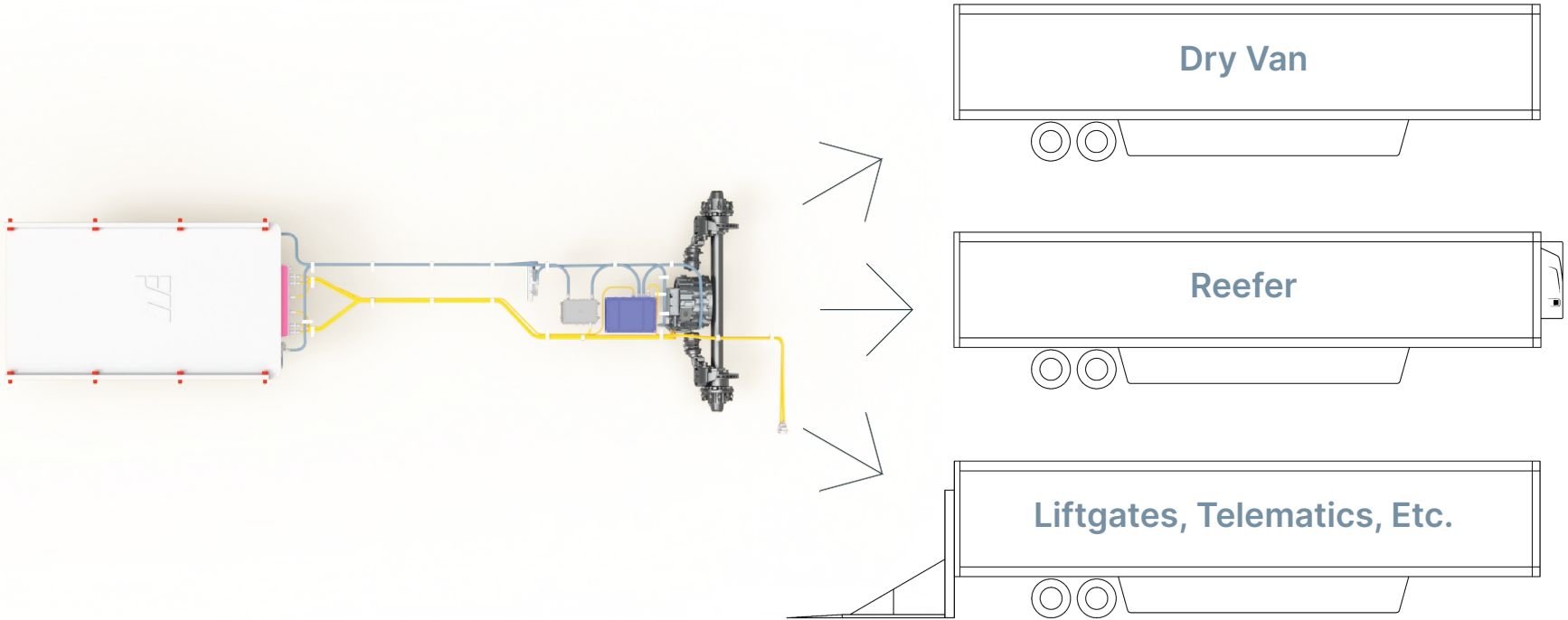


Measures the work the tractor is doing

Stores energy from regen and charge

Assists propulsion to reduce engine load

One Platform, Many Applications



Charging That Fits Existing Utilization Patterns

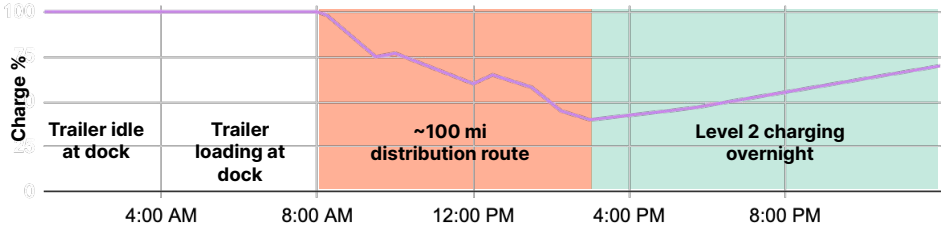
DOCK CHARGING: LOADING TRAILERS WITH ELECTRONS AND CARGO SIMULTANEOUSLY

Standard chargers take valuable space

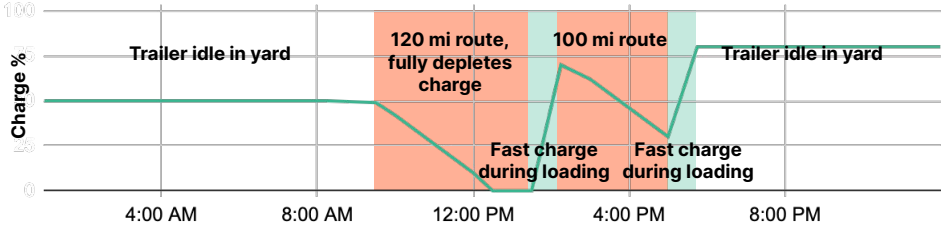
Aerial view of landlocked 55 acre customer site

Dock-based charging is space and time-efficient

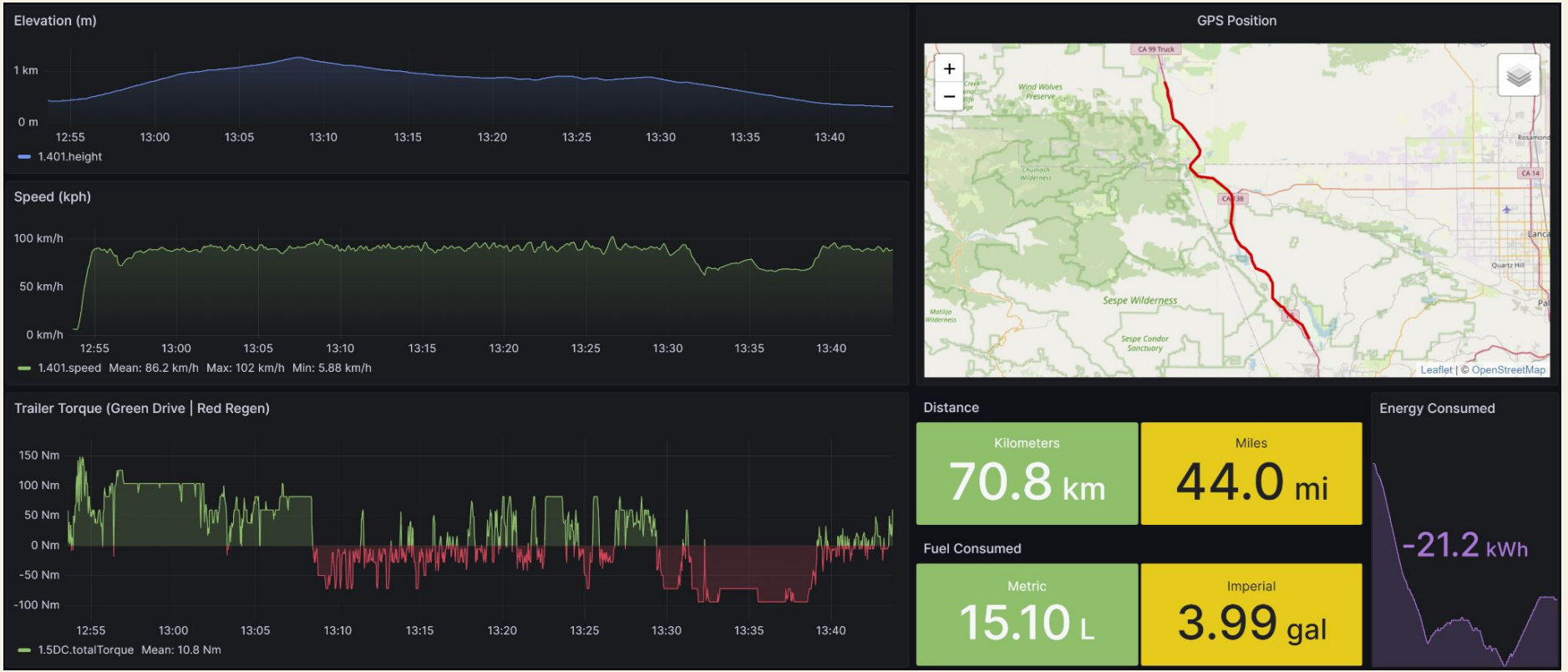
DSD route: Day-long route + Level 2 charging



Plant/DC route: Multiple longer trips + DC fast charge



Cruising up the Grapevine getting 11.03 mpg!



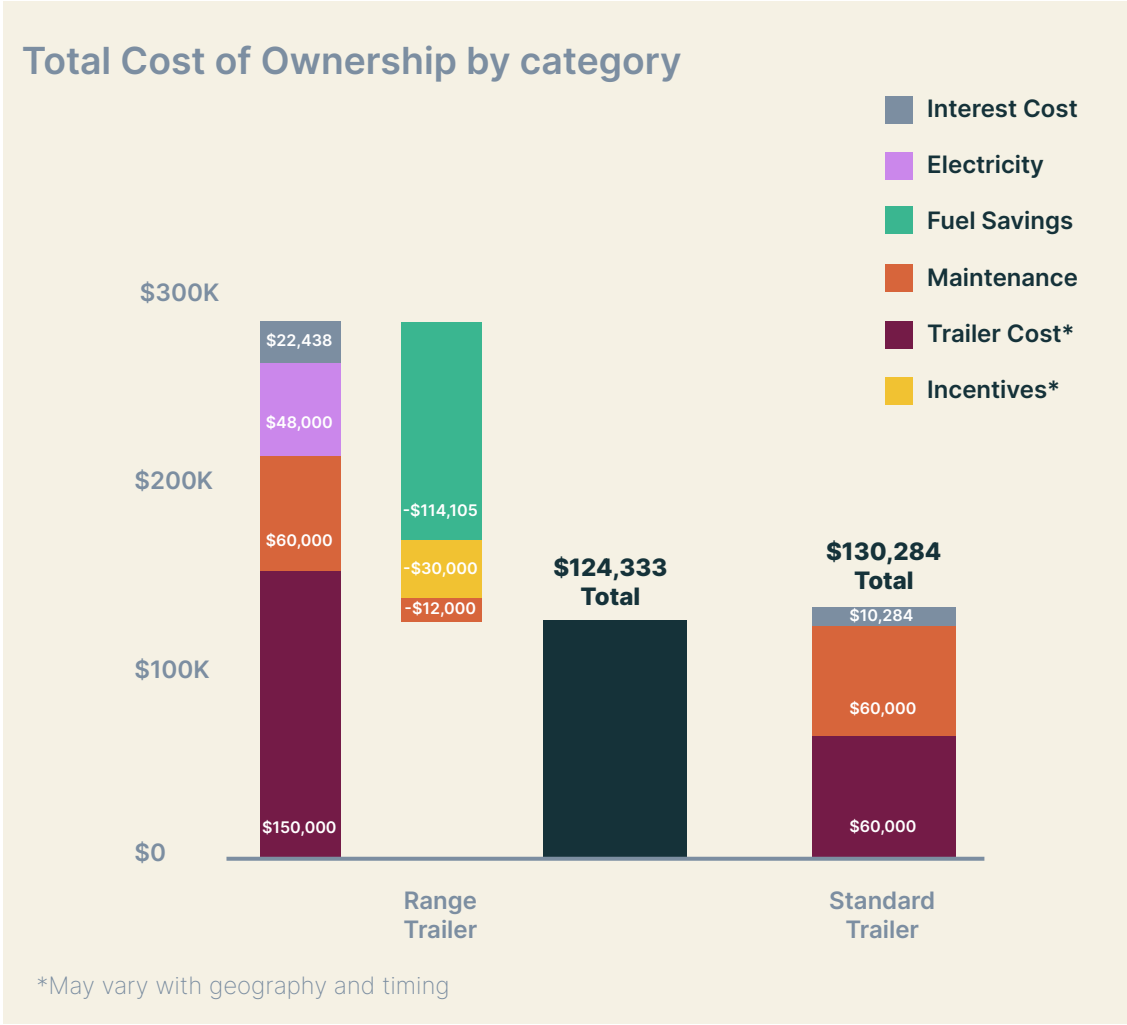
Customer Benefits

Lower fuel consumption

Lower maintenance costs

Lower CO2, NOx, and particulate emissions

Access to incentive programs (Range already eligible for a $80k voucher as part of California CORE)



Customer Interest

Interested Fleets in pipeline include:

5 of the top 25 private fleets

5 of the top 50 for-hire fleets

8 of the top 100 logistics companies

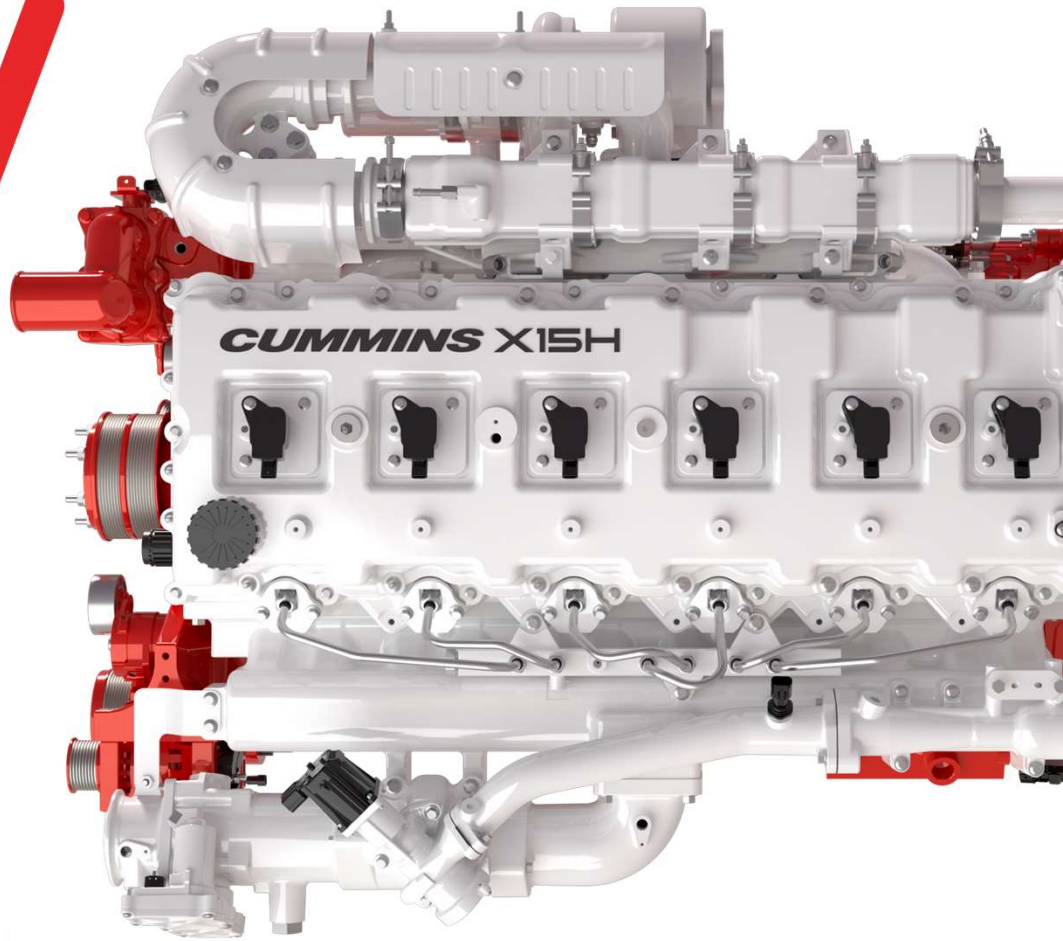
Thank You!

Hydrogen Internal Combustion Engines (ICE)

A PRACTICAL SOLUTION FOR DECARBONIZATION

Jim Nebergall

General Manager - Hydrogen Engines
Cummins Inc.



Accelerating toward

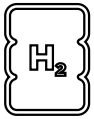
Destination Zero

Cummins will continue to innovate and invest as we advance along the path to zero, but we can't do it alone.

- Action is required today.
- Progress requires partnership.
- Technology leadership is critical.

ENERGY SOURCES

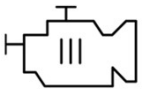
LOW CARBON FUELS



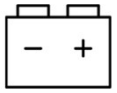
GREEN HYDROGEN ECONOMY

DECARBONIZED GRID

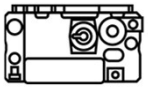
POWER SOLUTIONS



ADVANCED ENGINES
diesel | natural gas | hydrogen



BATTERY ELECTRIC



FUEL CELL ELECTRIC

OUR COMMITMENT TO HYDROGEN

CUMMINS IS INVESTING IN THE FULL HYDROGEN ECO-SYSTEM

PRODUCTION

STORAGE

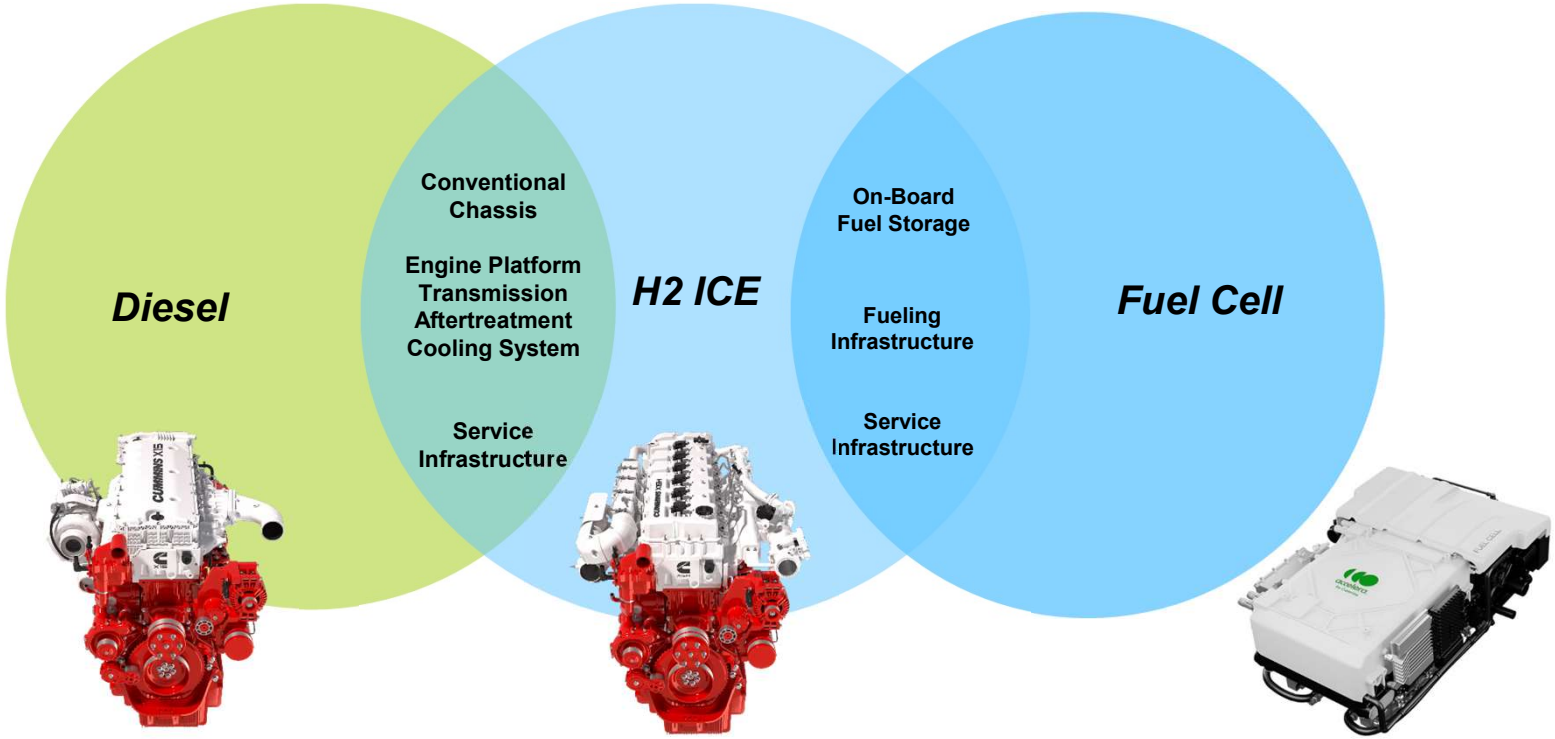
FUEL CELLS

HYDROGEN ICE

HYDROGEN IN COMMERCIAL VEHICLES

CUMMINS IS PROGRESSING TWO COMPLEMENTARY HYDROGEN POWER TECHNOLOGIES

H2 ICE has Fast Maturity due to Technology Commonality



…and accelerates Fuel Cells

HYDROGEN ICE IS WITHIN REACH

THE EVOLUTION OF AN EXISTING CONCEPT IS CREATING A REVOLUTION IN SUSTAINABILITY

Supports decarbonization of the commercial vehicle industry

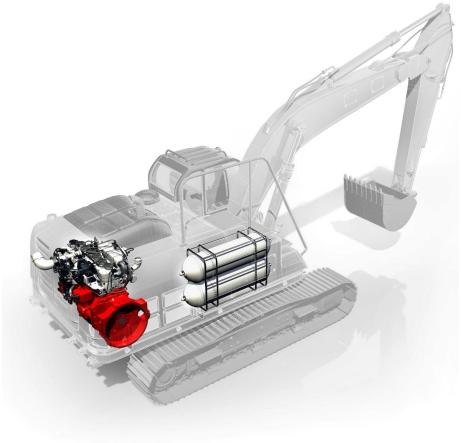
- Zero-carbon well-to-wheel with green hydrogen
- Scale production can begin within the decade

Benefits to end users

- Competitive initial cost
- Familiar powertrain technology, vehicle technology and maintenance practices
- Single fuel supply switch across a range of duty cycles

Complementary to hydrogen fuel cell

- Builds scale for hydrogen storage tanks on vehicle
- Drives hydrogen fueling infrastructure
- Common hydrogen service and support infrastructure



HYDROGEN ICE

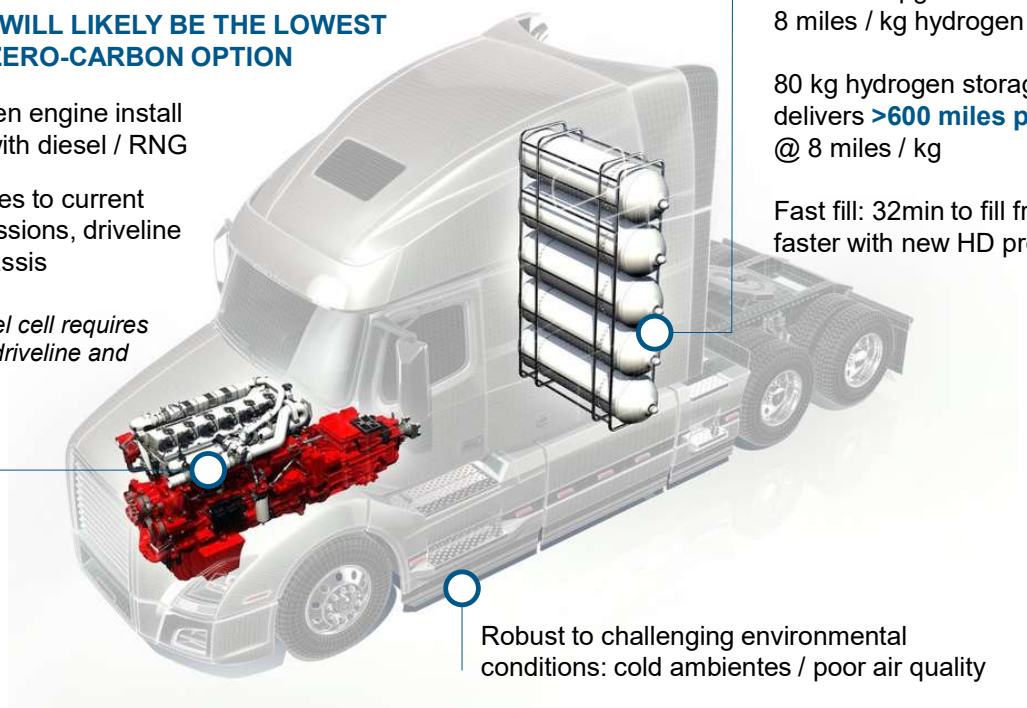
2027 / NORTH AMERICA / LINE HAUL / 120,000 MILES PER YEAR / 500+ MILE RANGE

H2-ICE WILL LIKELY BE THE LOWEST COST ZERO-CARBON OPTION

Hydrogen engine install aligns with diesel / RNG

Integrates to current transmissions, driveline and chassis

Note. fuel cell requires electric driveline and battery

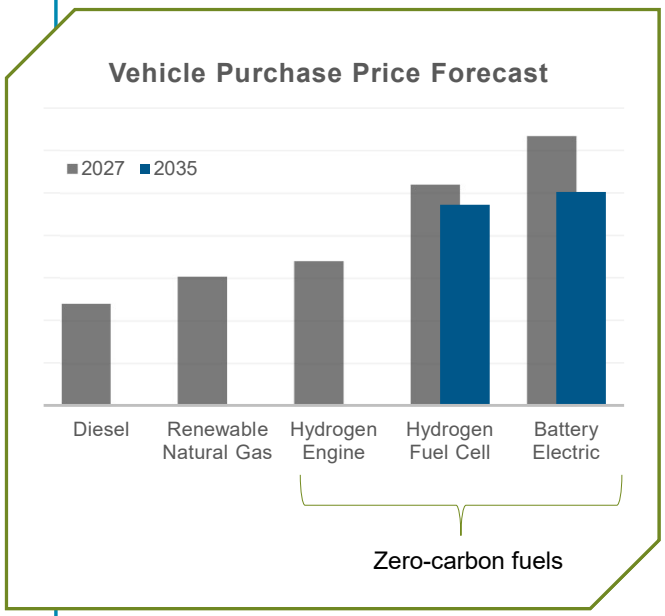


Diesel 9 mpg =
8 miles / kg hydrogen

80 kg hydrogen storage unit @ 700bar delivers **>600 miles per day range** @ 8 miles / kg

Fast fill: 32min to fill from empty, even faster with new HD protocol

Robust to challenging environmental conditions: cold ambientes / poor air quality



VECTO & GEM: CO_2 score forecast to be equivalent to battery electric and fuel cell powertrains

HYDROGEN ICE IS WITHIN REACH

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Complementary to hydrogen fuel cell

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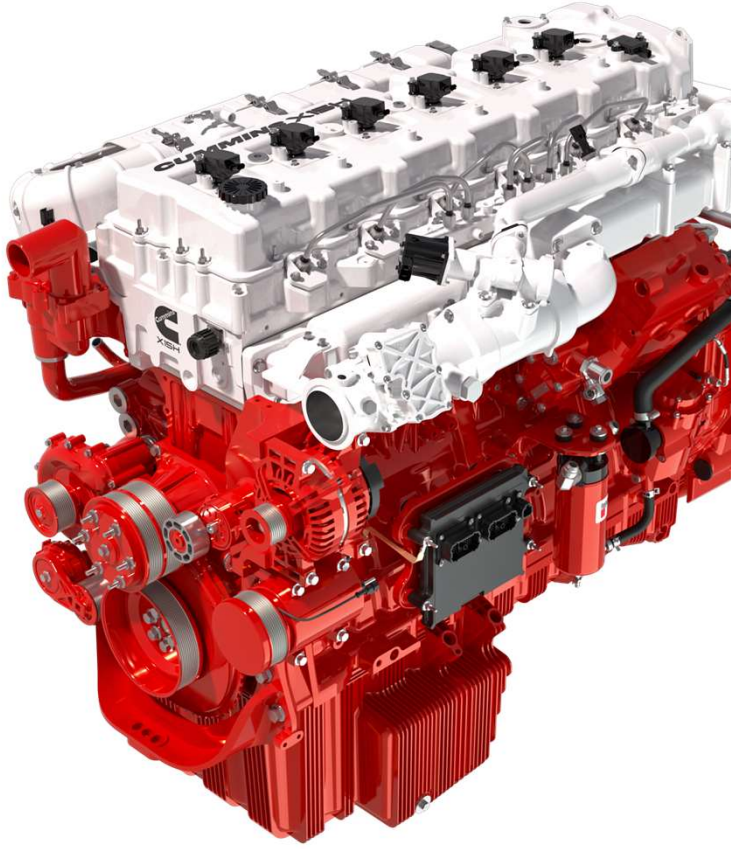
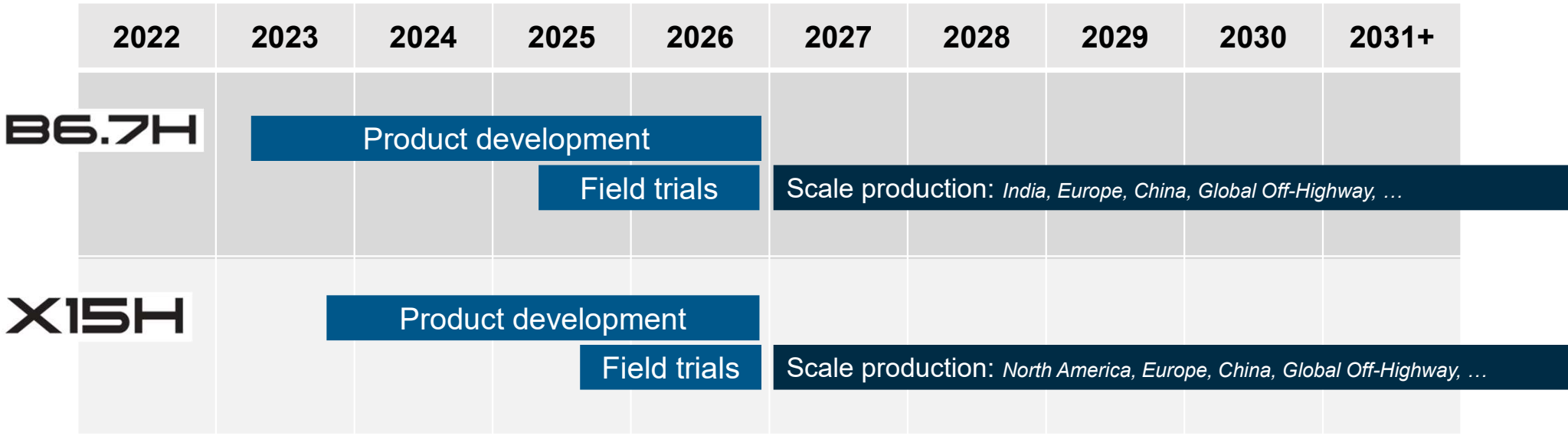


HYDROGEN ICE TECHNOLOGY READINESS

Global: Directional



Field trials: *limited quantiles available, pre-series*
Scale production: *production pricing, warranty, durability*

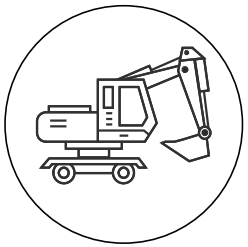
INITIAL TARGET HYDROGEN ICE APPLICATIONS

PERFORMS EFFICIENTLY IN DIVERSE APPLICATIONS AND DUTY CYCLES ACROSS MANY MARKETS

Regional Haul

Line Haul

Vocational



Construction

Agriculture

Terminal Tractor

Power Generation

…AND MORE

THANK YOU!

CONTACT:
Jim Nebergall
General Manager - Hydrogen Engines
jim.r.nebergall@cummins.com

ONLINE:
www.cummins.com/engines/hydrogen-engines

DEUTZ Solution Park
H2 for Off-Highway Applications

CLEAN FUELS PROGRAM ADVISORY GROUP
September 14th, 2023

Christoph Scholtes
CTO | DEUTZ Americas

DEUTZ Provides Drive Systems for Different Application Segments

Construction Machinery

Material Handling

Agricultural Machinery

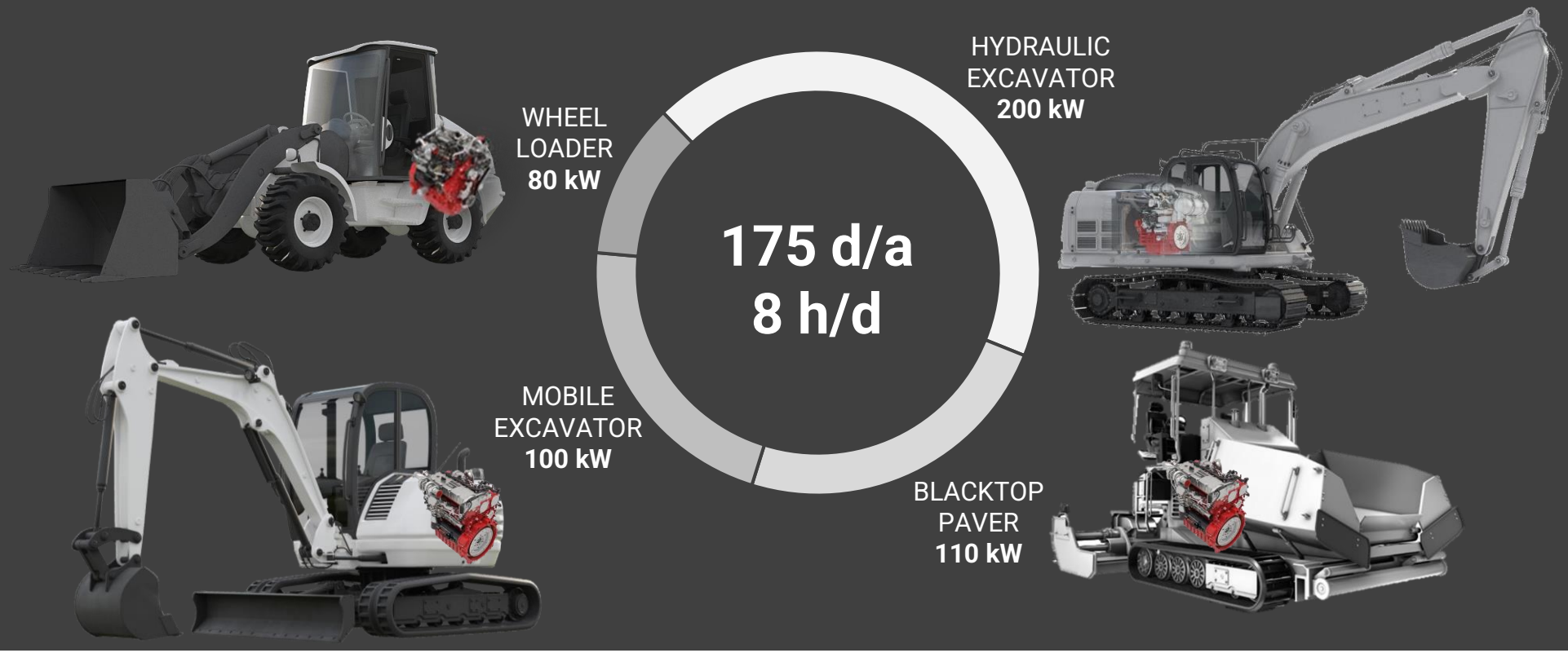
Stationary Systems

Other

Future Challenges

- Emissions Reduction
- Noise Cancellation
- Optimization of Drive Solutions
- Well-to-Wheel Analysis & Life Cycle Assessment
- CO_2 Neutrality

DEUTZ Engines Power Construction Sites That Are Responsible for Considerable Amounts of CO_2



140 TONS

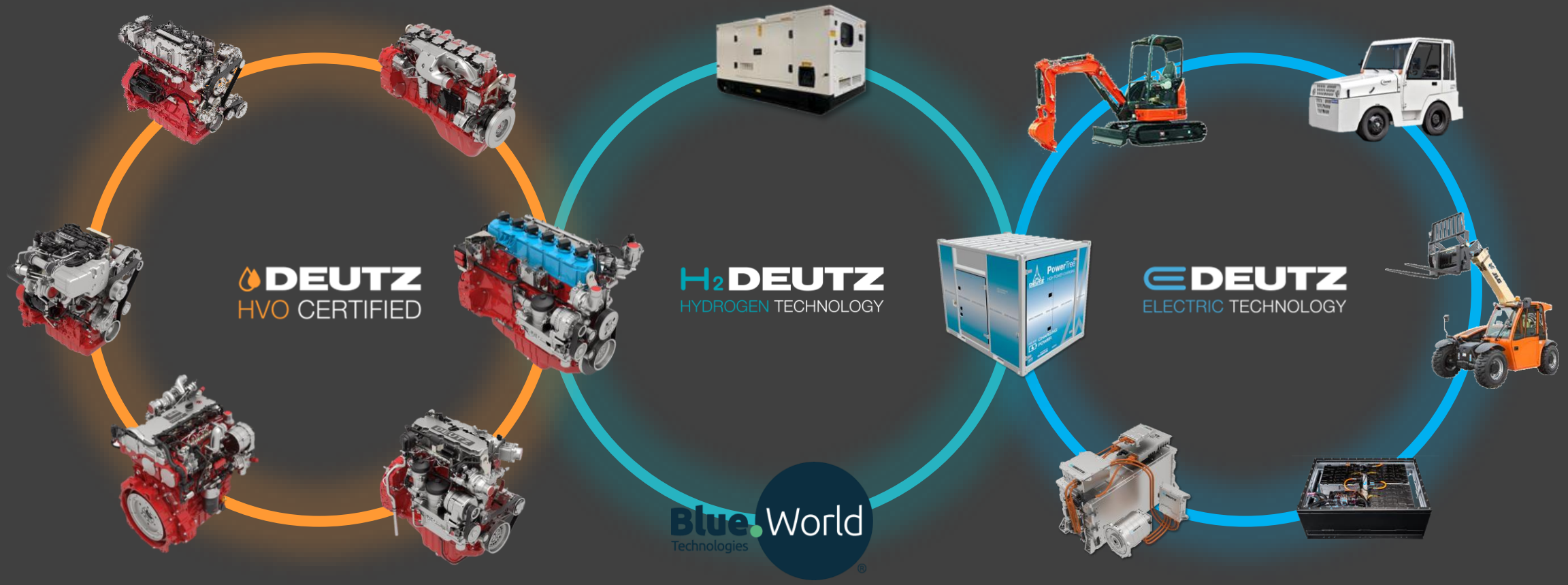
OF CO_2 ARE EMITTED BY THIS EXAMPLARY CONSTRUCTION SITE - PER YEAR

WE ARE COMMITTED TO MAKING OUR PRODUCT ECOSYSTEM

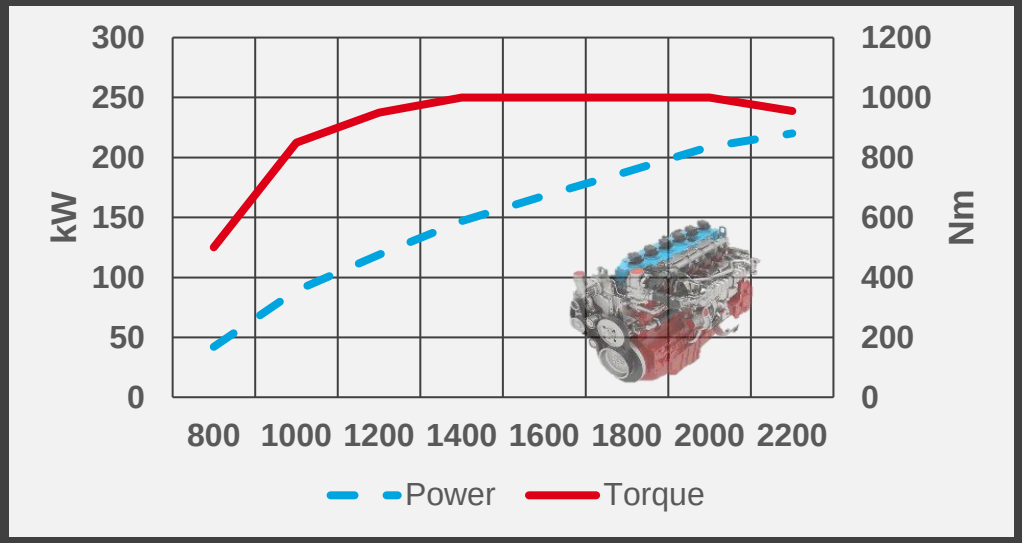
CLIMATE-NEUTRAL

BY 2050

DEUTZ Solution Park – No “One Solution Fits All” Approach

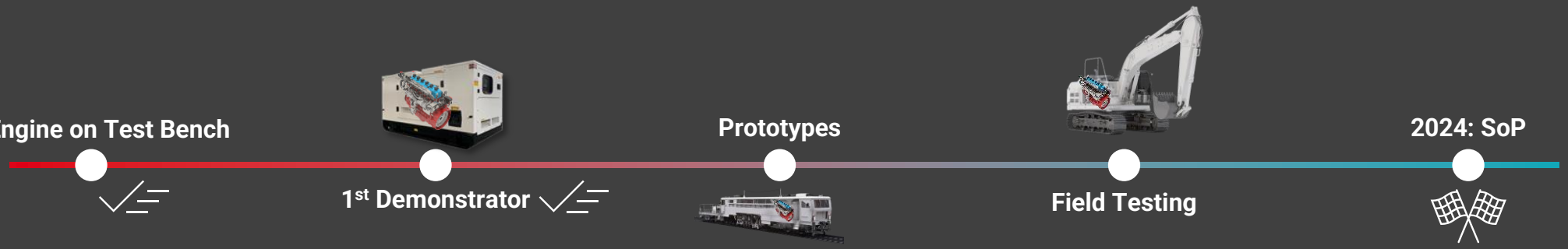


H_2 ICE: DEUTZ TCG 7.8 Hydrogen Engine - Specification



SPECIFICATION	
Cylinder	6 in-line
Displacement	7,8 liter
Bore / stroke	110 / 136mm
Max. power	220 kW @ 2200rpm
Max. torque	1000 Nm @ 1000 – 1600rpm
Certification	EU Stage V, EU Zero Emission[1]
Exh. Aftertreatment	SCR only[2]

1. <1 g CO_2/kWh 2. necessary for high power density and dynamic

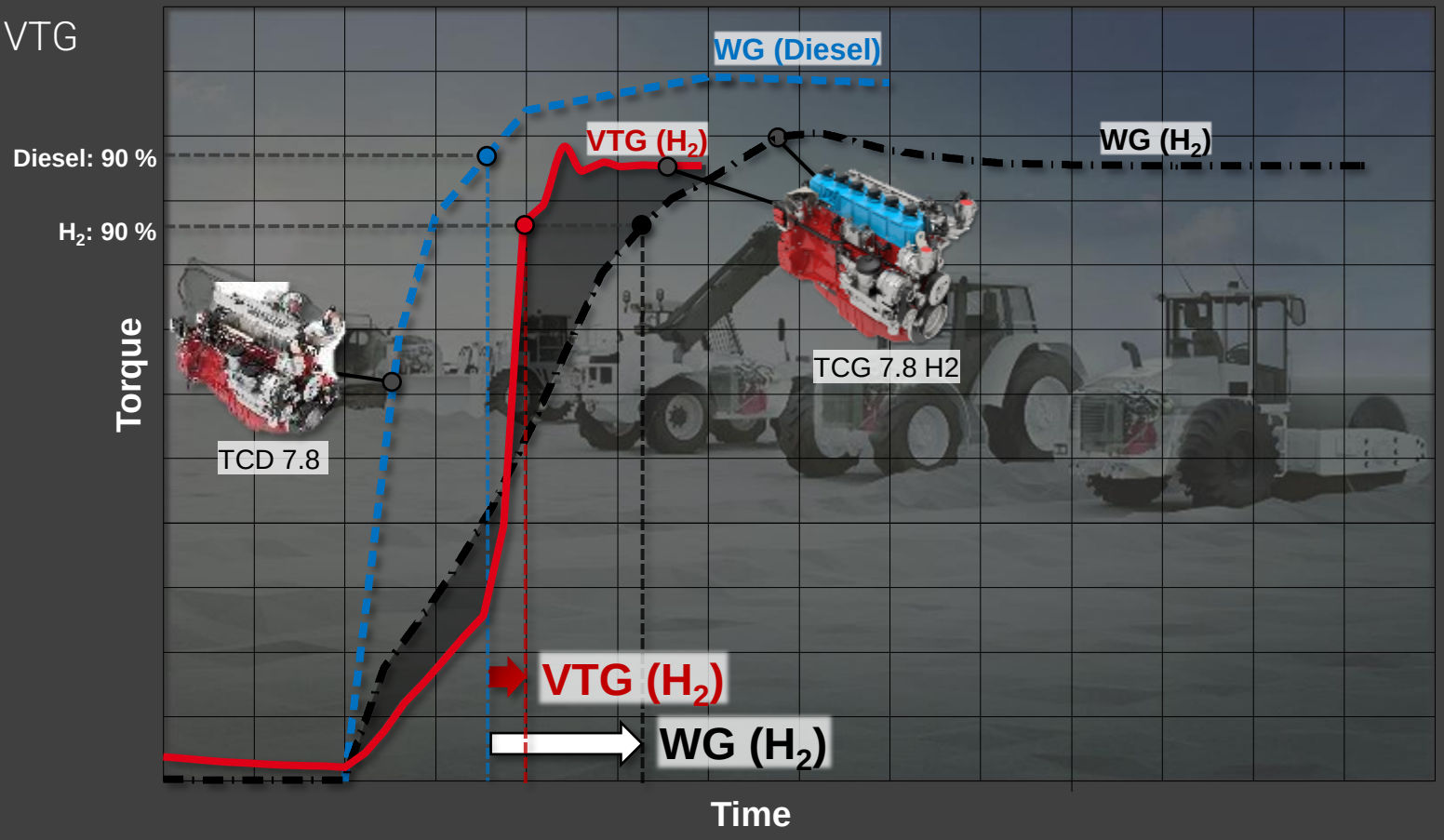


H_2 ICE: DEUTZ TCG 7.8 Hydrogen Engine – Transient Response

H2 characteristics in an ICE:

- Density (Energy to Volume) NA, WG or VTG

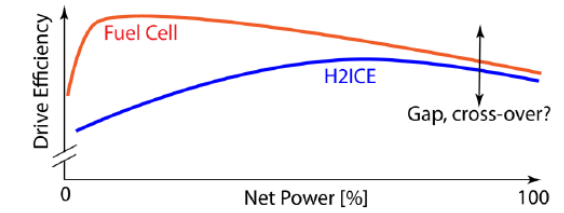
- Diffusivity
- Air/ Fuel Ratio
- Ignition Energy
- Auto Ignition Temp
- Flame Velocity

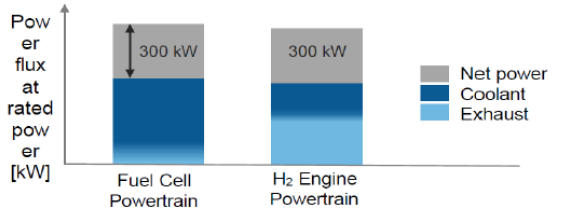


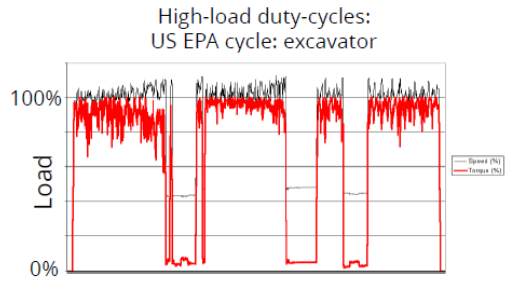
H_2 ICE: DEUTZ TCG 7.8 Hydrogen Engine – Some Characteristics in Comparison

3 RELATIVE STRENGTHS OF H2ICE AND H2FC – TODAY'S TECHNOLOGY

Characteristic	H2ICE	H2FC
Efficiency	Good: mid – high load	**Excellent: low – mid load**
Cooling needs	**Intermediate**	High, critical for stationary and slow-moving applications
Emissions	NOx (and minor CO_2) Low with aftertreatment	**None**
Durability	**High**	Improving with new R&D
Robustness	**High**	Sensitive to vibration
Noble metal consumption	**Low – intermediate** (after-treatment)	High
Fuel purity	**Tolerant to contaminants**	High-purity H2 required
Fuel flexibility	**Diesel/NG backup**	Can be flexible, efficiency penalty
Upfront cost	**Low**	High
Cold start	No issues	Temperature conditioning
Resale value	Depending on infrastructure	Unclear

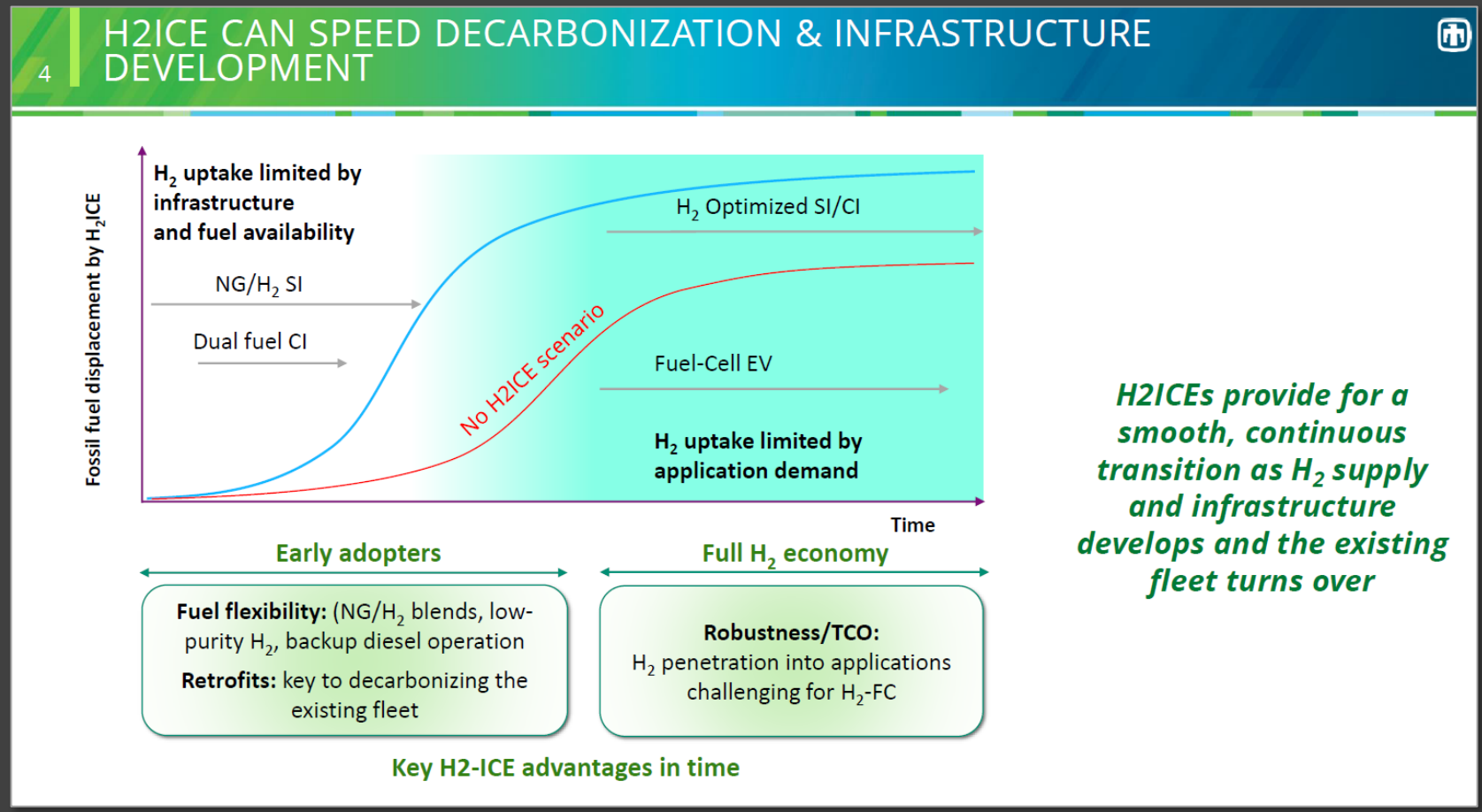






Source: Aleš Srna, Energy & Homeland Security „Is there a place for H2 internal combustion engines?“

H_2 ICE: DEUTZ TCG 7.8 Hydrogen Engine – H2 ICE can help accelerate CO2 reduction



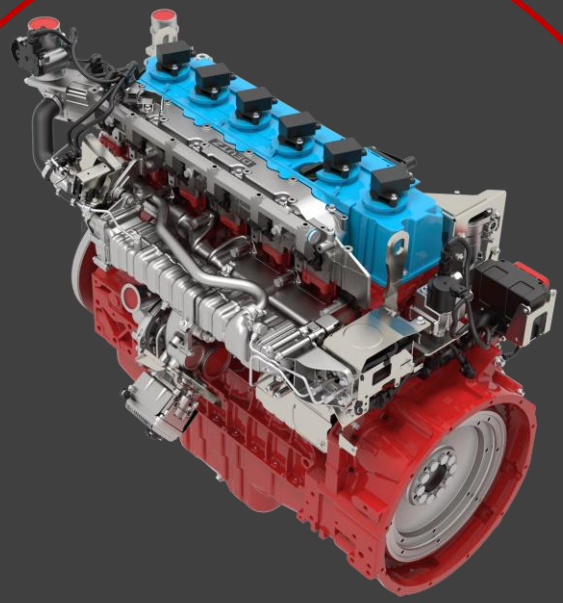
Source: Aleš Srna, Energy & Homeland Security „Is there a place for H2 internal combustion engines?“

H_2 ICE: DEUTZ TCG 7.8 Hydrogen Engine – Key Take Aways

CO2-FREE TECHNLOLOGY
Meets current emission limits for zero-emission heavy-duty vehicles (<1g CO_2/kWh)

ACCELERANT TECHNLOLOGY
Ideal Technology to accelerate supporting aspects around H2 usage (e.g. infrastructure) while Technologies further mature in Emission Reduction and Efficiency Increase

HIGH PERFORMANCE
Power density and efficiency comparable to diesel engine



ECONOMICAL ALTERNATIVE
Attractive overall cost perspective

HIGH RELIABILITY
Based on well-known engine technology
Quick Industrialization possible

A REGULARITY SUPPORT
towards a classification of Zero Emission and or Zero CO2 would help to promote this technology

Performance and Emission improvements – Collaboration Opportunity for demo [Georgios Karavalakis, Ph.D.]

Thank you for your Time and Attention

CLEAN FUELS PROGRAM ADVISORY GROUP
September 14th, 2023

Christoph Scholtes
CTO | DEUTZ Americas

South Coast Air Quality Management District

Clean Fuels Program Advisory Group Meeting

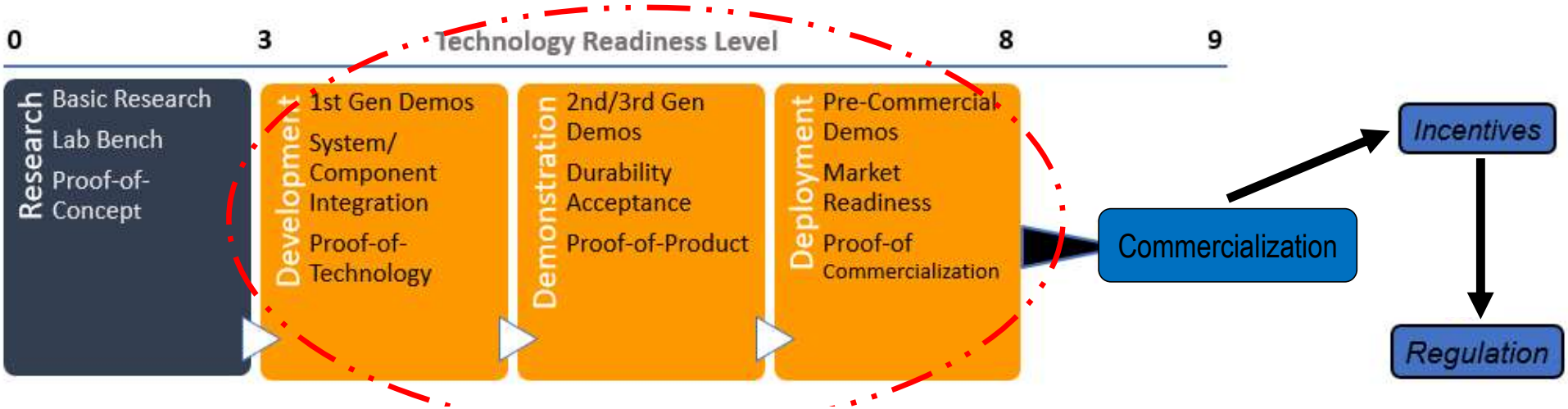
September 14, 2023

Vasileios Papapostolou
Technology Demonstration Manager

The 2024 Plan Update

Clean Fuels Fund Program

- Established in 1988
- $1 fee on DMV registrations ($~12M/yr)
- Stationary source fee (~$400k/yr)
- Research, develop, demonstrate, and deploy clean technologies



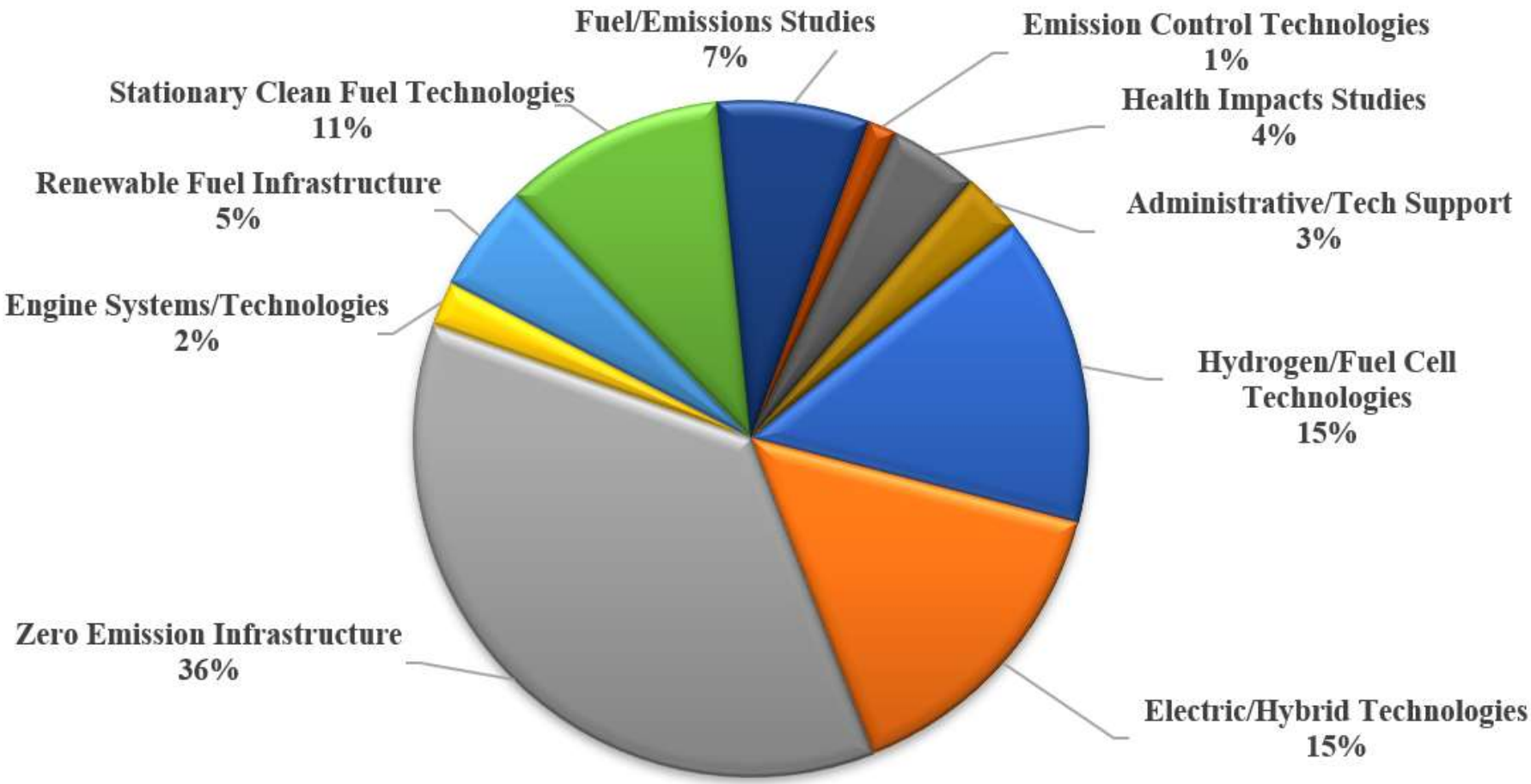
Draft 2024 Plan Update
(Key Technical Areas)

- Medium and heavy-duty zero emission trucks and equipment
- Alternative charging solutions to deploy zero emission infrastructure
- Zero emission microgrid technologies
- Ultra-low NOx and HD zero emission engine technologies
- Fuel and emission studies on NOx emissions from hydrogen fueled internal combustion engines and PM emissions from brake and tire wear
- Maintain other areas of emphasis

Draft 2024 Plan Update
Proposed Projects

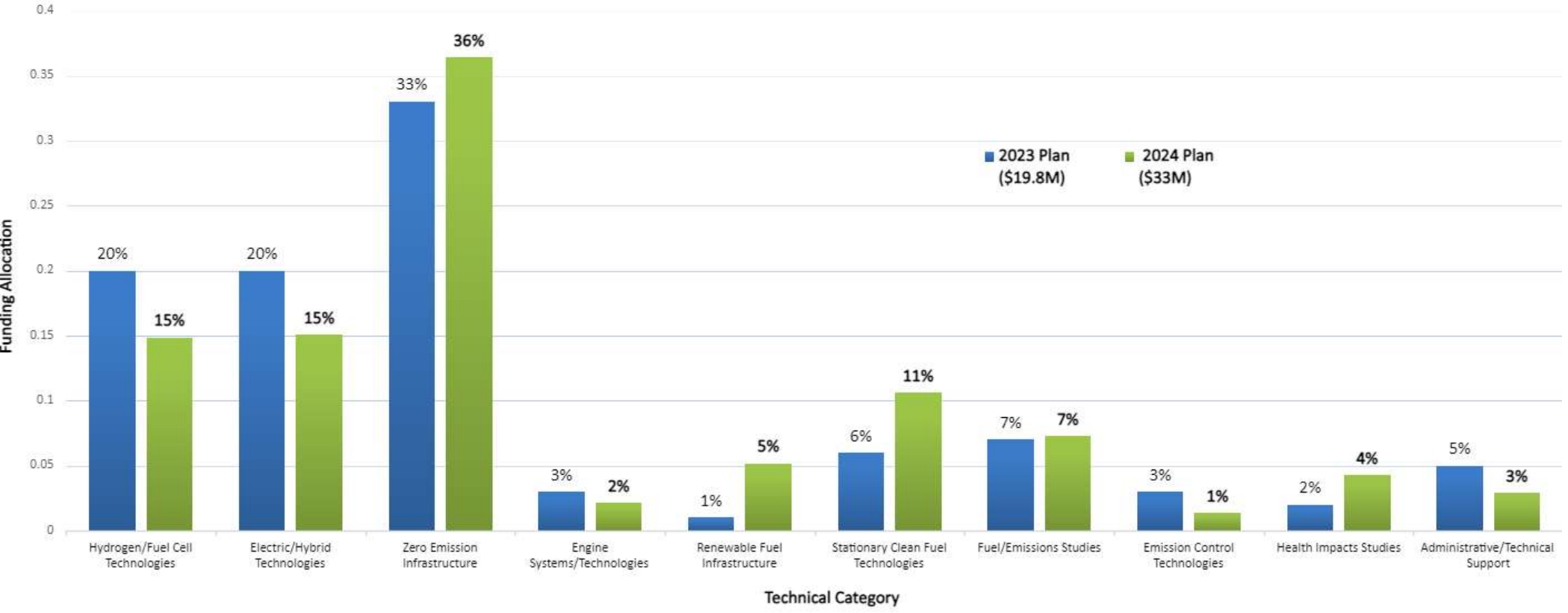
- Large deployments of medium and heavy zero emission trucks and infrastructure
- Innovative solutions to support HD truck charging and hydrogen fueling
- High-power charging including megawatt charging to increase battery electric truck range
- Develop and demonstrate long range Class 8 fuel cell electric trucks and equipment
- Develop and demonstrate green hydrogen production pathways

Proposed 2024 Plan Distribution



$33M

Plan Update Comparison



Proposed Distribution

	2023 Plan ($19.8M)	Draft 2024 Plan ($33M)
Hydrogen & Fuel Cell Technologies	20%	15%
Electric/Hybrid Technologies	20%	15%
Zero Emission Infrastructure	33%	36%
Engine Systems/Technologies	3%	2%
RNG Infrastructure	1%	5%
Stationary Technologies	6%	11%
Fuel/Emission Studies	7%	7%
Emission Control Technologies	3%	2%
Health Impacts Studies	2%	4%
Administrative/Technical Support	5%	3%
	100%	100%

Feedback

Email

Vasileios Papapostolou
vpapapostolou@aqmd.gov

or

Aaron Katzenstein
akatzenstein@aqmd.gov