



Locomotive Emissions Technology: Progress & Direction

Michael Iden ~ Union Pacific Railroad Company

Faster Freight Cleaner Air 2004 Conference

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Union Pacific

Environmental Policy



Union Pacific Railroad is committed to protecting the environment for our customers, our employees, and the communities in which we live. We strive to meet the highest principles of environmental responsibility in our role as a leader in transportation.

“Environmental protection is the responsibility of every UP employee.”

JIM YOUNG



Union Pacific employees accomplish this through:

Stewardship

- ☑ Protecting the natural resources where we operate
- ☑ Promoting the efficient use of energy
- ☑ Conserving resources through waste minimization, recycling and reuse of materials

Relationships

- ☑ Building relationships based on common safety and environmental goals
- ☑ Openly communicating with government agencies and communities

Process

- ☑ Assessing our environmental performance using measurable business objectives
- ☑ Using assessment results to guide environmental management improvement strategies

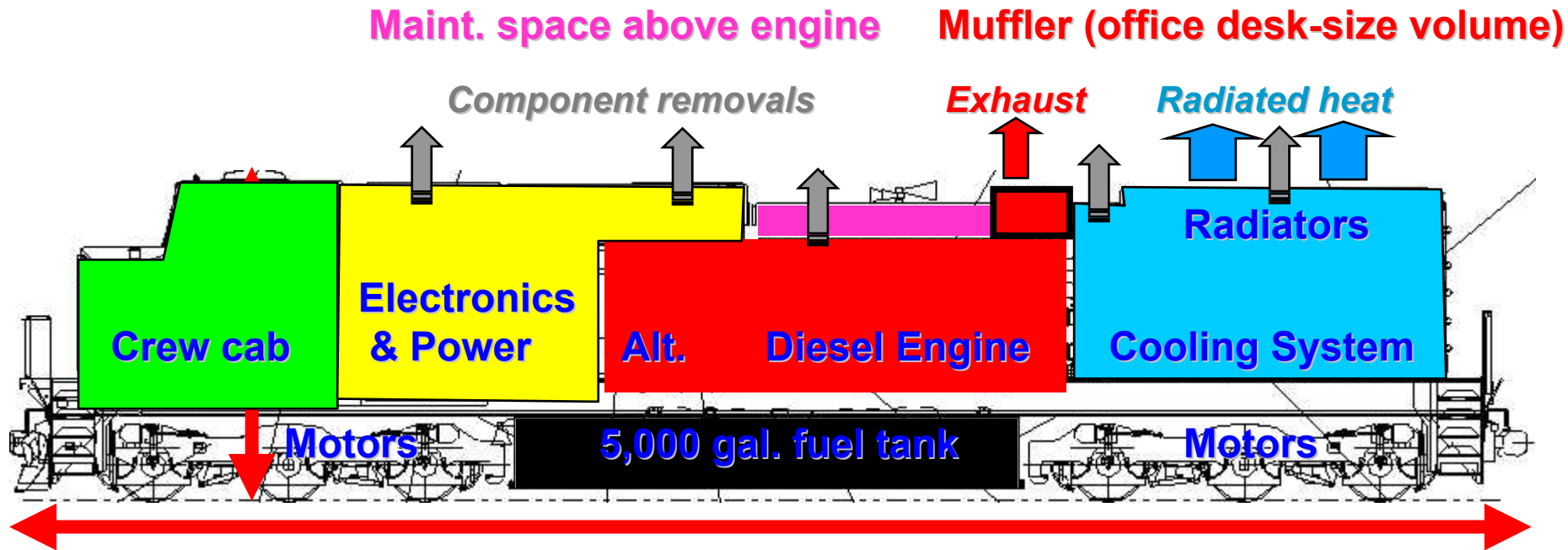
Results

- ☑ Meeting and exceeding compliance standards of environmental laws and regulations
- ☑ Supporting development of effective and balanced environmental laws and regulations
- ☑ Practicing and continually improving healthy work activities



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Road freight locomotive



4400 HP road freight locomotive

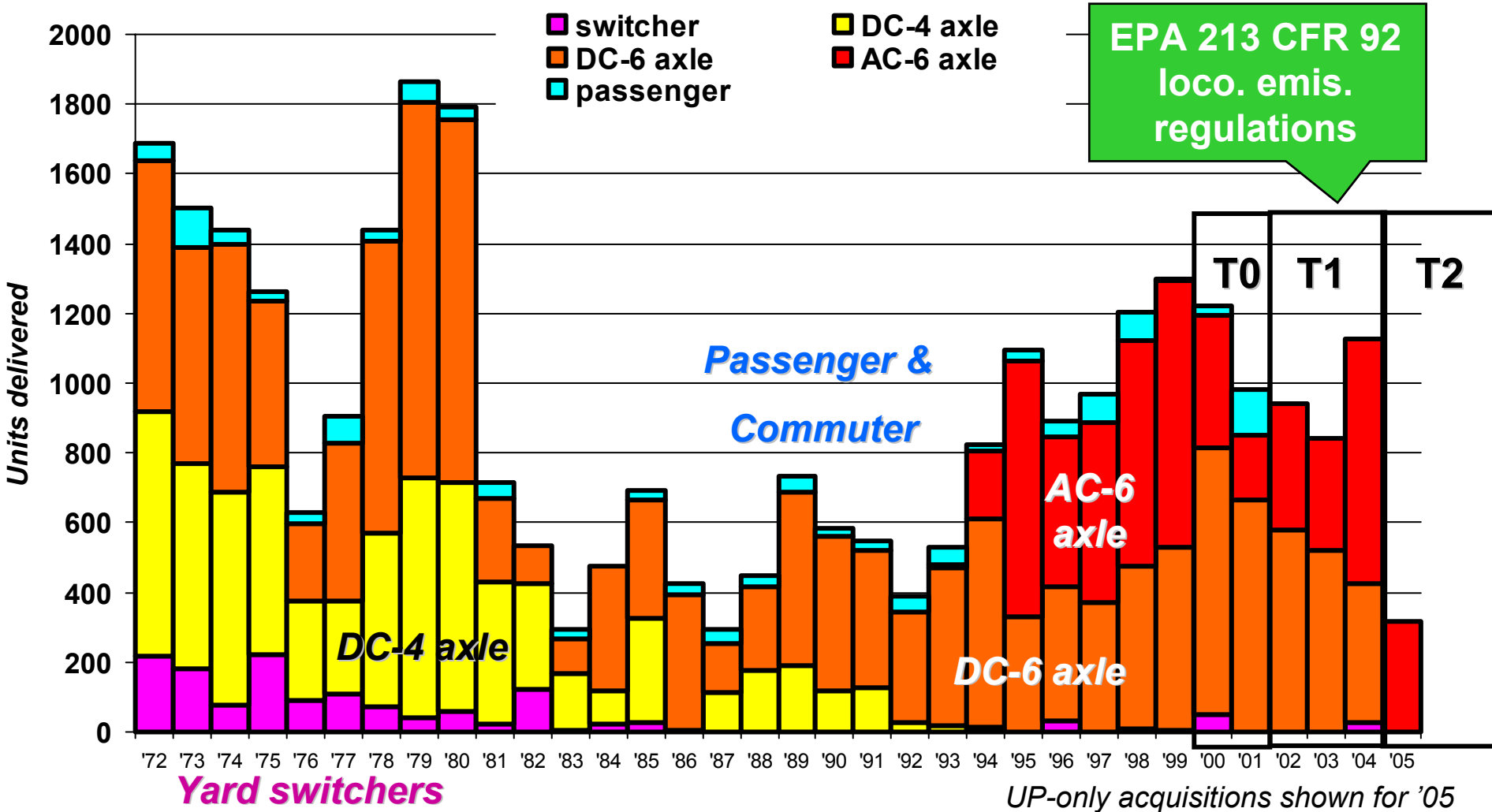
76' long x 15'3" high x 10' wide 425,000 pds. weight
("maxed out" dimensionally & by weight)

20+ year asset life



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N. Am. new locomotives '72~'04 (est.)



**21,000 locomotives built over 3+ decades
(versus 22 million+ diesel powered trucks)**



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Transcon., Int. & Inter-RR operations

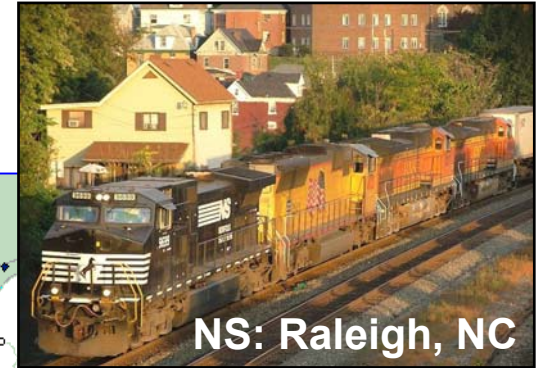
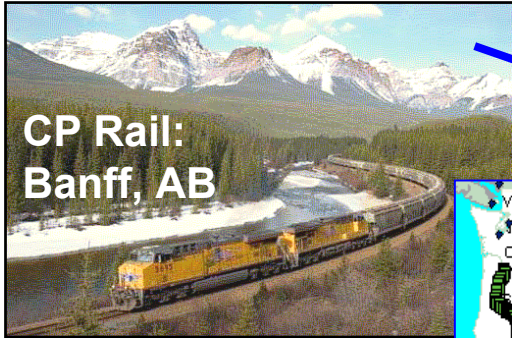


Photo courtesy of www.railpictures.net

**60-day GPS route log for one
Union Pacific EPA Tier 0
locomotive in 2001**



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Union Pacific RR

→ Locomotive fleet

- ⚡ Total 5,400 high-HP (>3000 HP) & 2,000 low-HP (<3000 HP)
- ⚡ 1800+ new EPA Tier 0-1 road acquired since '00 = 25%
- ⚡ 700+ engines overhauled to Tier 0 since '00 = 9%
- ⚡ 315 new Tier 2 on order for 1-2Q 2005 = 4%

→ Mid-2005, 38% of fleet will be EPA Tier 0, 1 or 2

- ⚡ UP loco acquisitions since January 2000 are equivalent to an exceptional 10 year HHP fleet turnover ... *versus 20 to 30 year asset life.*



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UPRR emissions R&D

- **LNG road & switch in '90s (\$15M)**
 - ↗ 4 road units & 2 switch
- **6000 HP road units '96-'00 (\$312M)**
 - ↗ 142 road units
- **Diesel particulate filter (DPF) program (\$2.5M)**
 - ↗ BNSF+UP thru AAR-TTCI at SWRI, for EMD non-turbocharged switch engines
- **New technology switch engines (\$1.0M)**
- **OEM R&D funded thru acquisitions**
 - ↗ Tier 0-1-2 redesigns, GE's new Tier 2 engine, etc.



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UP LNG project '93-'98

→ Yard switchers

- ✦ (2) 1200 HP units in LA-Commerce Yard
- ✦ Maintenance, fueling constraints, safety concerns, high cost & low availability

→ 2 each high-HP EMD & GE road units

- ✦ (2) EMD 3800 HP units (*produced ~3300 HP*) and (2) GE 4150 HP units (*produced ~ 3600 HP*)...*Requires more locos*
- ✦ Materials limitations in nozzles, cryo pumps, et al
- ✦ Never operated outside OEM factories. ~5 hours max. time



Diesel emissions are now converging on LNG because of technological improvements.



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New road technology: *Tier 2 units*



315 Tier 2 units under construction (1-2Q'05)
4300 HP (EMD) & 4400 HP (GE" *)

*** UP is "launch customer" for new GE engine design**



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New switch technology: *Hybrids*



“Hybrid” light-medium duty switcher (1Q’05)

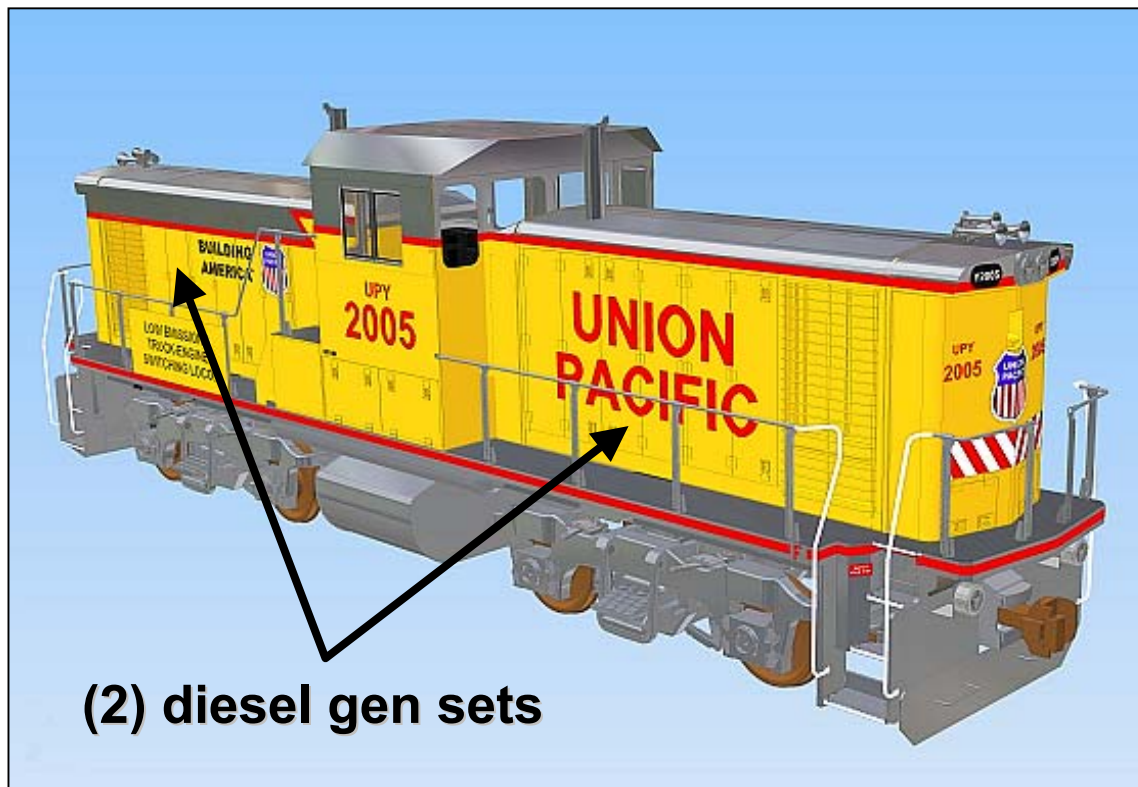
2000 HP batteries recharged by 290 HP EPA off-road Tier 2 diesel gen set
significantly exceeds EPA locomotive Tier 2 requirements

without aftertreatment



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New switch technology: *Truck-engines*



(2) diesel gen sets

“Truck-engine” heavy-duty switcher (2Q’05)

~1400 HP powered by (2) EPA off-road Tier 3 diesel gen sets

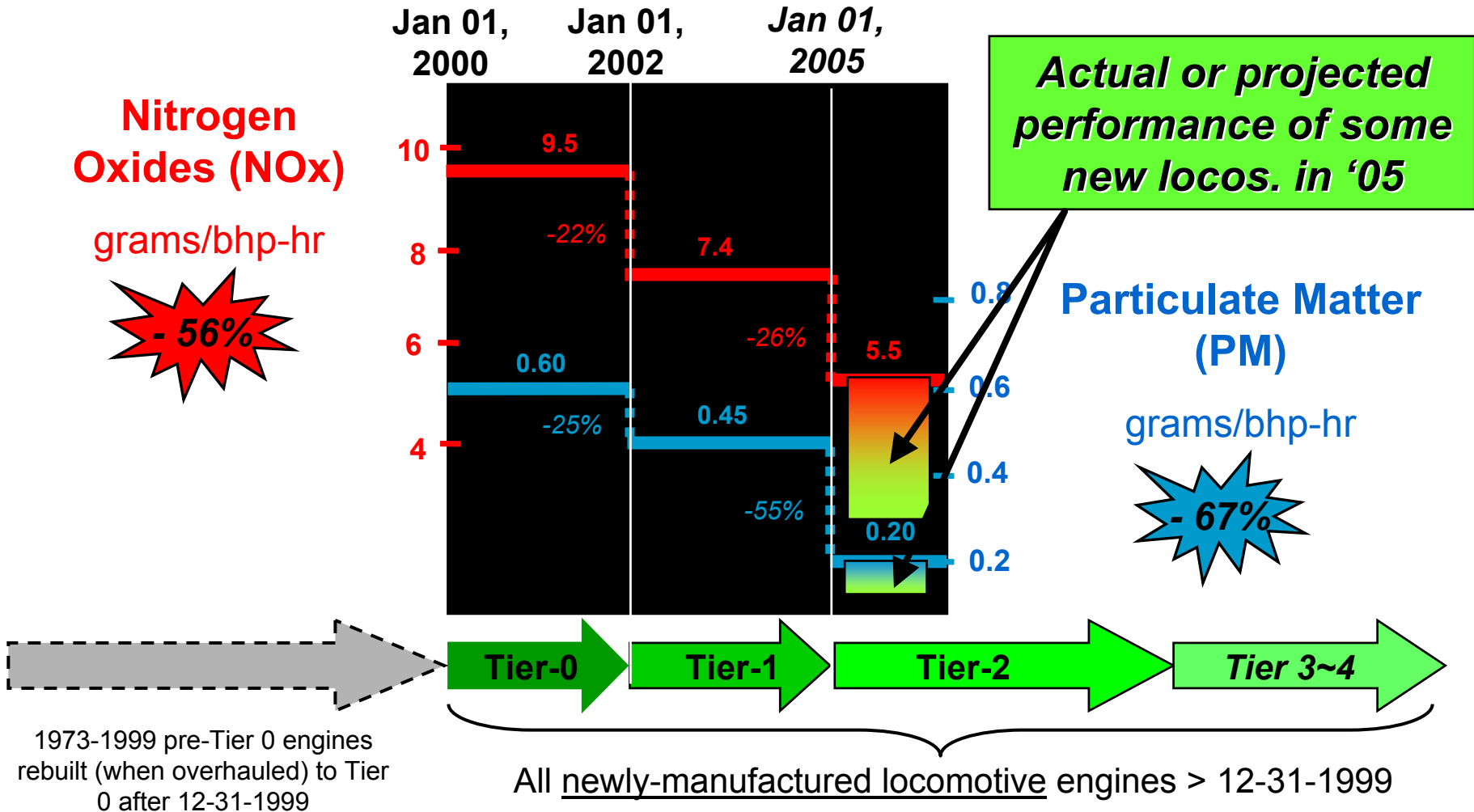
projected to exceed EPA locomotive Tier 2 requirements

without aftertreatment



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US EPA Loco. Emissions Reg's

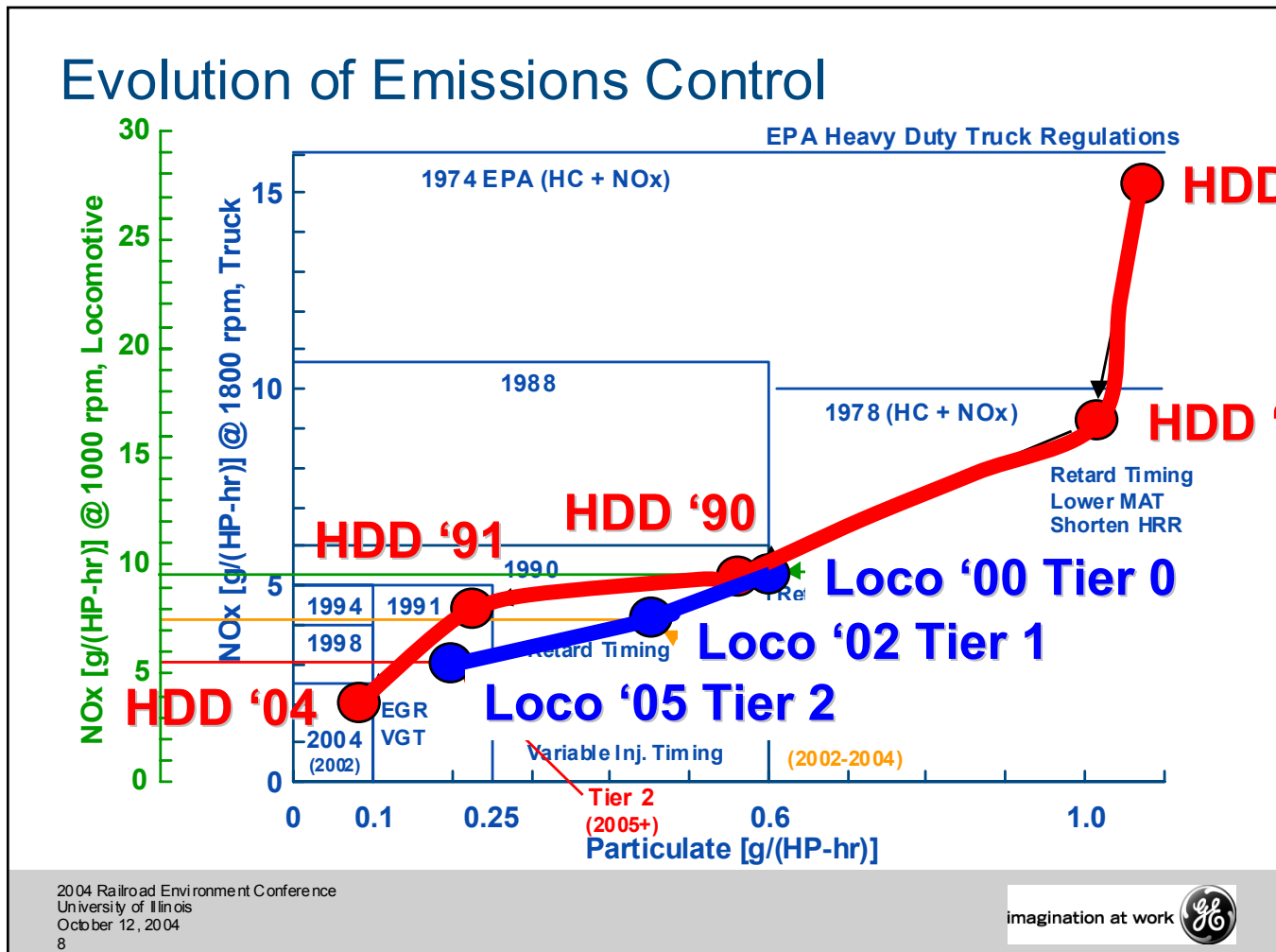


Original chart courtesy of Roy Primus, GE Global Research Center



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HD Diesel Truck v Loco emissions



Original slide courtesy of Roy Primus,
 GE Global Research Center



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Auto/Truck v Loco



Charge-air cooling (front rad.)

Automotive derivative technologies

Hi-speed design (lower NOx tendency)

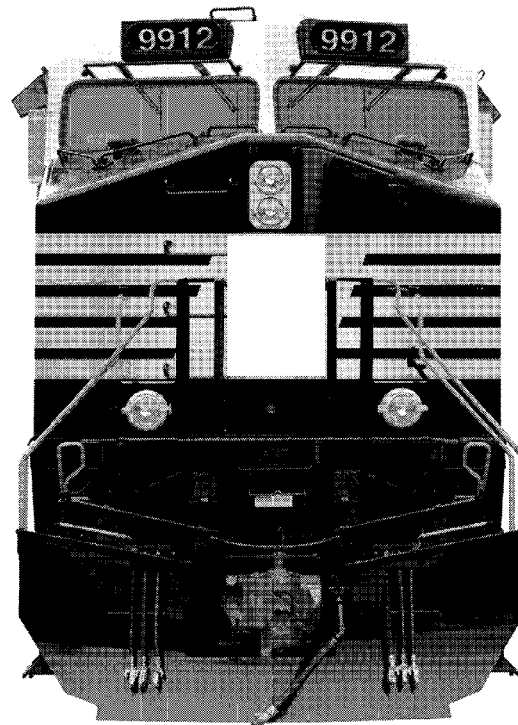
Lower fuel efficiency (gallons/GTM)

Mechanical transmissions

25+ years federally-funded R&D

Typ. 5 yr. Lifecycle

22 million produced over 3 decades



engines

No charge air cooling, more complex system

Large locomotive-size designs & technologies

Medium-speed design (higher NOx tendency)

Better fuel efficiency (gallons/GTM)

Diesel-electric transmissions

R&D funded mostly by railroads & suppliers

20+ yr. Lifecycle

21,000 ~ 3 decades



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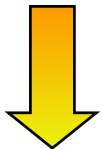
Technology: *from idea to use.*

→ **Basic discovery & “concept-to-device”**



⚡ SCR, Nox/PM filters, EGR, VGT, engine designs, etc.

→ **R&D *including “field hardening”***



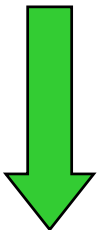
⚡ Laboratories > Test cells > Test locos > In-service locos

→ **Integration**



⚡ Loco. reliability, maintainability, onboard space, etc.

→ **Infrastructure**



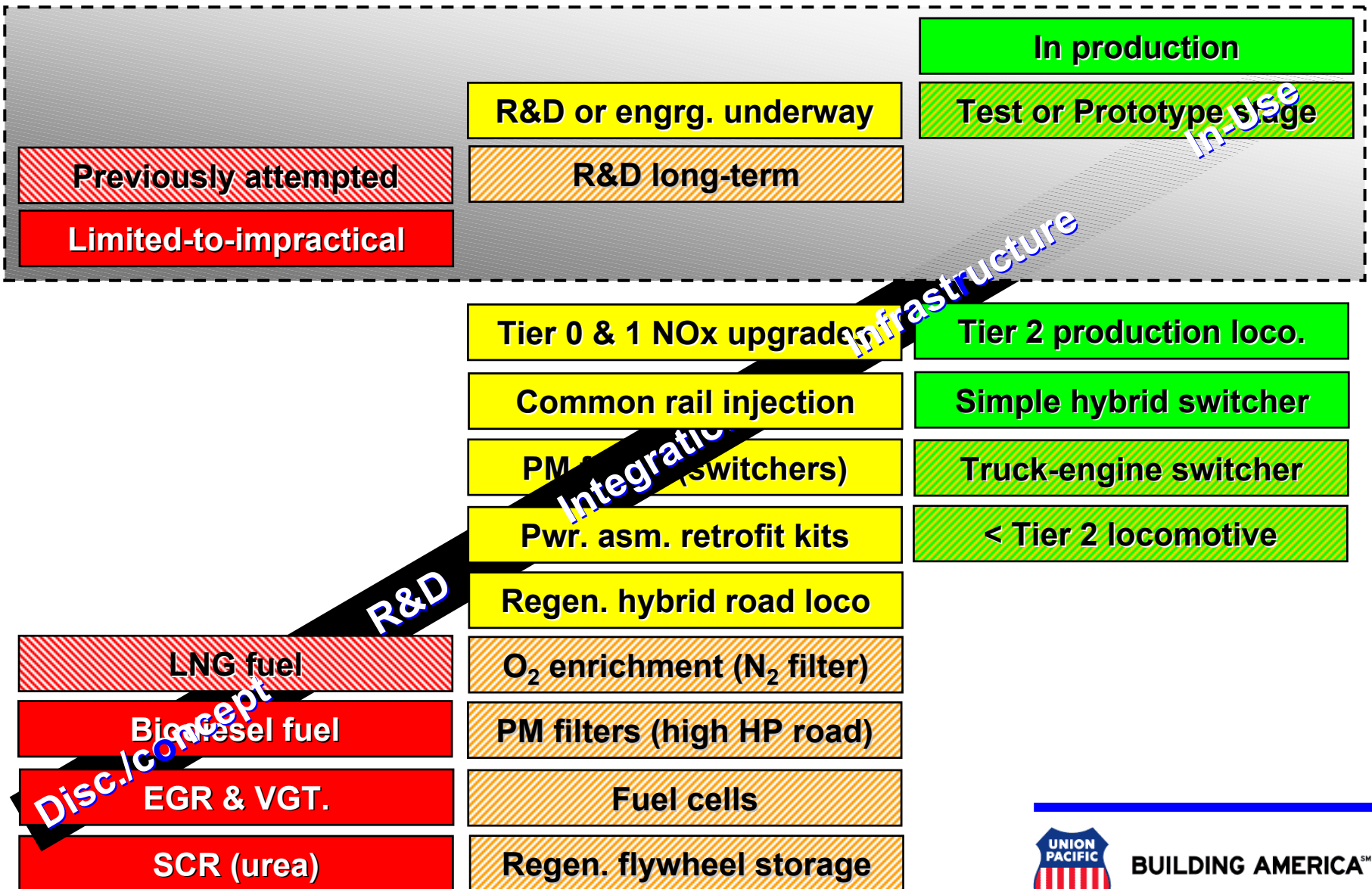
⚡ Fuels & fueling system, shops, route (track, yards, bridges, tunnels, etc.) and train operations

→ **Practical & affordable ... in use**



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Locomotive emissions technologies

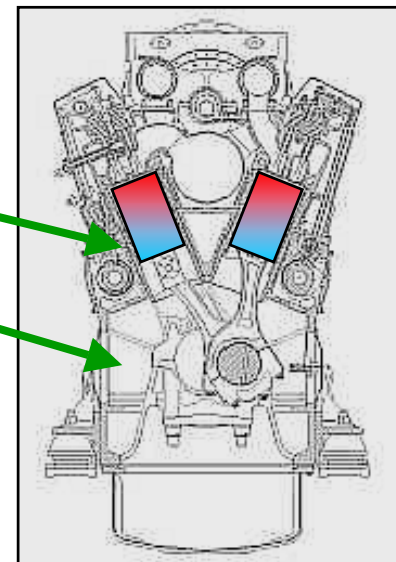


Loco. aftertreatment space reqm'ts.

→ “Engine displacement”: *total swept volume*

⚡ Displacement of a Tier 2 engine (EMD 710 & GE “Evolution”) is ~6.7 feet³

⚡ *Volume of entire eng. ~ 510 feet³*



→ Based on typical applications* ...

→ NOx aftertreatment ~ 70-80 x sw. vol.

⚡ Est. NOx requirement ~ 469-536 feet³ (= 1 entire engine!)

→ PM aftertreatment ~ 3-4 x sw.vol.

⚡ Est. PM requirement ~ 20-27 feet³ (= “an office desk”)

→ * *aftertreatment + “packaging”*



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SCR plus oxi catalyst on EMD engs.

Exhaust System Layout



- Exhaust Stack
- Emissions Sample Probe
- Oxidation Cat (Inside SCR housing)
- SCR catalyst
- Urea Injector
- Engine Muffler
- Engine Room

Note that the entire exhaust system is insulated.

SCR Package

The SCR package for the 16-710 engine is relatively large

- » Roughly 8' X 8' X 8'
- » = 512 ft³ = 78x swept engine volume!

- * The exhaust pipe ~ 24" diameter
 - » Plus insulation on outside of pipe
- * The oxidation catalysts are mounted as the last row of catalysts elements in the SCR housing
 - » Not in a separate housing



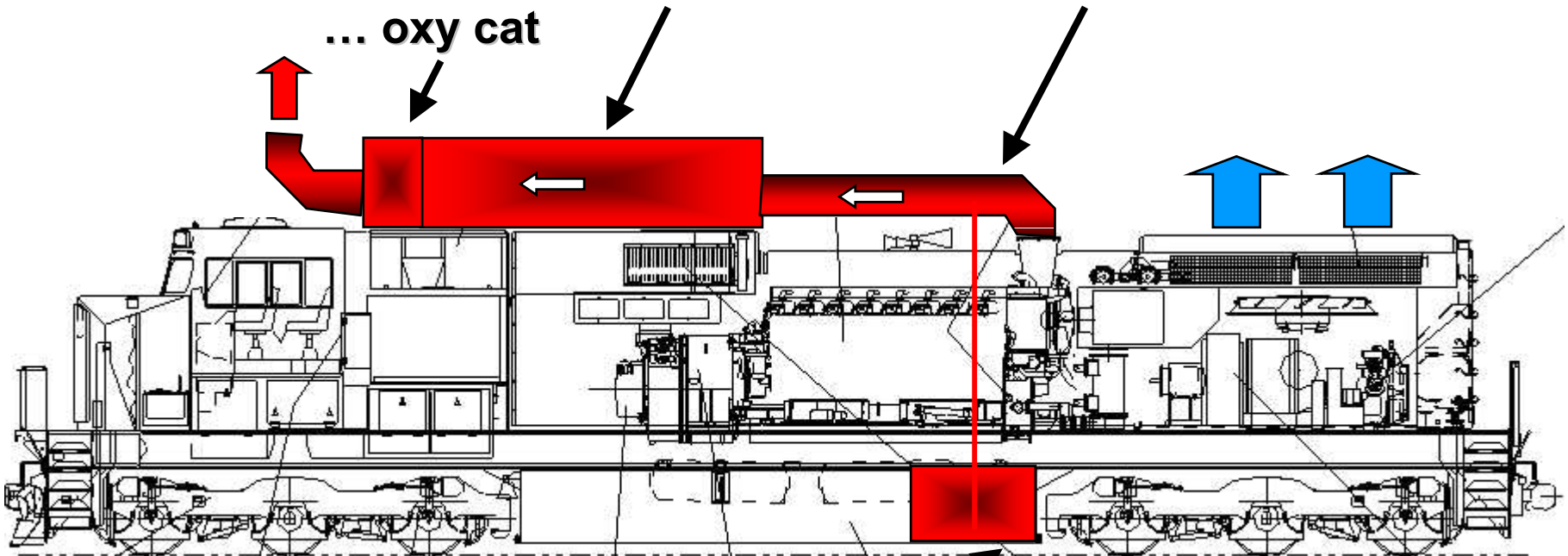
SCR scrubber on *Santa Catalina Island* ... EMD stationary engines (8'x8'x8' SCR scrubber *plus* mixing flue *plus* stack *plus* urea tank)

SCR + oxi cat package + flues = *78x swept volume*

Projected SCR on a locomotive

Nominal 512 cubic feet for SCR scrubber & oxy catalyst
(est. 6' wide x 4' high x 21' long) ... 15' urea mixing stack pipe

... oxy cat



750 gallon urea storage volume (12-15%
of fuel) ... *reduces operating range of
locomotive by 12-15%*

This is not a practical (realistic) locomotive!



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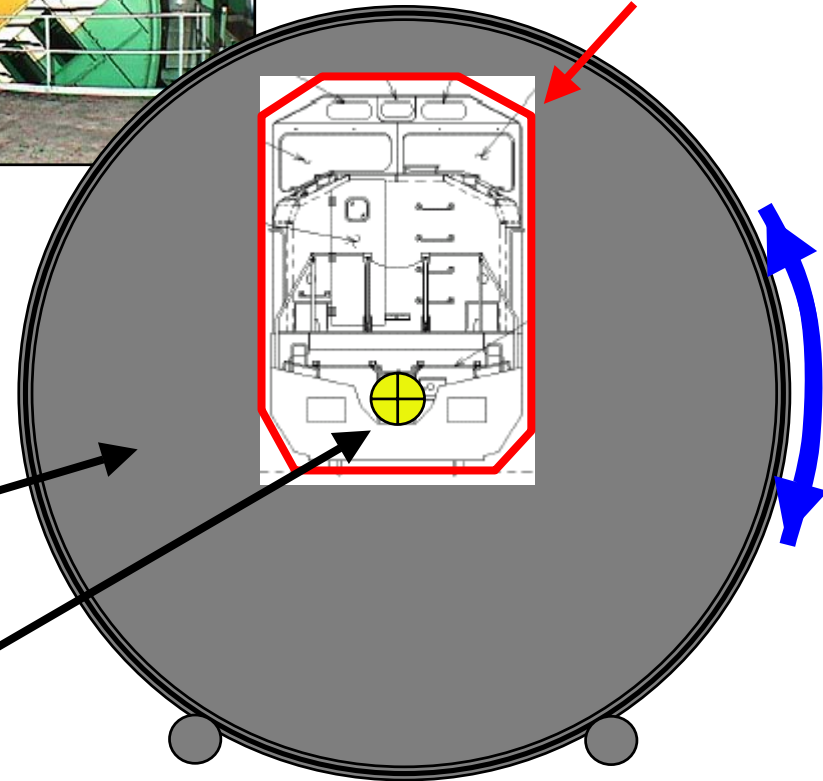
RRs & locos: customer infrastructure

There are GT 75 electric generating plants in the US with rotary dumpers for unloading unit coal trains.

All of these rotary dumpers have “end plate openings” shaped to accommodate locomotives meeting the AAR clearance diagram!



**End plate opening
meets AAR loco.
clearance diagram**



Steel end plate

Rotational center point for dumper allows cars to be rotated (dumped) without being uncoupled

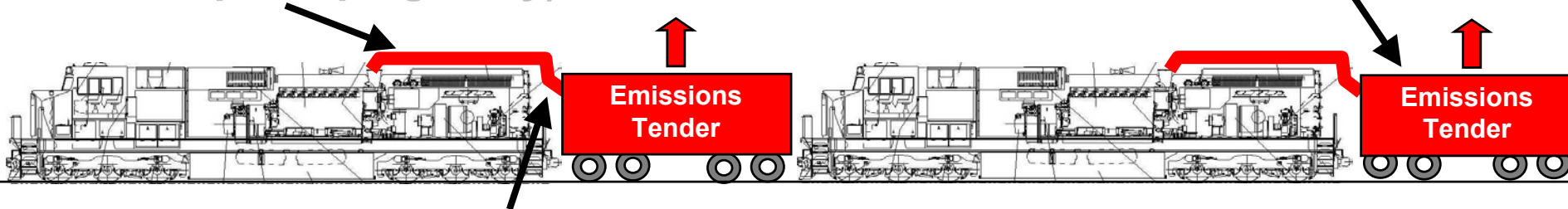


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“Emissions tender”

24” high-temp. exhaust ducting over locomotive radiator (still “violates” AAR clearance requirements ... exh. temp. drops greatly)

“Tender” car behind locomotive containing aftertreatment devices and supplies (loco+tender must be matched for movements)



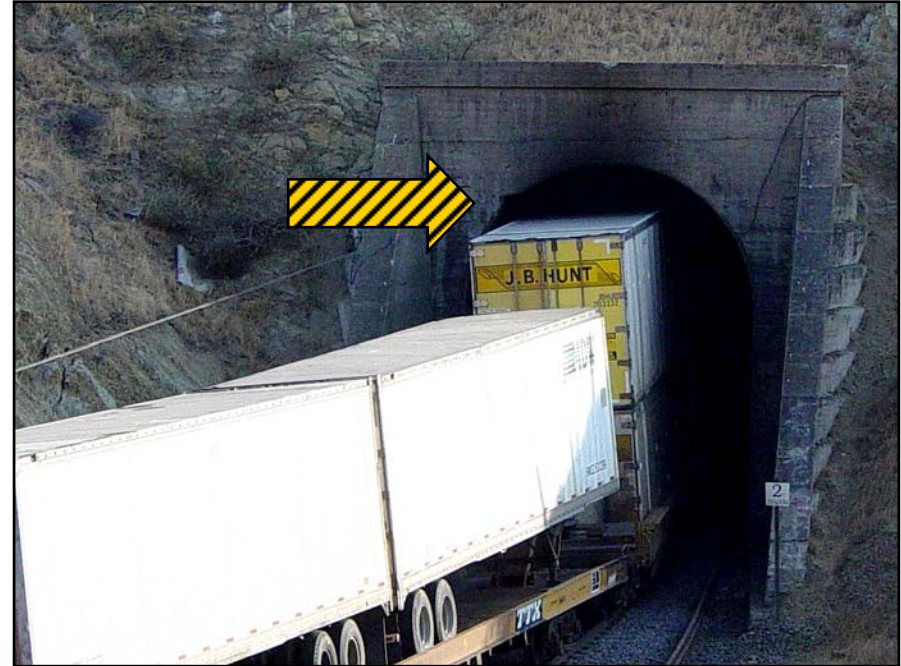
24” high-temp. flexible exhaust ducting between locomotive-and-tender moving at up-to-75 MPH ... designing, building and maintaining such flexible ducting will be a monumental R&D and engineering task in itself!

- **>12 loco. carbody configurations since '95 (i.e., tender interface)**
- **loco movements become highly restricted (reduced asset utilization)**
- **Engrg. demands of this approach are not trivial and carry major risks of failure**



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The “double stack height” fallacy



**Double-Stack cars are “excess height”
*permitted only by special agreement on
specific routes ... locomotives operate
across the entire continent***



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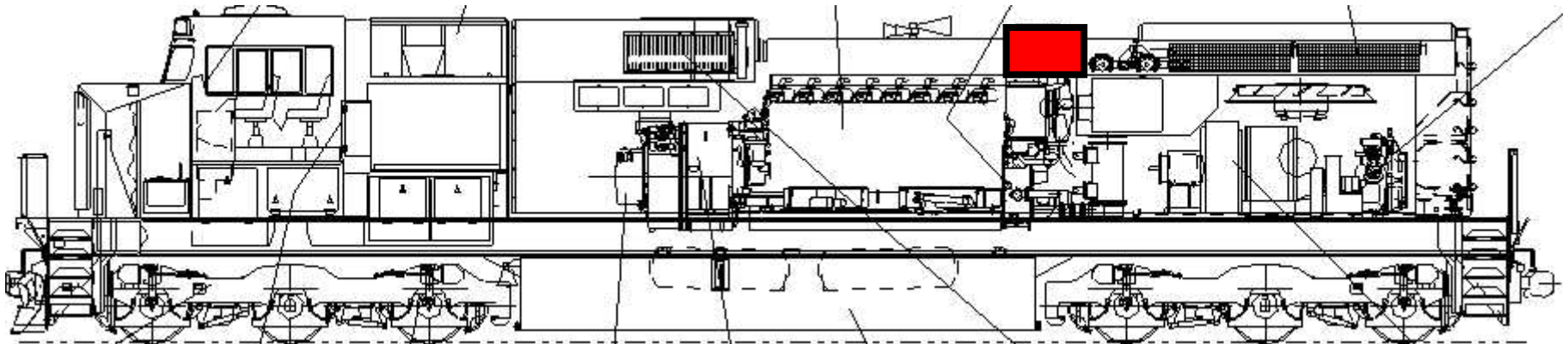
NOx versus PM

→ Very divergent aftertreatment space required

↗ NOx & PM devices ~ 1 entire engine + “office desk”

→ Restricted from making locos longer, wider or higher

↗ NOx + PM? NOx only? PM only?



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Loco engine emissions: *next*

- Continuing “in engine” R&D will likely produce even more reductions in NOx and PM than T2
- Ongoing discussions with EPA re locomotive Tier 3 regulations.
 - ↘ NOx & PM? NOx only? PM only?
- “Offboard” developments reducing emissions
 - ↘ Loco consist control schemes
 - ↘ Regenerative hybrid loco capturing downhill dynamic braking energy
 - ↘ Etc.



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Summary

- **UP & RR industry commitment to environment**
 - ⚡ UP massive fleet investment since '00
 - ⚡ Long history of engine-related R&D (rail industry R&D historically self-funded) thru new locomotive acquisitions
 - ⚡ UP funding significant R&D for yard switchers
- **Solid embracement of EPA Tiers 0 and 1 '00-'04**
 - ⚡ UP committed to new EPA Tier 2 technology '05
- **Fleet emissions are declining!**
- **Major technology decisions req'd. re future locomotive emissions reductions**



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Questions & comments

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“... difference of opinion leads to inquiry, and inquiry to truth ... if a nation expects to be ignorant and free ... it expects what never was and never will be.”

Thomas Jefferson



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