



Comments on Future EPA (Tier 4) Locomotive Emissions Aftertreatment Technologies

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**California Air Resources Board
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“Technology is dominated by two types of people:

- those who understand what they do not manage, and**
- those who manage what they do not understand.”**

Alexander Putt* in Research/Development magazine (January 1976)

* Alexander Putt is the pseudonym for a management consultant in the United Kingdom.



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The successful implementation of locomotive emissions aftertreatment technology will require intense cooperation and coordination between railroaders, locomotive and aftertreatment manufacturers, scientists, engineers, and regulators.

Ultimately, it will be accomplished by people who understand, *and* who manage, the development, testing, verification, manufacturing, acquisition, maintenance and operation of aftertreatment-equipped locomotives.



Technical challenges: *loco. aftertreatment*

→ Big engines (compared to motor vehicles)

- ⚡ ~12,000 cubic inches displacement per engine (10x-12x truck displacement), 4000-4400 HP (versus <600HP for trucks)
- ⚡ Medium-speed engines (versus high-speed auto and truck engines)
- ⚡ Radical difference in combustion chemistry, exhaust temperatures and cooling strategies (vis a vis over-the-road trucks)

→ Massive machines

- ⚡ 420,000 pound locomotives
- ⚡ Small production runs, 700-1400 per year (versus 320,000 Class 8 trucks)

→ Interoperability of equipment between carriers



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Auto > Truck > Locomotive engines

- “Scaling up” technologies is generally unsuccessful and leads to frequent “hard lessons learned”.
- Example: first application of Electronic Fuel Injection to US diesel locomotive engines in early-1990s.
 - ⚡ Fuel injection manufacturers “scaled up” large-truck EFI for locomotives.
 - ⚡ Major reliability problems for ~5 years.

190 HP gasoline
V-6 automobile
injector



4300 HP diesel V-16
locomotive injector
(>12” length)



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Locomotive technology experiences

-  **1974-1978** **locomotive manufacturing**
-  **1978-1995** **fleet planning & locomotive utilization management**
-  **1985-1994** **DC adhesion improvements, development of 4000-4400 HP engines**
-  **1990-1998** **pre-EPA regulatory emissions**
-  **1992-1997** **introduction of AC traction, distributed power & electronic air brakes**
-  **1994-1995** **maintenance management**
-  **1993-1998** **EFI reliability & maintainability shake-down**
-  **1995-2001** **technical consolidation of merged fleets**
-  **1995-2002** **6000 HP diesel engines**
-  **1997-2000** **predictive engine maintenance technologies**
-  **2002-2007** **hybrid & genset switcher development**
-  **2002-2007** **early aftertreatment experiments**



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“Why doesn’t #%\$@&! work as expected?”

“Managers’ Misconceptions About Technology”

Magazine article by Lowell Steele, Harvard Business Review
(November-December 1983) as summarized in a management handbook.

Steele was formerly the chief technology planner
for General Electric at the corporate level.



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Steele's 9 misconceptions: *technology change*

MISCONCEPTIONS

(1) Always go for "best possible".

(2) Technology is picked rationally.

(3) Change always occurs as planned.

(4) Success follows initial application.

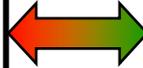
(5) Technology has intrinsic value.

(6) Radical change will always succeed.

(7) Success is guaranteed by investment.

(8) Enhancements guarantee progress.

(9) New technologies can be grafted onto existing businesses and operations.



REALITIES

Use only what is "good enough".

Past practice limits future changes.

Plan for things to go wrong ("Murphy").

Future unknowns are risky.

The customer (user) determines value.

New is not necessarily better.

Infrastructure is often the weakest link.

Critical: Standards, constraints, routine.

A new technology and supporting business systems must be jointly produced and installed.

* From the book "Managing Technology" (1989, McGraw-Hill, pp 52-67), by Lowell W. Steele.



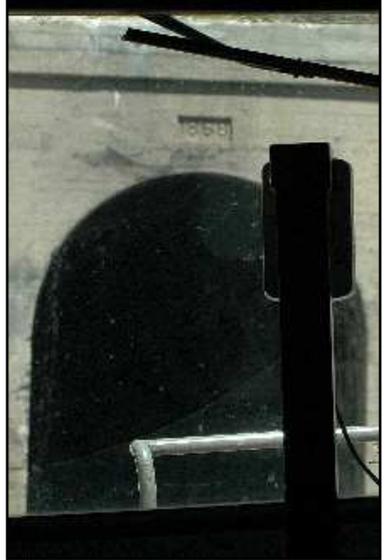
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(2) Past practice/designs v future changes

- Physical limitations of locomotive: weight, height, width (length)**
- Radiator placement (no “ram air effect” as on trucks)**
- Treated water coolant instead of antifreeze (except for gensets)**
- Locomotive & train operations, configurations**
- Physical layout & dimensions of RRs including tunnels**
- Physical layout of manufacturing plants & maintenance shops**
- Physical layout & dimensions of RR customer infrastructure such as rotary dumpers, mine loading structures**



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(3) Planning for things “going wrong”

- “Murphy’s Law”*
- Technological change is a complicated process involving scientific discovery, engineering development, commercialization and end-user possession.
- Complexity and risks generally follow a squared-relationship.
- Test, test and test again.



* Capt. Edward Murphy, USAF (back to camera), at Edwards AFB (1949), preparing rocket sled for 649 MPH-to-stop in 1 second test.

All 16 accelerometers were accidentally mis-wired and no data was collected.



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Tunnel testing

- Data collection to occur this summer on Tier 2 EMD and GE units on Donner Pass.
 - ↗ BNSF Evolution & UP SD70ACe (after in-use testing at SWRI).
- EPA instrumentation to gather temperatures, etc.
- Focusing on temperature-related catalyst degradation issues.



(4) Future unknowns and their risks

→ “Shaking down” complex technologies requires testing; re aftertreatment, this means:

⚡ Laboratory testing.



⚡ Engine test cell operation.



⚡ Pre-production locomotive field testing.



⚡ In-production & continual verification.



2007 2017



First Tier 2 pre-production test locomotives in revenue service, February 2003 (22 months before production started)



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Ex: *Genset locomotive development*

- UP **concept** 2002-2004; **funded** NRE prototype in June 2004
- **Specification** writing July-December 2004
- **Dismantling core** unit February-March 2005, **assembling prototype** UPY 2005 March-November 2005 at NRE-Mount Vernon IL
- **Delivery** to UP on December 5, 2005 ... **testing** at ICTF-Long Beach February-June 2006 and on PHL-San Pedro June-November 2006
- ***~50% availability for operation during first year of service due to failures, in-field modifications***
- December 27, 2006 ... first-of-60 **production units** arrived ... successful launch for service in LA basin



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(6) Radical change isn't always successful

- AC traction was commercialized in Europe in 1960s, did not become commercialized on North American until 1992.
 - ⚡ North American DC motors and adhesion controls were adequate.
 - ⚡ Risky investment in new technologies, European components not always transferable to North American operating environment.
- Initially, most US and Canadian railroads (users) did not see the paradigm shift in operations which AC traction ultimately enabled.
 - ⚡ 3-4 DC units (all-head-end) hauling 115 cars *versus* 3 AC units (all-head-end) would haul the same 115 car train
 - AC economics could not be justified!
 - ⚡ 3 AC (2+1 *with* distributed power) began hauling 135-140 cars
 - AC economics good (but longer trains required changes in RR and customer trackage!)



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(7) Infrastructure is often the weak link

- Lessons learned outside the RR industry: EV's, alternate fuels.**
- Urea supply infrastructure will be critical to support operation of Tier 4 SCR-equipped locomotives.**
- Unlikely that massive urea infrastructure will be constructed “everywhere” at early date.**
- This will likely result in Tier 4 loco operation being initially limited to specific major corridors or areas having urea support (provided asset utilization doesn't diminish).**



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“Run-thru” inter-RR & international ops.

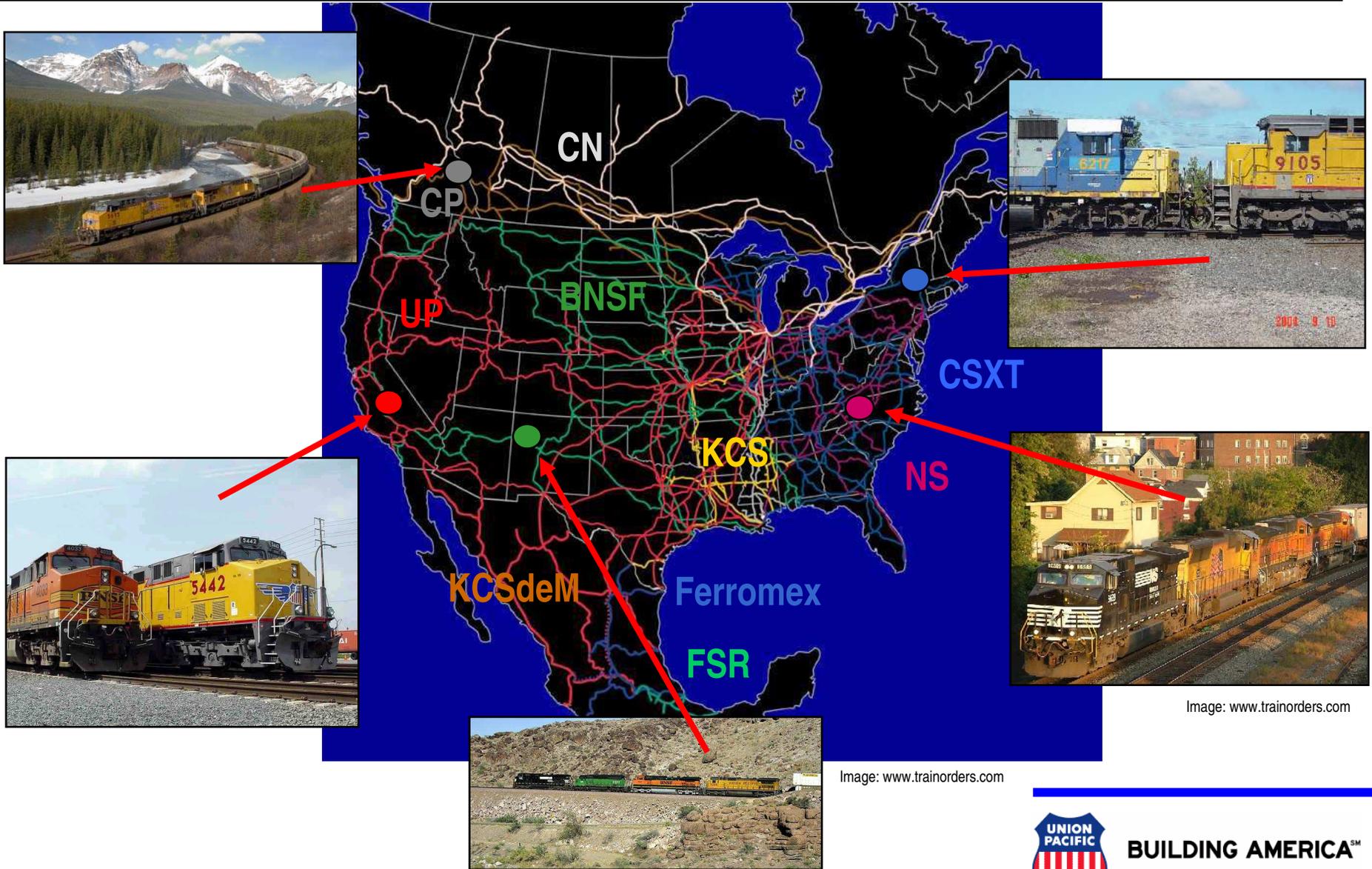


Image: www.trainorders.com

Image: www.trainorders.com



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(8) Standards are critical to success

- RR industry has a standardized refueling network (fixed & mobile).
- Interchangeability of systems, parts, procedures.
- RR industry has long experience with locomotive standards to facilitate safety, efficiency and asset utilization.
 - ⚡ New standards will be required for onboard urea servicing.



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(9) Technology + business system

 *Aftertreatment technology cannot be developed in isolation.*

↓ **Regulatory framework & requirements**

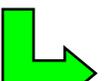
↓  **Scientific breakthroughs**

↓   **Engineering developments**

↓   **Technology testing & verification**

↓     **Starting commercial production**

↓ **Plan & build support infrastructure (urea, maintenance, etc.)**

↓  **Ordering aftertreatment-equipped locomotives**

↓ **Training operating & maintenance personnel**

**R&D
unit
#1**

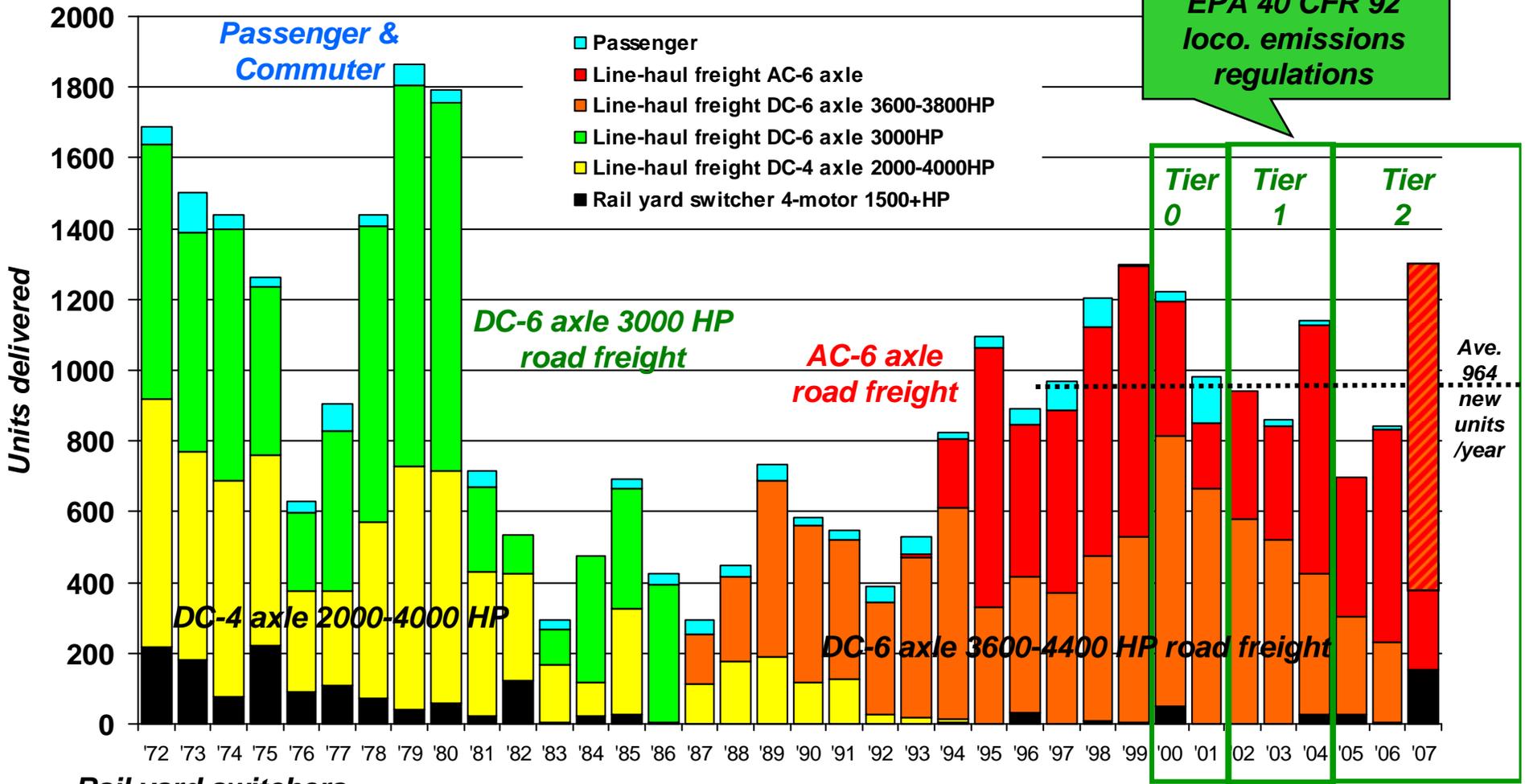
**Prod.
unit
#1**



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N. American new loco. prod. '72-'06

NOTE: Chart is based on estimated deliveries, data obtained from numerous public sources.



All switcher deliveries in 2007 are ULEL gensets. 2007 total-industry production of road units is an unofficial estimate.



Technology & technology users

- Regulators and “environmental managers”
- Scientists and engineers
- Manufacturers of locomotives & aftertreatment technology
- Railroad managers
- Locomotive engineers & mechanics as Tiers 3-4 enter service



Loco. aftertreatment: *worldwide*

→ Diesel particulate filters

- ⚡ **-97** “new” (1-3 years) 2000 HP switchers on SBB Cargo & SBB Infrastructure in Switzerland and **6** retrofitted “older” 1200 HP switchers on SBB Cargo
- ⚡ **1** former-engineering German demo unit 3600 HP in Sweden
- ⚡ **5** Eurotunnel “older” 1200 HP switchers, 1st unit now being commissioned
- ⚡ **2** UP-BNSF-CARB “California test program” switchers: UPY1378 @ Oakland, BNSF3703 still @ SWRI

→ Oxidation catalyst

- ⚡ **1** “older” Union Pacific 3800 HP SD60M (EPA-SWRI-UP test)

→ Urea-SCR

- ⚡ **5** Eurotunnel “older” 1200 HP switchers, *1st unit now being commissioned*



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Eurotunnel 1200 HP diesel-hydraulic switchers (5), currently operated with water-scrubber “tender” cars ... locomotives being retrofitted with Hug DPF+SCR at Biel, Switzerland ... water scrubber tenders to be retired.





1st retrofitted older-US switcher retrofitted with DPF, operating at Oakland CA since December 2006.

DPF currently achieving ~80% particulate removal v 90% target due to internal leaks.



1st retrofitted older-US line-haul locomotive (3800 HP) retrofitted with oxidation catalyst, operating in Los Angeles area since January 2007.

Oxicat elements being repaired, achieved ~50% reduction in SOF particulates,



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~54 diesel-battery non-regenerative hybrid ULEL switchers in service in US (21+ on UP).

UP: 1@Fresno, 10 in LA basin, 5@Houston, 5@Ft. Worth.

All temporarily removed from service at request of manufacturer pending modifications.



(61) gendset ULEL switchers being installed in Los Angeles basin, and another (98) in Texas.

80% reduction in NOx, 90% reduction in PM and 16-25% reduction in fuel and GHG.



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Union Pacific Railroad was awarded the 2006 “Environmental Excellence in Transportation” (E²T) award by the Society of Automotive Engineers (SAE) in the mobility and engine emissions category, on May 15, 2007 in Washington, DC, for leadership in developing and promoting ultra-low emissions “genset” switching locomotives.

This award recognizes an individual or groups of individuals who through their ingenuity and dedication make significant innovations in reducing the environmental impact caused by the transportation industry. These innovative achievements may occur in motorized vehicles for land, sea, air, and space in the areas of fuels, alternative propulsion methods, fuel usage, materials, energy usage, manufacturing methods, logistics support, as well as in education, training and improving public awareness.

The key criteria for recognition are innovation, originality, demonstrated significant favorable impact on the environment and improvement over any existing technologies, methods and public acceptance.



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Summary & conclusions

- New locomotive aftertreatment is coming.
- Very limited time and opportunities to perform critical pre-production testing of technologies and materials.
- Failures in test *can be tolerated* (and are generally welcome); failures in revenue service *are intolerable*.
- All concerned must not treat the introduction of locomotive aftertreatment technology as being a trivial task; there are major hurdles and constraints to overcome. Avoid misconceptions.
- Must manage introduction and use of aftertreatment technologies jointly with changes in locomotive design, maintenance and operation.



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