Diesel Particulate Filter (DPF) Technology for Locomotives in the US and Europe

→ BNSF-UP-SWRI meeting with CARB staff
Sacramento, CA
December 7, 2006
Known US DPF investigations ~ Europe

➡️ February 2005:

✔️ BNSF-UP-SWRI trip to Switzerland & Germany
   • Jennifer Anderson-BNSF, Mike Iden-UP, Steve Fritz-SWRI
   • Visited Hug Engrg. (Winterthur CH), L’Orange Injection (DE), MTU Engine (Friedrichshafen DE), SBB Cargo (Biel CH) & Vossloh Locomotive (Kiel DE)

➡️ August 2005

✔️ SCAQMD trip to Switzerland
   • Dr. Chung S. Liu-SCAQMD, visited Hug and SBB Cargo

➡️ November 2005

✔️ UP-SWRI trip to Switzerland, Germany & UK
✔️ Iden-UP and Fritz-SWRI
   • Visited SBB Cargo (Basel CH), MTU Engine and Eurotunnel (Folkestone UK)
Nomenclature

- **AAR**: Association of American Railroads
- **Am841**: Vossloh loco. w/ MTU 396 1200HP engine in Switz. & Europe
- **Am843**: Vossloh loco. w/ Cat 3512 2000HP engine in Switz. & Europe
- **CEP**: Ca. Emissions Program (ARB-BNSF-UP-SWRI DPF testing)
- **DOC**: Diesel Oxidation Catalyst (PM control)
- **DPF**: Diesel Particulate Filter (PM control)
- **EC**: European Commission (sets diesel engine emissions reg’s for Europe)
- **EMD**: Electro-Motive Diesels, Inc. (former Electro-Motive Div. of GM)
- **Euro4000**: EMD-Vossloh loco. w/ EMD 710 4000HP engine, ‘06 Europe sales
- **GE**: General Electric
- **Hug**: Hug Engineering (DPF manufacturer in Switzerland)
- **MaK2000BB**: Vossloh prototype loco w/ MTU 3600HP engine w/ Hug DPF
- **MTU**: German diesel engine mfr, subsidiary of DaimlerChrysler
- **SBB**: Swiss Railways (recently privatized)
- **UIC**: International Union of Railways (“AAR for rest of the world”)
# New Locomotives

<table>
<thead>
<tr>
<th>Category</th>
<th>U.S.</th>
<th>Switzerland</th>
<th>Other Europe</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Road Power</strong></td>
<td><em>EMD/GE</em> investigating DPF technology for potential Tier 3 use. Utilizing data from CEP. <em>OxyCat being researched for Tier 3 (see EPA-SWRI-UP test on retrofit page).</em></td>
<td>No Swiss diesels in this HP range. All higher-HP Swiss road freight locos (450) are electric up to 10,000HP</td>
<td>1 prototype 3600HP with <em>factory-applied DPF</em> (none ordered or delivered yet). 4000HP “Euro4000” (~EMD Tier 2) engine to be introduced in ’06. <em>No DPF planned now.</em></td>
</tr>
<tr>
<td>3600-6000HP</td>
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<td></td>
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<tr>
<td><strong>Local</strong></td>
<td>None being manufactured in US</td>
<td>Am843 (2000HP)</td>
<td>Same Am843 as in Switzerland <em>without Hug DPF Filter</em></td>
</tr>
<tr>
<td>2000-3000HP</td>
<td></td>
<td>73 new units operating with <em>Hug DPF.</em></td>
<td></td>
</tr>
<tr>
<td><strong>Switch</strong></td>
<td>No traditional switchers mfr’d since early-1980s. UP genset switcher being tested. Hybrid units in-service.</td>
<td>Am841 (1200HP)</td>
<td>Comparable switchers &lt;2000HP throughout Europe compliant with UIC II/EC standards <em>with no DPF.</em></td>
</tr>
<tr>
<td>1200-2000HP</td>
<td></td>
<td>No “new” units in fleet. 40 electric switchers</td>
<td></td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td>Not used in US</td>
<td>All new Swiss locos of this type will be mfr’d with DPF.</td>
<td>Comparable switchers &lt;600HP throughout Europe compliant with UIC II/EC standards <em>with no DPF.</em></td>
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<td>150-600HP</td>
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### Existing Locomotives (DPF retrofits)

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<tr>
<td><strong>Road Power</strong></td>
<td>General consensus: not enough space in carbody for DPF. EPA-SWRI-UP test of diesel oxidation catalyst (DOC) inside exhaust manifold on (1) SD60 in LA Basin in 2Q’06</td>
<td>No Swiss diesels in this HP range. All higher-HP Swiss road freight locos (450) are electric up to 10,000HP.</td>
<td>No DPF retrofit developments known.</td>
</tr>
<tr>
<td>3600-6000HP</td>
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<td></td>
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</tr>
<tr>
<td><strong>Local</strong></td>
<td>General consensus: not enough space in carbody for DPF.</td>
<td>Am843 2000HP (All Swiss Am843s are NEW locomotives.)</td>
<td>No DPF retrofit developments known.</td>
</tr>
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<td>2000-3000HP</td>
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<tr>
<td><strong>Switch</strong></td>
<td>CEP Program developing DPF for application on 2-to-3 1500HP roots blown EMD switchers. Will use Hug DPF technology (same as in Switzerland). In-service testing by 2Q’06.</td>
<td>Am841 1200HP 40 existing diesel units operating. 6 diesel units with Hug DPF retrofits. 40 electric switchers</td>
<td>No DPF retrofit developments known.</td>
</tr>
<tr>
<td>1200-2000HP</td>
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<tr>
<td><strong>Other</strong></td>
<td>Not used in US</td>
<td>201 existing diesel Units 0 units operating with retrofitted DPF.</td>
<td>No DPF retrofit developments known.</td>
</tr>
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<td>150-600HP</td>
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What’s Different: Europe v California?

→ New locomotives, i.e., original equipment installation
  ✔ Germany: 1 new demo on 3600hp. None ordered or delivered.
    • European Community stage IIIA ~ US EPA Tier 2
  ✔ ... will likely be superceded by new design using EMD Tier 2 engine without DPF!
  ✔ US:
    • Diesel genset switchers, likely ULELs.
    • Diesel-battery hybrids (“Green Goats”), likely ULELs.
    • LNG switchers.

→ Retrofit locomotives
  ✔ Switzerland: retrofit 6 1200hp switcher locomotives with Hug filters.
  ✔ Europe: Euro Standard = US standard
  ✔ US:
    California Emissions Project will retrofit and field test (3) 1500HP switchers in southern CA with Hug filters, 2006
    Oxy Cat test on 3800HP UP 2Q’06
Progression of Locomotive NOx Emission Regulations

European locomotive NOx limit values are similar to US EPA regulations.
Progression of Locomotive PM Emission Regulations

European and US standards can be met without DPF until at least 2012.

European locomotive PM limit values are similar to US EPA regulations.

Proposed 2012 PM limit of 0.025 g/kW-hr to be reviewed in 2008.

Higher PM for engines > 2200 kW was acceptable during the first 2 years if UIC II, "for exceptional cases..."

Before 2003, UIC 1 only limited Smoke, not PM.
DPF performance: Switzerland

- 1-2 years service on 73 “new” Am843 2000HP locos & 6-of-40 retrofitted Am841 1200HP

✓ Only synthetic engine lube oil (low-ash).

✓ Low-sulfur (<300 ppm) fuel.

✓ SBB has had no DPF maintenance responsibility until warranty expires (oldest units ... December ‘05 expiration).

- Various “unknowns” regarding ash disposal, ash cleanout cycles, etc.

- No in-service DPF emissions testing made or planned
California Emissions Program ... 3 years “engine reconfiguration & filter screening” work at SWRI

- SWRI screened >12 DPF candidates on 2-stroke EMD engine (not Cat or MTU 4-stroke engines as used in Switzerland)
- Conventional non-synthetic lube oils & low-oil-consumption power assemblies (Swiss DPF apps use synthetic oil)
- Tested for performance and durability in engine cell
- Hug DPF technology is best candidate (same technology used in Switzerland)
- 2-to-4 1500HP switchers to be retrofitted for revenue testing in southern CA in 2006
More than 300 Vossloh 2000HP locomotives **without** Hug DPF

Same Vossloh 2000HP locomotive **but with** $100,000 Hug DPF

Only 73 in Switzerland ... SBB calls this the “Am843”
In line with all European standards
The EURO 4000 was designed by the world’s leading specialists in the railway sector – Vossloh and EMD. These two companies have already supplied hundreds of customers around the world with diesel locomotives that guarantee a high degree of availability, optimum life-cycle cost and the added assurance of a ready supply of spare parts for the rest of the locomotive’s service life. The EURO 4000 naturally also complies with all European norms (for example: emissions, noise, crash, fire), is suitable for UIC-gauge lines and capable of running on all European railway networks.

http://emdiesels.com/pdf_files/2.4.1%20EURO%204000%20202005-09-30.pdf
GE *4400 HP* diesel-electric AC locomotive

420,000 pound weight
76' long

Exhaust muffler

Hug diesel particulate filter (DPF) inside muffler

MTU high-speed 4000 HP diesel engine

Vossloh MaK 2000BB *4000 HP* diesel-hydraulic locomotive

GE Evolution-series medium-speed 4400 HP diesel engine (EMD 710 engine identical size)
SBB Am841 1220HP w/ retrofitted Hug filter (1 of 6)

SBB Am843 2000HP w/ new Hug filter (1 of 73)

Vossloh MaK2000BB 3600HP w/ new Hug filter (1 of 1)

ARB-BNSF-UP 1500HP EMD switchers with retrofitted Hug DPF

EPA-SWRI-UP 3800HP SD60 with retrofitted DOC
There is no different technology being utilized in Europe that is not being investigated in the U.S.!

New locomotives

- Switzerland is ahead of US on implementing Hug DPF filters on 73 new 2000HP switcher locomotives.

- US focus for new switchers has shifted to hybrids and genset switchers, both using truck-derivative diesel engines.

- For high horsepower, there is only 1 prototype new locomotive with DPF in Europe.

- But ... European manufacturer is now partnering with EMD to use US Tier 2 type engine without DPF.

Retrofits: only 6 in Switzerland completed, 2-to-4 to be completed in US in ‘06
Visit to Eurotunnel: *not promising!*

Vossloh G1206 locomotive (same as Swiss Am843) without DPF

Water scrubber tender car
Questions & Comments