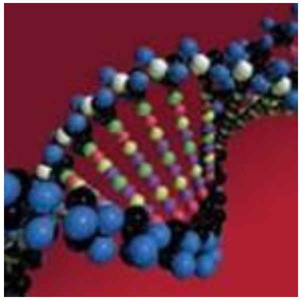
Locomotive Emissions Project



Potential Measures to Reduce Emissions from New and In-service Locomotives in NSW and Australia

Industry Presentation, ENVIRON North Sydney Offices

Thurs 21 June 2012

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Project Proponent:

- NSW Office of Environment & Heritage

Project Team:

- ENVIRON Australia
- Interfleet Technology (fleet characterisation)
- EMGA Mitchell McLennan (noise)

Presentation Overview

- Background to study
- Study objectives and scope
- Regulatory and policy review – key outcomes
- Locomotive Fleet Characterisation
- Air emissions from locomotives
- Emission reduction measures
  - Practicability review
  - Emission reductions achievable
  - Health benefits
  - Cost-effectiveness
- Study outcomes

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Background

- PM_{10} and ozone air quality limits are exceeded within a number of Australian airsheds, with adverse health outcomes. WHO (2012) classified diesel exhaust as carcinogenic to humans.
- Emission from diesel-powered locomotives concluded by previous studies to be significant anthropogenic source of PM_{10} and Nox.
- Australia has no air emission limits for new or re-manufactured locomotives. Nor are substantive programs addressing air emissions from in-service locomotives.
- Emission standards for locomotives introduced by the US (1997), International Union of Railways (2002), EU (2004), Turkey (2010). Standards under development by Canada (2012).

Background

- In NSW, locomotive emissions are expected to increase as a result of:
  - Increased freight movements along metropolitan and country networks due to increased investment in rail infrastructure and targets for increasing rail's share;
  - Increased coal mine outputs especially in the Gunnedah Basin, the northern part of the Western Basin and the Hunter Valley to the Port of Newcastle;
  - Increasing length and load of freight trains; and
  - Aging locomotive fleet.

Study Objective & Scope

- **Objective:**
  - Identify measures to reduce $PM_{2.5}$, PM_{10} and NO_x emissions from new and in-service locomotives in NSW and Australia.
- **Key components:**
  - Review of local, national and international air emission regulations and policies for new and in-service locomotives.
  - Characterise the locomotive fleet industry in NSW and Australia.
  - Quantify air emissions from locomotives in NSW and Australia.
  - Identify potential cost-effective measures for reducing air emissions from new and in-service locomotives in NSW and Australia.
  - Consultation with industry:
- **Consultation with Industry Stakeholders**
  - Potential stakeholders identified (rail operators; manufacturers; rail track managers; industry associations), notified of project, and asked to register.
  - Rail operators and rail track managers asked to supply or verify information.
  - Results of study communicated to stakeholders and feedback invited.

Program & Policy Review – Australia

- No emission standards issued nationally or by states.
- Queensland – dust from coal wagons
- NSW – pollution reduction programs Environmental Protection Licences (RailCorp – diesel exhaust emissions monitoring; compliance with manufacturer's emission specs; ARTC – dust from coal wagons)
- Peak industry bodies identified:
  - Australasian Railway Association (ARA)
  - Australian Railway Industry Corporation (ARIC)
  - Rail Innovation Australia (RIA), previously Rail CRC
  - Rail Industry Safety and Standards Board (RISSB) - owned by ARA
- Other departments with focus of interest:
  - Department of Innovation Industry Science and Research (DIISR)
  - Department of Resources, Energy and Tourism (DRET)

Program & Policy Review – Australia

Initiatives identified:

- ARA's review of short and longer term opportunities for freight rail, as documented in its 2010 document *Draft Environmental Solutions for Freight Rail.*
- RISSB's development of Exterior Environment Standards through its Australian Rolling Stock Standards Project, which include emission standards for new locomotives. This initiative is on-going.
- DIISR's On Track to 2040 project aimed at progressing future technologies, and including emission reduction strategies, within the Australian rail industry.
- Development of energy efficiency opportunities for the rail sector through collaboration between major rail operators and DRET
- NSW OEH commissioned study in 2011 to identify potential measures to reduce air emissions from NSW ports, including rail-related emissions.
- Advances in driver advice systems.
- Voluntary initiatives by individual rail operators including: fuel efficiency improvements (LGTK benchmarking; driver assistance systems), intentions to purchase cleaner locomotives

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US Emission Standards

US-EPA Tiered Standards for Line Haul and Switch Haul Locomotives				
Line Haul Emission Standards (g/kW-hr)				
Tier Classification	**PM_{10}**	**HC**	**NO_X**	**CO**
Uncontrolled	0.43	0.64	17.43	1.72
Tier 0	0.43	0.64	11.53	1.72
Tier 0+	0.27	0.40	9.66	1.72
Tier 1	0.43	0.63	8.98	1.72
Tier 1+	0.27	0.39	8.98	1.72
Tier 2	0.24	0.35	6.64	1.72
Tier 2 + and Tier 3	0.11	0.17	6.64	1.72
Tier 4	0.02	0.05	1.34	1.72
Switching Shunting Emission Standards (g/kW-hr)				
Tier Classification	**PM_{10}**	**HC**	**NO_X**	**CO**
Uncontrolled	0.59	1.35	23.33	2.45
Tier 0	0.59	1.35	16.90	2.45
Tier 0+	0.31	0.76	14.21	2.45
Tier 1	0.58	1.35	13.28	2.45
Tier 1+	0.31	0.76	13.28	2.45
Tier 2	0.25	0.68	9.79	2.45
Tier 2 +	0.15	0.35	9.79	2.45
Tier 3	0.11	0.35	6.03	2.45
Tier 4	0.02	0.11	1.34	2.45

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EU Emission Standards

European Union (EU) Stage III A Standards for Locomotive Engines					
Category (kW)	**CO (g/kWh)**	**HC + NO_X (g/kWh)**	**HC (g/kWh)**	**NO_X (g/kWh)**	**PM (g/kWh)**
130 <kW (Railcars)	3.5	4.0			0.2
130 ≤kW≤560 (Railroad Locomotives)	3.5	4.0			0.2
kW > 560 (Railroad Locomotives)	3.5	-	0.5	6.0	0.2
kW > 2000 and Swept Volume > 5l/cylinder (Railroad Locomotives)	3.5	-	0.4	7.4	0.2

European Union (EU) Stage III B Standards for Locomotive Engines					
Category (kW)	**CO (g/kWh)**	**HC + NO_X (g/kWh)**	**HC (g/kWh)**	**NO_X (g/kWh)**	**PM (g/kWh)**
130 <kW (Railcars)	3.5	-	0.19	2.0	0.025
130 <kW (Railroad Locomotives)	3.5	4.0	-	-	0.025

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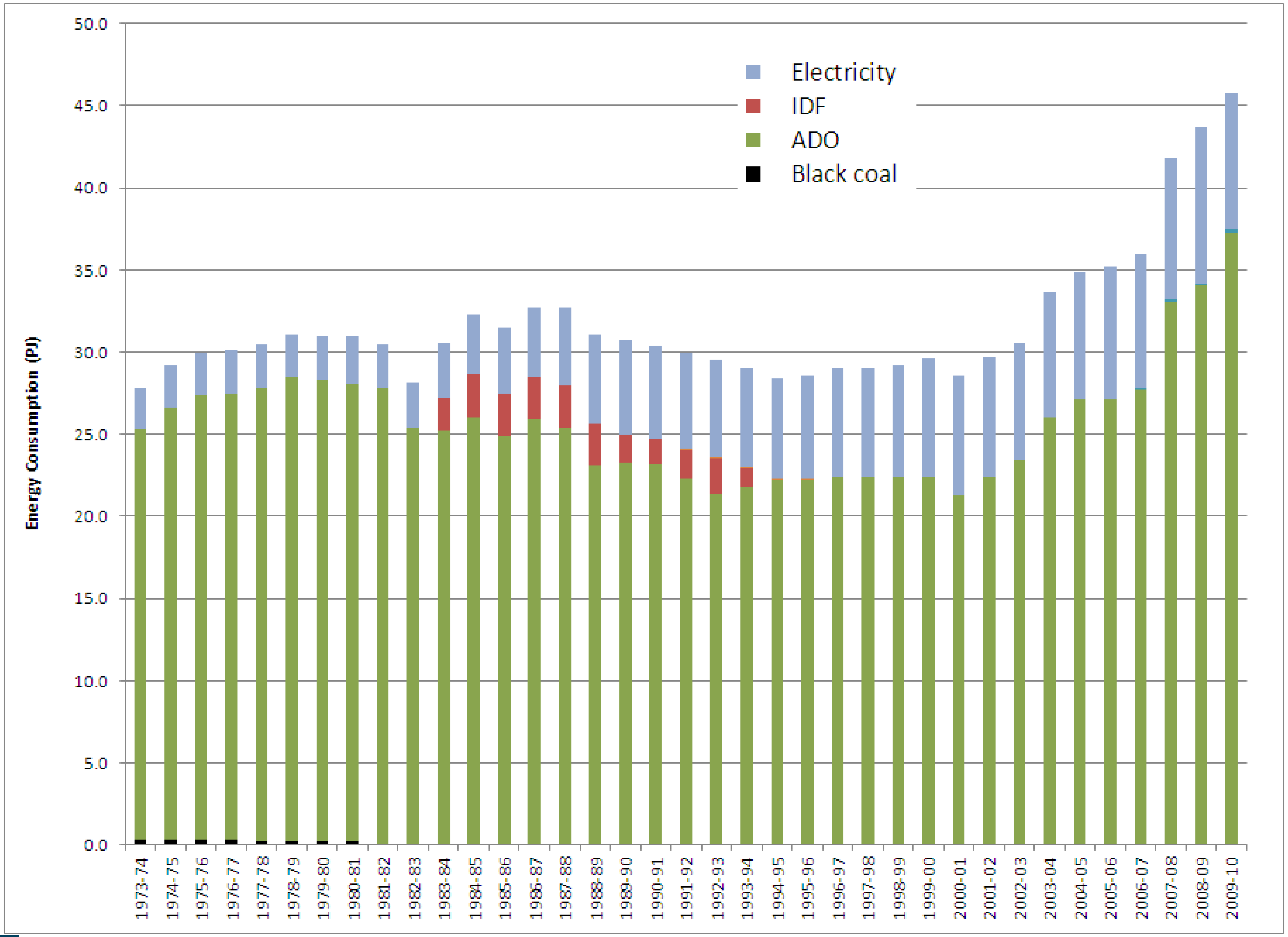
Other Initiatives - Overseas

Initiatives identified (Canada, California, Europe):

- MoUs with major rail operators to realise progressing improvements in existing fleets.
- Funding (cost-sharing) of improvements to existing locomotive fleet focusing on replacing, repowering or rebuilding old engines with newer technologies.
- Research into the technical feasibility, emission reductions, costs and cost-effectiveness of emission reduction measures.
- Diesel fuel regulation, notably reductions in fuel sulphur to ensure the effectiveness of after-treatment technology.

Quality of Diesel

- Diesel use by rail industry in Australia (ABARE, 2011):



Quality of Diesel

- The *Fuel Standard (Automotive Diesel) Determination 2001 (amended 2009)*:

Substance	Amount	Date
Sulfur	500 mg/kg	31 December 2002
Sulfur	50 mg/kg	1 January 2006
Sulfur	10 mg/kg	1 January 2009
Ash	0.01% (m/m)	1 January 2002
PAH (Polycyclic aromatic hydrocarbons)	11% mass by mass	1 January 2006
Biodiesel	5.0% volume by volume	1 March 2009

- US Clean Air Nonroad Diesel Rule of 2004:
  - reduced sulphur levels in non-road diesel fuels to 500 ppm, (effective June 2007), for non-road, locomotive and marine diesel fuels
  - sulfur content reduced to 15 ppm (ultra-low sulfur diesel) for non-road fuel (effective June 2010) and locomotive and marine fuels (effective June 2012).

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Fleet Characterisation

Focus Areas:

- Existing locomotive operator industry structure in NSW and Australia
- Age of locomotives within existing fleet
- Emissions performance of new locomotives sold into Australia relative to US and EU standards
- Projected change in emission performance over the next 20 years (business as usual)
- Amount of fuel used by NSW and Australian locomotive fleets
- Current repowering and rebuilding schemes, NSW and Australian locomotive operators
- Rail transport air emissions per tonne of freight compared to equivalent emissions from the road transport fleet.

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Fleet Characterisation – Loco Types

Australian Rail Freight Operator Locomotive Types				
Operator	**Diesel Electric**	**Diesel Hydraulic**	**Electric Locomotive**	**Total**
QR National	543	7	244	794
Pacific National	558		23	581
BHP Billiton	139			139
Pilbara Rail	134			134
CFCLA	77			77
Genesee & Wyoming Australia	75			75
Tarsal	52			52
QUBE Logistics	51			51
V/Line	41			41
SCT	32	2		34
IRA (former LVRF)	22			22
RailCorp	21	1		22
GrainCorp	20			20
Fortescue Metals Group	19			19
BHP One Steel	13			13
Edie Rail	12	1		13
El Zorro	10			10
Xstrata	10			10
Manildra Group	2	6		8
Patricks	6	2		8
Centennial Coal	7			7
Junee Railway Workshop	7			7
AWB	4			4
CRT	0	4		4
Southern Short haul Railroad	4			4
Australian Loco Lease	3			3
Whitehaven Coal	3			3
Comalco	2			2
BlueScope, Port Kembla	1			1
ComSteel	1			1
Rail Power	1			1
RTS	1			1
Total(a)	**1871**	**23**	**267**	**2161**

Includes locos in service and those not currently active.

Accurate to within +-5%

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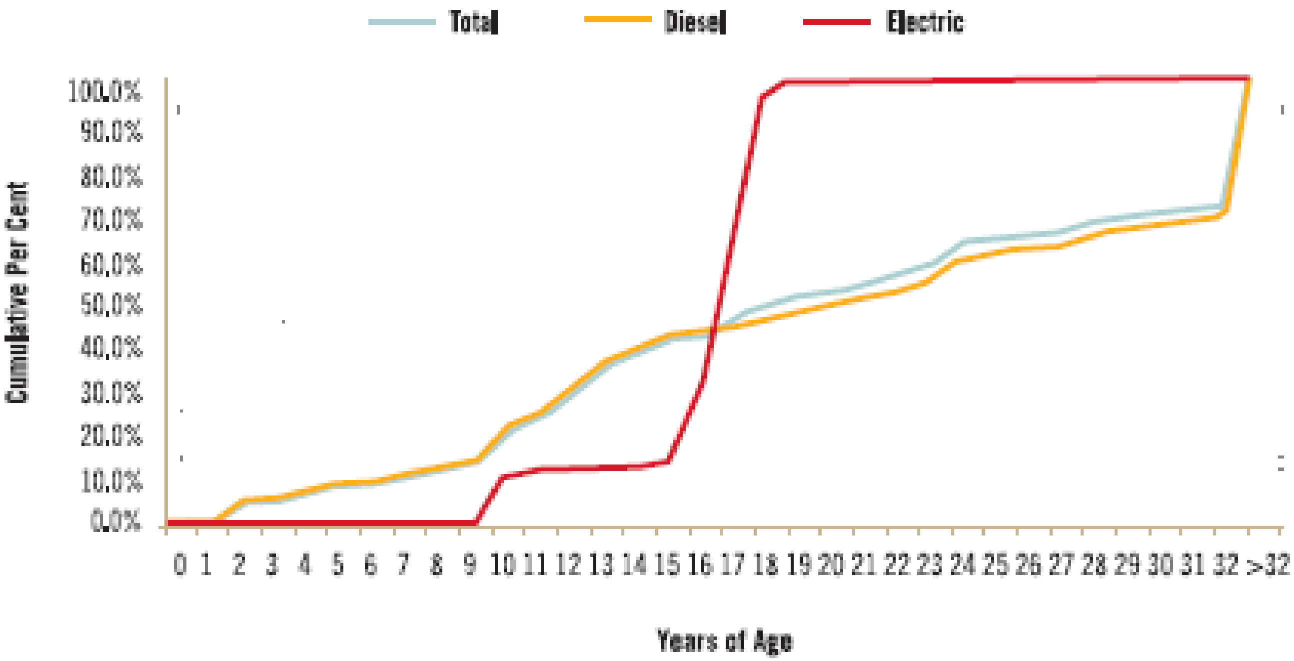
Fleet Characterisation - age



Approximate locomotive age profile (ARA, 2007)[1]:

•50% of the total locomotive fleet was aged 17 years or older, now 22 years or older.
•50% of the diesel locomotive fleet was aged 19 years or older, now 23 years or older.
•26% of the total locomotive fleet was aged 30 years or older, now 37%.
•30% of the diesel locomotive fleet was aged 30 years or older, now 44%.

[1] ARA Australian Rail Industry Report 2007

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Fleet Characterisation – emission performance of new engines

Examples of emission performance of newer engines:

- MTU 4000V20R43
  - Favoured high speed engine for new generation of locomotives
  - 2700kW engine that is EU IIIA and EU IIIB ready
  - Introduced by KiwiRail and SCT, with other engines also about to enter service in Australia from other large manufacturers of raod truck engines Caterpillar and Cummins (but not yet in service)
- EMD – 710 engine family
  - achieve US Tier 2 and EU IIIA when used with EMDEC electronic fuel injection control system
  - Used in Australia, but not to be loaded with Tier 2 engine control software in current applications
  - Nearest uses Tier 1 software (Tier 2 software without retarded injection timing)
- GE – 7FDL
  - Capable of only Tier 0 performance (or upgrade to Tier 0)
  - Tier 1 tuning exists, but less fuel efficient
  - Likely that existing Australian locos running at pre Tier 0 levels
- GE – GEEVO
  - Tier 2 capable
  - Only in service with Pilbara Rail
  - Can not be used on interstate rail network and former govt railways (too “tall”)

Fleet Characterisation – current repowering & rebuilding schemes

- Potential repowering and rebuilding schemes under consideration in Australia at present :
  - Repowering of older and low powered locomotives as described in ARA's **draft** report *Environmental Solutions for Freight Rail* released in December 2010.
  - Repowering of specific classes of locomotives using modern high speed diesel engines.
  - Upgrading existing engines during overhaul generally, e.g.:
    - QR Maxi Overhaul Program
    - Freight Australia Engine Cascading

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Locomotive Categorisation Matrix and Emissions Performance Projections

- Locomotive fleet characterised for 3 years:
  - 2012, 2022 and 2032
- Emission Performance Projection Scenarios:
  - Business as Usual' (BAU)
  - 'Maximum Upgrade Possible for Existing Fleet' (by changing engine internals and accessories)
- Considerations:
  - Locomotive turnover rate and BAU assumptions for 10 and 20 years with engine overhauls 'in-kind'.
  - All new locomotives to have at least Tier 1 performance if capable of Tier 2.
  - Upgrade of the existing engines of all locomotives to the maximum extent possible as they pass through their usual engine overhaul cycle.

Locomotive Categorisation Matrix and Emissions Performance Projections

- Business as Usual’ (BAU):
  - New locomotives are predominantly bought for minerals traffic.
  - Locomotives bought from Downer EDI Rail for standard and narrow gauge operate at Tier 1 but are capable of Tier 2 with Tier 2 engine management software loaded.
  - Locomotives bought from United Group for the standard gauge networks of former government railways are categorised as pre Tier 0 with Tier 0 understood to be the limit of the GE 7FDL engine used.
  - Locomotives bought from United Group for the Pilbara and the forthcoming narrow gauge demonstration locomotive are categorised as Tier 1 with the capability of operating at Tier 2 with Tier 2 software loaded.
  - Locomotives from Chinese suppliers are expected to be Tier 2 capable.
  - As new locomotives are acquired, older locomotives are cascaded into intermodal or intrastate services while old locomotives are not retired due to the lack of a viable business case to replace them.
  - The rail operators in the Pilbara operate their locomotives for shorter lives with 20 to 30 years being common.

Fleet Characterisation – emission performance of 2012 fleet

Emission Performance and Upgradability of 2012 Locomotive Fleet (Active Locomotives Only)					
	Current Emission Performance				
	Pre Tier 0	Tier 0	Tier 1	Tier 2	Total
No. of Locomotives	1497	52	299	6	1854
% of Locomotives	80.7	2.8	16.1	0.3	
	Upgradable to:				
	Pre Tier 0	Upgradable to T0	Upgradable to T1	Upgradable to T2	Total
No. of Locomotives	241	1259	348	6	1854
% of Locomotives	13.0	67.9	18.8	0.3	100

- Locomotive classes with EMD and GE engines - upgrade of emissions capability included where upgrade paths are understood to exist for implementation at overhaul.
- Locomotive classes with other makes of engine - assumed to be unchanged in emissions performance at overhaul.

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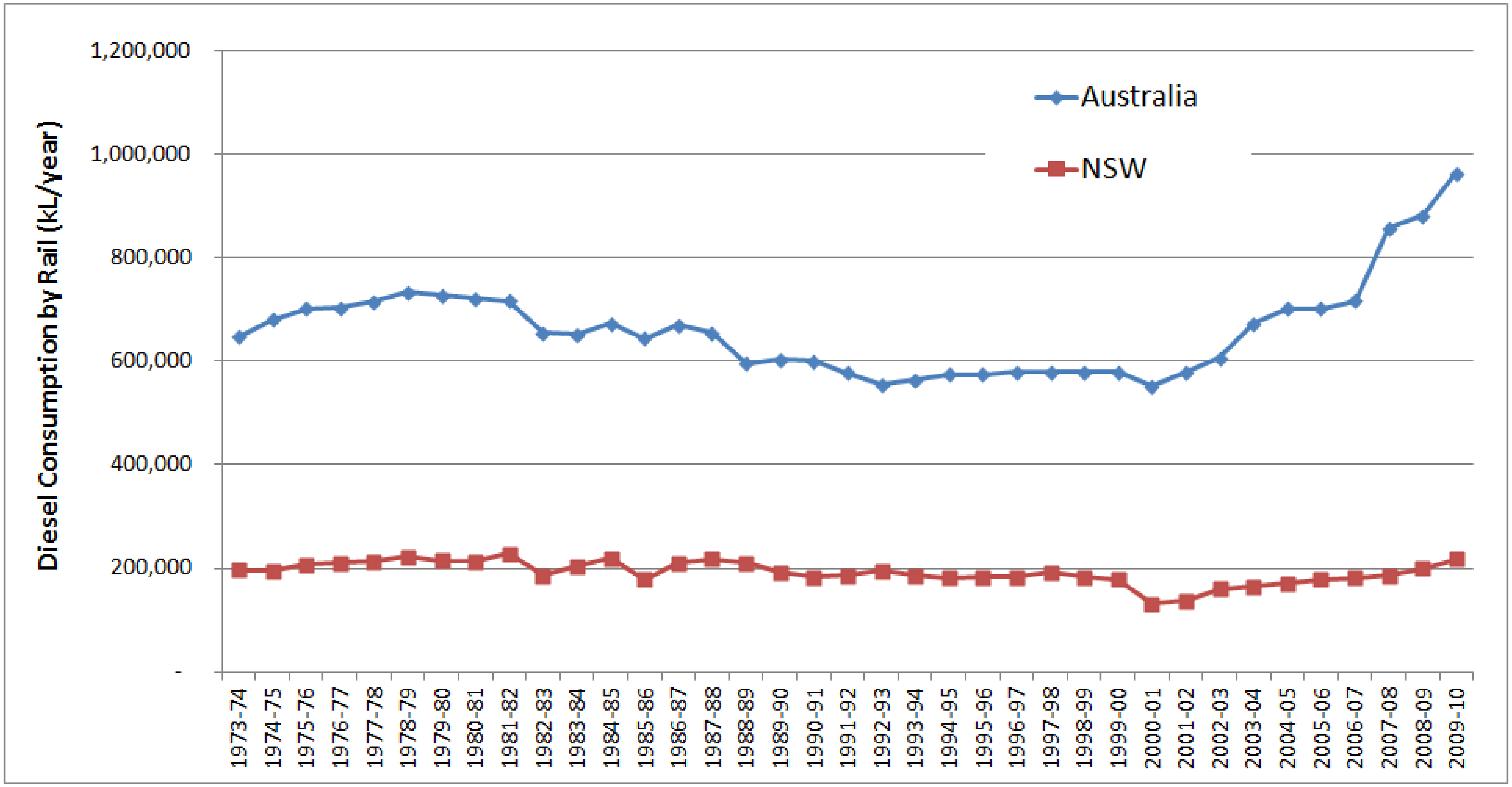
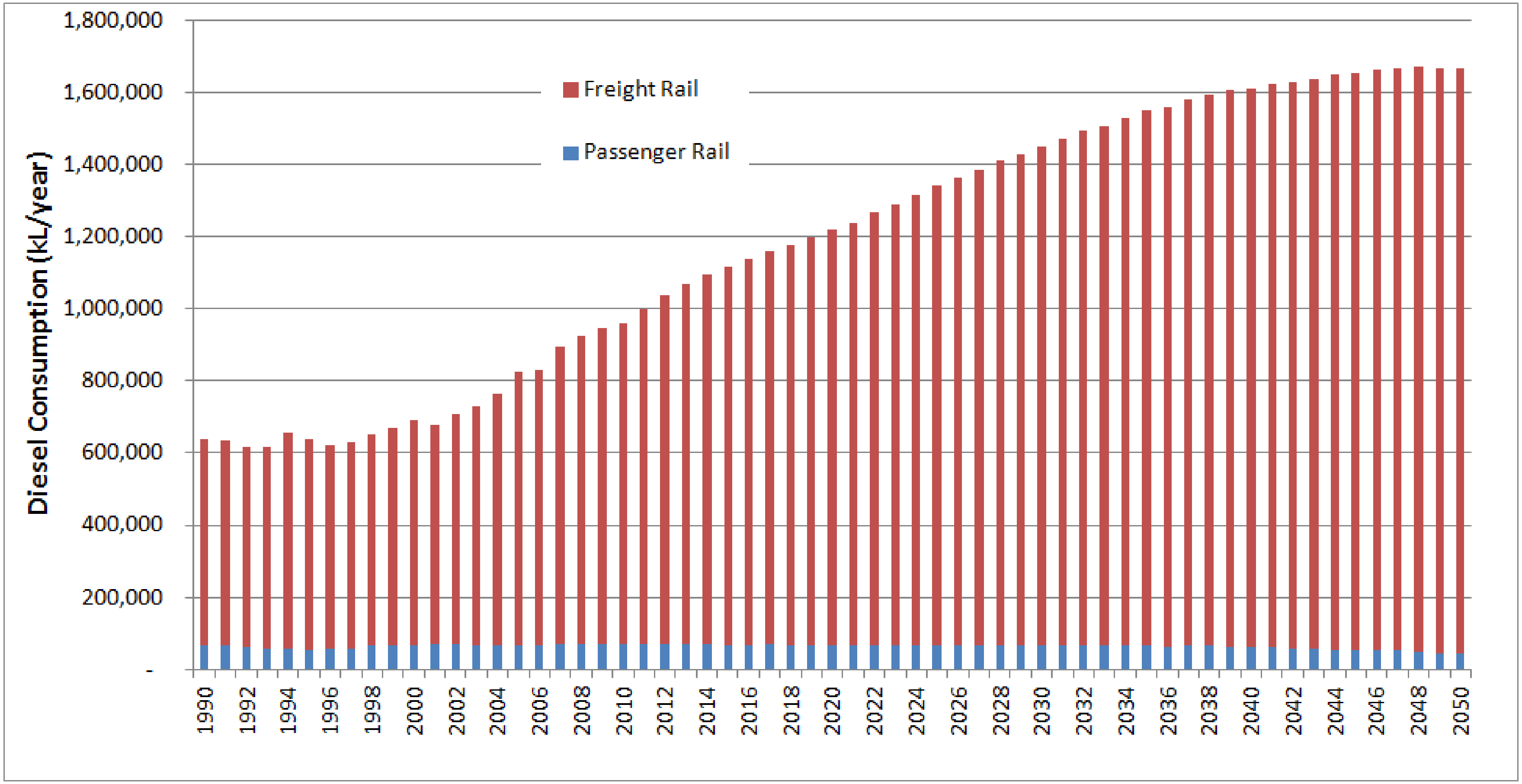
Diesel Consumption by Rail



Diesel Consumption by Rail Transport, 1973 to 2010 (ABARE, 2011)

Diesel Consumption by Rail



Diesel Consumption by Rail Transport with Projections to 2050 (BITRE, 2010)

Diesel Consumption by Rail

Diesel Consumption in Australia for Scenario Years					
Year	**Annual Diesel Consumption (kL/year)**			**% Passenger**	**Data Source**
	Passenger Rail	**Freight Rail**	**Total**		
2012	72,539	963,731	1,036,270	7%	BITRE, 2010
2022	67,358	1,202,073	1,269,431	5%	BITRE, 2010
2032	64,767	1,427,461	1,492,228	4%	BITRE, 2010

Diesel Consumption in NSW for Scenario Years					
Year	**Annual Diesel Consumption (kL/year)**			**% Passenger**	**% of Australian Consumption**
	Passenger Rail	**Freight Rail**	**Total**		
2012	25,099	200,290	225,389	11%	21.8
2022	*25,099(a)*	*231,378(a)*	256,477	10%	20.2
2032	*25,099(a)*	*265,056(a)*	290,155	9%	19.4

Based on: ABARE Projections; recent consumption figures for passenger & freight rail
(a) Assumed or estimated, given that only total consumption available.

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Spatial Disaggregation of Diesel Consumption & Loco Activity

- Required to enable emission estimates to be spatially disaggregated sufficiently to distinguish between emissions in urban and non-urban areas
- Locomotive activity rates and resultant fuel consumption figures projected for following regions:
  - NSW Greater Metropolitan Region (GMR)
  - NSW Outside of the GMR (non-GMR).
  - Other States (outside of NSW) Urban which assumes a GMR with similar margin around capital cities to that in NSW.
  - Other States (outside of NSW) non-Urban.
  - Other States (outside of NSW) East-West which refers to operation on the TransAustralia line from Adelaide to Perth.

According to GTK data provided by the ARTC, an estimated 65% of the fuel consumption within NSW occurs within the GMR

Definition of the NSW GMR comprising Sydney, Newcastle and Wollongong Regions (OEH, 2007)

Air Emission Estimation

- US emission factors, adjusted to lower sulphur content

Emission Factors Applied (grams of pollutant per litre of diesel combusted)			
PM_{10} Emission Factors (g/litre)			
Tier Classification	**Large Line-Haul and Passenger**	**Small Line Haul**	**Switching**
Uncontrolled	1.321	1.101	1.329
Tier 0	1.321	1.101	1.329
Tier 1	1.321	1.101	1.289
Tier 2	0.552	0.428	0.326
Tier 3	0.440	0.385	0.321
Tier 4	0.082	0.072	0.060
NOx Emission Factors (g/litre)			
Tier Classification	**Large Line-Haul and Passenger**	**Small Line Haul**	**Switching**
Uncontrolled	71.4	62.5	69.9
Tier 0	47.3	41.3	50.6
Tier 1	36.8	32.2	39.8
Tier 2	27.2	23.8	29.3
Tier 3	27.2	23.8	18.1
Tier 4	5.5	4.8	4.0

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Air Emission Projections

- Australia

Annual Locomotive Emissions given Business as Usual for Australia				
PM_{10} Emissions (kg/year)				
Year	Urban	Non-Urban	Total	% Urban
2012	364,284	979,527	1,343,810	27
2022	436,157	1,215,913	1,652,070	26
2032	494,869	1,451,451	1,946,320	25
$PM_{2.5}$ Emissions (kg/year)				
Year	Urban	Non-Urban	Total	% Urban
2012	353,355	950,141	1,303,496	27
2022	423,073	1,179,436	1,602,508	26
2032	480,023	1,407,908	1,887,930	25
NO_x Emissions (kg/year)				
Year	Urban	Non-Urban	Total	% Urban
2012	18,897,619	46,433,101	65,330,721	29
2022	21,118,760	52,919,237	74,037,997	29
2032	22,849,746	59,880,654	82,730,400	28

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Air Emission Projections

- NSW

Annual Locomotive Emissions given Business as Usual for NSW				
PM_{10} Emissions (kg/year)				
Year	GMR	Non-GMR	Total	% within GMR
2012	191,247	112,386	303,633	63
2022	203,330	141,019	344,349	59
2032	214,155	174,720	388,876	55
$PM_{2.5}$ Emissions (kg/year)				
Year	Urban	Non-Urban	Total	% within GMR
2012	185,510	109,015	294,524	63
2022	197,231	136,788	334,019	59
2032	207,731	169,479	377,209	55
NO_x Emissions (kg/year)				
Year	Urban	Non-Urban	Total	% within GMR
2012	10,010,911	6,044,864	16,055,775	62
2022	10,536,363	7,080,023	17,616,386	60
2032	11,004,676	8,434,266	19,438,942	57

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Health Cost Projections

Health Cost Data			
Study	**Case**	**Pollution Costs per Tonne (2010 A$)**	
		NOx	**PM_{10}**
Euro 5/6 RIS 2010	Aust. capital cities - upper	1,629	362,932
Euro 5/6 RIS 2010	Aust. capital cities - central	1,086	241,955
Euro 5/6 RIS 2010	Aust. capital cities - low	543	120,977

Annual Health Costs due to Locomotive Emissions given Business as Usual			
	Annual Health Costs due to Locomotive Emissions (Millions AUD)		
	Urban	**Non-urban**	**Total**
PM_{10} emissions	88.1	0.2	88.4
NOx emissions	20.5	0.1	20.6
Total (PM_{10} and NOx emission)	**108.7**	**0.3**	**109.0**

Emission Reduction Measures

Evaluation criteria:

- **Environmental benefits:**
  - reduce air emissions (urban/rural impacts)
  - reduce fossil fuel consumption
  - as a minimum, avoid increases in noise impacts / or noise co-benefits
- **Emission Reduction categories:**
  - <u>Low</u>: 0-5% reduction
  - <u>Medium</u>: 5-10% reduction
  - <u>High</u>: 10-30% reduction
  - <u>Very High</u>: over 30% reduction

Emission Reduction Measures

Evaluation of Practicability:

- **Technical viability:**
  - Low: Low to moderate complexity, accepted technology, no major barriers to implementation.
  - Medium: Moderate complexity, standards require alteration, limited industry consensus on benefits, limited track work required, limited technological barriers, limited external issues.
  - High: Highly complex, significant standards alteration and/or legislative change, no industry consensus, major track work required, high technical barriers, considerable external issues.
- **Economic feasibility**
  - Capital and operating costs associated with implementation, and sectors responsible for covering such costs.
  - Fuel penalties; fuel savings
- **National and/or State applicability**
- **Timeframes for implementation and environmental benefit realisation**
  - Shorter timeframes for implementation (and benefit realisation) given preference.

Emission Reduction Measures

Evaluation of Benefits and Practicability of Inventoried Measures									
Measure	National or State Measure	Applicability - Locomotive Type	Applicability - New or Existing Locos	Emission Reduction	Fuel Savings	Implementation Difficulty / Technical Viability (Examples)	Economic Feasibility – Cost	Timeframe	Other
Existing Fleet Upgrade									
Upgrade to the best Tier achievable, if there is one, at their next overhaul	National or State	Switching/ shunting and line haul	Existing locomotives	**High (NOx)** **Low (PM)**	**Yes/No** Specific to locomotive	**Low / Viable**	**Medium**	**Short term***	*Timeframe depends on when locos are due for overhaul
Alternative Drivetrain Technology									
Replace with ULEL, e.g. Gen-set switch locomotives	National or State	Switching/ shunting	Replace existing with new	**Very High** 85% reduction from Pre Tier 0(c)	**Yes** 20-40% reduction(c); 49% when combined with hybrid regenerative braking technology (b)	**Low / Viable** E.g. California, Texas	**Medium** Up to six times more expensive than conventional locomotives(b)	**Short term**	Long timeframe for realising benefits if limited to new locomotives (and no accelerated replacement)
Replace with Battery electric hybrid switch locomotives (Green Goats)	National or State	Switching/ shunting	Replace existing with new	**Very High** Over 80% reduction from Pre Tier 0(c)	**Yes** 15-25% reduction(b)	**Low / Viable** E.g. California, Texas	**Medium**	**Short term**	
Replace with Battery hybrids for line hauls	National or State	Line haul	Replace existing with new	**Very High**	**Yes** 15-25% reduction(b)	**Medium** Commercial line-haul hybrid release in the US not suitable for non-standard gauge rail networks	**Medium**	**Longer-term**	
Alternative fuels (CNG, LNG)	National or State	Switching/ shunting	Replace existing with new	**Very High**	**Yes**	**Medium** (design adaptations required)(a)(b)	**Medium/High**(a)(b)	**Longer-term**	
AC Traction	National or State	Line haul (interstate)	Replace existing with new	**Low/Medium** Up to 10%(a)		**Medium** (design adaptations required)(b)	**Low/Medium** 10% more expensive than DC locomotive(b)	**Longer-term**	(b)
Battery storage	National or State	Switching/ shunting	Replace existing with new	**Very High**	**Yes**	**Not proven** Prototype; no commercially viable systems	**Medium/High(b)**	**Longer-term**	
Standardise Gauge	National	Line haul	Replace existing with new	**Very High**	**Yes**	High(a)	High(a)	**Longer-term**	
Track Electrification	National / State	Line haul	Replace existing with new	**Very High**	**Yes**	High(a)	High(a)	**Longer-term**	

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Emission Reduction Measures

Evaluation of Benefits and Practicability of Inventoried Measures

Measure	National or State Measure	Applicability - Locomotive Type	Applicability - New or Existing Locos	Emission Reduction	Fuel Savings	Implementation Difficulty / Technical Viability (Examples)	Economic Feasibility – Cost	Timeframe	Other
Fuel Efficiency Improvements									
Driver assistance/advice software	State-wide	Line haul	Existing and new locomotives	**Medium** 5-20%(b)(d)	**Yes** 5-20% reduction(b)(d)	**Low** Locally developed and implemented. Proven.	**Low**	**Short-term**	Applied by Pacific National; To be applied/trialled by Manildra Group and QR National
Electronically controlled pneumatic (ECP) brakes	State-wide		Existing and new locomotives	**Low/Medium** 4-11% reduction(b)	**Yes** 4-11% reduction(b)	**Low** Extensive local trials. Proven.	**Low**	**Short-term**	Wagon manufacturers in Australia indicate a very rapid uptake is possible(b)
Idle management devices	State-wide	Primarily switching/ shunting, but potentially also line haul	Existing and new locomotives	**Low/Medium** 3-10% reduction(c)	**Yes** 3-10% reduction(c)	**Low** Proven abroad, e.g. California.	**Low**	**Short-term**	
Retrofitting of After-treatment									
Diesel particulate filters (DPF), selective catalytic reduction (SCR), exhaust gas recirculation (EGR).	State	Line haul	Existing locomotives	High	**No. May increase fuel consumption.**	**Medium** Limited experience with retrofitting. Only DPF feasible for pre-1990 locomotives	**Medium**	**Short-term**	

Sources:

(a) ARA (2010). Draft: Environmental Solutions for Freight Rail, Australasian Railway Association Inc.

(b) Potential for noise impact raised by Rare Consulting (2012). Energy Efficiency Opportunities in the Australian Road and Rail Sectors– Supplementary information for EEO participants, February 2012. However, the potential for such impact was found to be unsubstantial based on further investigations.

(c) CARB (2009). Technical Options to Achieve Additional Emissions and Risk Reductions from California Locomotives and Rail yards, California Air Resources Board.

(d) Information received from TTG Transportation Technology (May 2012).

(e) Kollamthodi (2006). Rail Diesel Study – Management Summary, AEA Technology Environment, Final Report, March 2006.

Graduated scale used in the table:

Favourable				Unfavourable

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Emission Reduction Measures Selected for Quantitative Analysis

- Quantitative assessment focused on measures which are:
  - able to realise an emission reduction and possible fuel saving,
  - unlikely to result in noise impacts,
  - implementable in the short-term (with benefits realisable in the near-term in most cases),
  - technically viable and potentially economically feasible, and
  - have higher degrees of certainty in terms of being successful.
- A mix of measures was selected to ensure that:
  - existing and new locomotives are addressed,
  - line haul and switching/shunting locomotives are addressed, and
  - options for implementation nationally and by states are considered.

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Emission Reduction Measures Selected for Quantitative Analysis

No.	Measure:
1	Replacement/Repowering of old freight line haul locomotives to meet Stage III, as proposed by ARA 2010. This measure comprises 150-183 locomotives being repowered over 10 years.
2	Upgrade of existing fleet to the highest Tier achievable at overhaul, with accelerated overhaul to ensure overhaul occurs in the short-term.
3	All new locomotives to comply with Tier 2 (not accelerated)
4	All new locomotives to comply with Tier 4 (not accelerated)
5	Replacement of line haul locomotives over 25 years old with Tier 4 compliant locomotives, and all new locomotives to comply with Tier 4
6	Replacement of existing switch locomotives with gen-set locomotives, and requirement for future switching/shunting locomotives to be of this type. Only applied to locomotives with over 20 years of life remaining, with fuel consumption over 100,000 litres per year.
7	Installation of a driver assistance system on freight and passenger line haul locomotives in the short-term
8	Retrofitting of ECP Brakes to existing line haul locomotives in the short-term
9	Installation of idling reduction systems in existing switching/shunting and line haul locomotives in the short-term

Emission Reduction and Health Benefits of National Measures

Annual Health Benefits due to National Measures				
		Annual Health Benefits due to Measures (Millions AUD)		
No.	Measure	NO_x Emission Reductions	PM_{10} Emission Reductions	Total
1	Repower/replace solution (ARA, 2010)	NQ	NQ	NQ
2	Upgrading of existing fleet (accelerated overhaul)	5.8	-	5.8
3	New Locos Tier 2	0.7	9.5	10.2
4	New Locos Tier 4	2.0	15.3	17.3
5	Accelerated old line haul replacement to achieve Tier 4 and new locos Tier 4	7.4	37.5	44.9
6	Replace switching locos with gen-sets	0.2	0.8	1.0
7	Driver assistance system (line haul locos)	1.6	7.6	9.2
8	ECP Brakes (line haul locos)	0.7	3.5	4.2
9	Idle reduction system (switching and line haul locos)	0.7	3.4	4.1

NQ – not quantifiable as the urban / non-urban distribution of emission reductions is not known.

Emission Reductions due to Selected National Measures													
No.	Measure	Scale	Non-Urban PM_{10} Reduction (tpa)	Urban PM_{10} Reduction (tpa)	Total PM_{10} Reduction (tpa)	Non-Urban NOx Reduction (tpa)	Urban NOx Reduction (tpa)	Total NOx Reduction (tpa)	Urban PM_{10} Reduction (%)	Total PM_{10} Reduction (%)	Urban NOx Reduction (%)	Total NOx Reduction (%)
1	Repower/replace solution (ARA, 2010)	National	ND	ND	148	ND	ND	4,200		9		6
2	Upgrading of existing fleet (accelerated overhaul)	National	-	-	-	13,402	5,336	18,738	-	-	25	25
3	New Locos Tier 2	National	150	39	189	2,325	685	3,010	9	11	3	4
4	New Locos Tier 4	National	241	63	304	6,552	1,792	8,344	15	18	9	11
5	Accelerated old line haul replacement to achieve Tier 4 and new locos Tier 4	National	475	155	629	18,983	6,766	25,749	36	38	32	35
6	Replace switching locos with gen-sets	National	12	3	15	726	200	926	1	1	1	1
7	Driver assistance system (line haul locos)	National	82	31	113	3,303	1,507	4,810	7	7	7	6
8	ECP Brakes (line haul locos)	National	40	14	55	1,756	688	2,445	3	3	3	3
9	Idle reduction system (switching and line haul locos)	National	35	14	49	1,538	680	2,217	3	3	3	3

ND – no data

Cost Effectiveness of National Measures

Cost Effectiveness of National Measures								
No.	**Measure**	**Scale**	**Cost of Measure over 20 years (Millions AUD)**	**Pre Unit Costs(a)**	**Emission Reduction (tonnes over 20 years)**		**Control Effectiveness for NOx ($/tonne)**	**Control Effectiveness for PM_{10} ($/tonne)**
					NOx	**PM_{10}**		
1	Repower/replace solution (ARA, 2010)	National	573 ±149	$1.5-$2.5 million per locomotive for repowering; $3.5-$6 million/locomotive for replacement	74,000 ±10,000	2,740 ±200	4,078 ±1,555	107,339 ±35,717
2	Upgrading of existing fleet (accelerated overhaul)	National	235 ±156(a)	$50k to $300k per locomotive for Pre Tier 0 to Tier 0 upgrade; $400k to $700k per locomotive for Pre Tier 0 to Tier 1 upgrade	374,757	No reduction	314±208	NA
3	New Locos Tier 2	National	414	$475k per locomotive for purchasing and operating a Tier 2 compared to Tier 1	60,202	3,781	3,436	54,713
4	New Locos Tier 4	National	610	$700 per locomotive for purchasing and operating a Tier 4 compared to Tier 1	166,876	6,087	1,827	50,080
5	Accelerated old line haul replacement to achieve Tier 4 and new locos Tier 4	National	3,655 ±725	$4-6.5 million per locomotive for replacements and $700k for new locomotives (purchasing and operating a Tier 4 compared to a Tier 1)	514,976	12,589	3,548 ±704	145,157 ±28,795
6	Replace switching locos with gen-sets	National	166 ±28	$1-$1.4 million per locomotive replaced	18,527	297	4,469 ±745	278,457 ±46,409
7	Driver assistance system (line haul locos)	National	29	$16k per locomotive (accounting for capital and operating costs, and fuel savings)	96,195	2,259	379 ±227	16,120 ±9,658
8	ECP Brakes (line haul locos)	National	1,587 ±543	$500k to $1 million per locomotive	48,892	1,092	16,228 ±5,553	726,27 8±248,518
9	Idle reduction system (switching and line haul locos)	National	518 ±454	$25k to $385k per locomotive	44,344	977	5,838 ±5,123	264,938 ±232,482

(a) Excludes normal overhaul costs.

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Emission Reduction and Health Benefits of NSW GMR Measures

Annual Health Benefits due to Regional Measures

No.	Measure	Annual Health Benefits due to Measures (Millions AUD): NO_x Emission Reductions	PM_{10} Emission Reductions	Total
2	Upgrading of existing fleet (accelerated overhaul)	3.5	No reduction	3.5
3	New Locos Tier 2	0.3	1.7	2.0
4	New Locos Tier 4	0.5	2.8	3.3
5	Accelerated old line haul replacement to achieve Tier 4 and new locos Tier 4	4.4	18.4	22.8
6	Replace switching locos with gen-sets	<0.01	0.01	0.01
7	Driver assistance system (line haul locos)	0.9	3.8	4.7
8	ECP Brakes (line haul locos)	0.5	2.3	2.8
9	Idle reduction system (switching and line haul locos)	0.4	1.8	2.2

Emission Reductions due to Selected Regional Measures

No.	Measure	Scale	Non-Urban PM_{10} Reduction (tpa)	Urban PM_{10} Reduction (tpa)	Total PM_{10} Reduction (tpa)	Non-Urban NOx Reduction (tpa)	Urban NOx Reduction (tpa)	Total NOx Reduction (tpa)
2	Upgrading of existing fleet (accelerated overhaul)	NSW GMR	No reduction	No reduction	No reduction	6,004	3,256	9,260
3	New Locos Tier 2	NSW GMR	21	7	28	716	282	999
4	New Locos Tier 4	NSW GMR	34	11	45	1,311	482	1,793
5	Accelerated old line haul replacement to achieve Tier 4 and new locos Tier 4	NSW GMR	107	76	182	5,166	4,020	9,186
6	Replace switching locos with gen-sets	NSW GMR	0.4	0.0	0.4	22	2	24
7	Driver assistance system (line haul locos)	NSW GMR	12	15	28	591	831	1,422
8	ECP Brakes (line haul locos)	NSW GMR	14	9	23	712	498	1,210
9	Idle reduction system (switching and line haul locos)	NSW GMR	10	7	18	547	389	935

Cost Effectiveness of NSW GMR Measures

Cost Effectiveness of Regional Measures

No.	Measure	Scale	Cost of Measure over 20 years ($ Million)	Pre Unit Costs(a)	Emission Reduction (tonnes over 20 years)		Control Effectiveness for NOx ($/tonne)	Control Effectiveness for PM_{10} ($/tonne)
					NOx	PM_{10}		
2	Upgrading of existing fleet (accelerated overhaul)	NSW GMR	108±77*	$50k to $300k per locomotive for Pre Tier 0 to Tier 0 upgrade; $400k to $700k per locomotive for Pre Tier 0 to Tier 1 upgrade	185,201	-	291 ±207	
3	New Locos Tier 2	NSW GMR	67	$475k per locomotive for purchasing and operating a Tier 2 compared to Tier 1	19,977	563	1,664	59,081
4	New Locos Tier 4	NSW GMR	98	$700 per locomotive for purchasing and operating a Tier 4 compared to Tier 1	35,855	906	1,367	54,078
5	Accelerated old line haul replacement to achieve Tier 4 and new locos Tier 4	NSW GMR	1,568±350	$4-6.5 million per locomotive for replacements and $700k for new locomotives (purchasing and operating a Tier 4 compared to a Tier 1)	183,721	3,649	4,267 ±953	214,856 ±47,959
6	Replace switching locos with gen-sets	NSW GMR	7±1	$1-$1.4 million per locomotive replaced	487	8	7,400 ±1,233	461,056 ±76,843
7	Driver assistance system (line haul locos)	NSW GMR	-2	$16k per locomotive (accounting for capital and operating costs, and fuel savings)	28,440	553	-37	-1,926
8	ECP Brakes (line haul locos)	NSW GMR	554±191	$500k to $1 million per locomotive	24,199	463	11,444 ±3,946	598,114 ±206,258
9	Idle reduction system (switching and line haul locos)	NSW GMR	165±147	$25k to $385k per locomotive	18,708	358	4,416±3,935	230,815 ±205,708

Study Outcome

- National measures warranting further consideration:
  - Introduction of emission standards requiring emission performance equivalent to Tier 4 standards for new locomotives.
  - Continued identification and funding for the uptake of fuel efficiency measures as a component of Energy Efficiency Opportunity programs.
  - Provision of incentives to operators to promote the upgrading of existing locomotives to achieve improved emissions performance during routine overhauls, and/or accelerated retirement of old locomotives operating in urban areas.
  - Identification of longer-term measures through consultative programs, notably On Track to 2040. (Possible measures include natural gas, standardised gauge and track electrification.)

Study Outcome

- State measures which warrant further investigation:
  - Support of fuel efficiency measures
    - Driver assistance systems for line haul locomotives, including passenger and freight locomotives.
    - Idle reduction systems, particularly for switching locomotives operating within urban areas.
  - Accelerated replacement of old (25 years+) locomotives
    - Switching locomotives operating within urban areas, and
    - Line-haul locomotives with high utilisation rates, particularly those travelling through urban areas (e.g. passenger) and to and from ports (coal haul, freight).
  - Accelerated overhaul of other existing locomotives (<25 years old) to the highest Tier achievable, focussing on:
    - Switching locomotives operating within urban areas, and
    - Line-haul locomotives with high utilisation rates, particularly those travelling through urban areas (e.g. passenger) and to and from ports (coal haul, freight).

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