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MRC-DICE Risk Review

Final Report

201020-06973 – SR-REP-0002

24 Sept 2014

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CSIRO / BCIA
MRC-DICE RISK REVIEW
FINAL REPORT

SYNOPSIS

This report summarises WorleyParsons' risk review for CSIRO (undertaken as a BCIA funded activity) for the commercialisation of the MRC-DICE technology. The report outlines the technology, describes the risk review's methodology, identifies the risks in the three stages to full commercialisation (R&D, Demonstration and Commercialisation) and proposes mitigation strategies and actions. The report finds no "showstoppers" to the commercialisation of the technology.

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PROJECT 201020-06973 - MRC-DICE RISK REVIEW

REV	DESCRIPTION	ORIG	REVIEW	WORLEY-PARSONS APPROVAL	DATE	CLIENT APPROVAL	DATE
0	Issued for use	P O'Neil	P Lawley	I Waterman	16 Sept 2014	N/A	
1	Reissued	P O'Neil	P Lawley	I Waterman	24 Sept 2014		N/A
							N/A
							N/A

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Document No : SR-REP-0002

EXECUTIVE SUMMARY

This report provides a summary of the risk review that WorleyParsons has undertaken for the CSIRO of the three stages of the commercialisation pathway (R&D, demonstration and commercialisation) of the MRC-DICE technology. This fuel and engine technology aims to be a viable competitor to diesel-fuelled gensets in the power generation sector. The report outlines the study's methodology, the risks it identified, and their mitigation.

MRC-DICE Technology

The MRC technology micronises solid carbonaceous feedstock, refines it to remove most of the mineral matter, and disperses it in water to produce a slurry fuel called MRC (micronised refined carbons). The use of MRC would enable a delivered efficiency (from resource through to delivered electricity) of around 50% HHV. A standard diesel engine needs to be modified to operate on an MRC fuel. The modified Direct Injection Carbon Engines (DICE) would be based on large low-medium speed diesel engines.

The commercialisation of the MRC-DICE technology is proposed to occur in three broad stages: Research and Development (R&D), Demonstration and Commercialisation. The diagram in shows the three stages and possible timelines and estimated budgets for each stage.

Figure 1 - MRC-DICE Commercialisation Stages

MRC-DICE Risk Review

A risk review has been undertaken to identify the key risks for the development programme of the MRC-DICE technology. This review was undertaken in two stages:

1. A desktop risk review

2. Two workshops with key stakeholders, focusing on:
    a. Risks and showstoppers held in Newcastle (technical and near term risks)
    b. Commercialisation held in Melbourne (longer term, commercial and project execution risks)

During the workshops risks were identified and then for each risk it was discussed how to:

- Identify current measures to manage the risk
- Determine a risk rating from "low" to "extreme" based on agreed likelihood and consequence scales
- Identify further treatment actions that could reduce the risk further
- Determine the final rating for the risk

From this process sixty five risks were identified, with ratings that ranged from "extreme" to "low". The risk map is shown below for before and after treatment. A listing of "high" and "extreme" risks and their treatments is given in Appendix 1.

Though there remains a significant area of risk for the commercialisation of MRC-DICE technology, it has the potential to be successful if the risk treatments summarised above are implemented expeditiously. After treatment, none of the risks identified were considered by stakeholders as "showstoppers" that would otherwise indicate that the MRC-DICE development programme should be halted immediately.

Risk Map
Before Treatment

Likelihood		Consequence: Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
A	Almost Certain		26 27			
B	Likely			99 7 28 63 68 22 84	86 108 110 82 85 129	
C	Moderate		2 3 96	100 19 21 20 61 62 65 67 69 73 74 77 89 10 81	112 60 64 75 87 88 90 93 95	111
D	Unlikely		4	6 8 102 24 30 76 109	101 70 104 66 72 78 79 80 83	
E	Rare	29		1 5 9	92	

Low	Moderate	High	Extreme
2	13	34	16

Risk Map
After Treatment

Likelihood		Consequence: Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
A	Almost Certain					
B	Likely			99 28 63 68 22 84	85	
C	Moderate		27 2 3 96	100 61 62 65 67 69 73 74 77 89 81	82 112 60 88 129	
D	Unlikely		26 4	7 19 20 10 6 8 102 24 76 109	86 108 110 64 75 90 93 101 70 104 72 78 79 80 83	111
E	Rare	29		21 30 1 5 9	87 95 66 92	

Low	Moderate	High	Extreme
3	19	36	7

Figure 2 - MRC-DICE risk review risk map

After risk treatment plans are applied, seven risks were rated as being "extreme":

- four are related to commercialisation:
  - (111) MAN contract and timing restrictions
  - (129) $40m required for the demonstration phase
  - (60) Competing technologies develop more quickly
  - (88) Non-commercial funding not available
- two are related to project execution:
  - (82) Financial market uncertainty
  - (85) Due Diligence information requirements
- one is related to power generation:
  - (112) Engine durability for 8000hrs running

During the Melbourne commercialisation workshop it was agreed with MAN to combine all the engine-durability related risks into 112.

Another thirty four risks were rated as being "high" after treatment.

The treatment plans for these risks are summarised in Table 1 along with the stage of the commercialisation pathway they relate to. This table is presented as a chronological flow of proposed major actions in each stage.

Table 1 – Risk treatment plans

No,	Risk treatment title	Description	Risks treated	Stage
1	Engine test project plan	Clear and articulated project plan for MAN engine test programme to secure support from MAN, confirm outcomes particularly with respect to durability and protect IP aspects. Ensure this aligns with Glencore XT plant operational constraints imposed by plant relocation. Consider combined business case fuel and engine.	111, 112, 87, 66, 92, 7, 19, 61, 10	R&D

No,	Risk treatment title	Description	Risks treated	Stage
2	Develop a fuel specification for MRC-DICE fuel	The 20 hour injection test and the 20 hour engine test being undertaken by MAN will provide valuable information to support the development of a draft fuel spec by June 2016. Spec should include as a minimum: • particle size distribution • particle top size • maximum ash content • ash mineralogy • slurry density (% solids) • ignitability / combustibility energy content	70,	R&D
3	Develop fuel preconditioning system	Development of a small skid (pallet size) to precondition fuel and supply it to an engine fuel tank. Includes procuring suitable tanks for transporting fuel to MAN. April 2015	26,27	R&D
4	Develop consortium approach for demonstration phase	$40m is estimated to be required for the demonstration phase of MRC-DICE. A consortium approach is required and could involve a number of different government agencies in a range of countries including Australia, Japan, Germany, Indonesia etc. Engagement has already started	129	Demonstration
5	Next stage commercialisatio n plan	Develop a plan that includes funding requirements for the next stage of investment and development. Should include strategies for: 1. Timing of development to suit appropriate market and investment conditions 2. Development of information appropriate for investors 3. Consideration of all non-financial factors e.g. social license to operate, exhaust emissions, transport of fuel MSDS etc 4. Timing of fuel production, transport infrastructure and standards development to match engine development programme	86,108,82, 85,60,75,8 8,90, 93, 95, 104, 99, 63, 21	Commercialis ation

No,	Risk treatment title	Description	Risks treated	Stage
		•		
6	Develop a communications strategy	1. "Build the story" for MRC-DICE e.g. lower emissions coal, support renewables, CCS, cogeneration applications, biomass blending etc. Target potential investors and international governments.	110, 63, 100	Commercialisation

CONTENTS

Appendices

1 INTRODUCTION

WorleyParsons has been engaged by CSIRO to perform a risk review for the MRC-DICE technology (Micronised Refined Carbons – Direct Injection Carbon Engine). The risk review scope covers the two value chains considered in the review, namely:

1. MRC-DICE for power generation (grid connected in Australia); and
2. MRC-DICE for power generation (off grid including export)

Each of these value chains are made up of the following blocks:

1. Feedstock materials for slurry preparation;
2. Slurry preparation, including grinding and de-ashing of feedstock;
3. Slurry transport;
4. Slurry storage; and
5. Power generation in DICE generators.

The purpose of the review is to examine possible technical, commercial and project execution risks of each of the blocks in the MRC-DICE value chains to evaluate potential showstoppers and significant opportunities and issues. For each significant risk, identify the treatment that may be required that will result in changes to the development programme to reduce risk.

The risk review consisted of two stages:

1. A desktop risk review and report that contained a ranked list of risks highlighting the significant risks identified. This report was prepared by WorleyParsons with reference to MRC-DICE background information, discussions with key stakeholders and WorleyParsons' own experience with the blocks of the value chain. The desktop report was released for feedback prior to the stakeholders gathering for two workshops to discuss the showstoppers, significant risks, and commercialisation and project execution risks.
2. Two risk review workshops and a final report (this report) highlighting the key risks and controls that could be implemented to mitigate the risks. Risks identified through the desktop risk review were discussed with key stakeholders at two workshops in Newcastle and Melbourne to arrive at the final risk ratings and controls.

The controls identified in this final report will feed into the project plan for the engine trials and for commercialisation of the technology.

2 BACKGROUND TO MRC-DICE TECHNOLOGY

This section contains a brief introduction to the MRC-DICE technology using material from the DICEnet website http://dice-net.org where further information can be found. A paper providing answers to 23 frequently asked questions about MRC-DICE has been included in Appendix 4 of this report.

Large compression ignition (diesel) engines are an efficient means of converting chemical energy in hydrocarbons energy to electricity. Currently the main fuel for these engines is diesel (such as road diesel or heavy fuel oil). However, coal and other sources of carbon could also be used to fuel these engines.

The MRC technology micronises solid carbonaceous feedstock, refines it to remove most of the mineral matter, and disperses it in water to produce a slurry fuel called MRC. The use of MRC would enable a delivered efficiency (from resource through to delivered electricity) of around 50% HHV. A standard diesel engine needs to be modified to operate on an MRC fuel. The modified Direct Injection Carbon Engines (DICE) would be based on large low-medium speed diesel engines.

The DICE fuel cycles for black and brown coals are shown in Figure 3 and Figure 4, respectively.

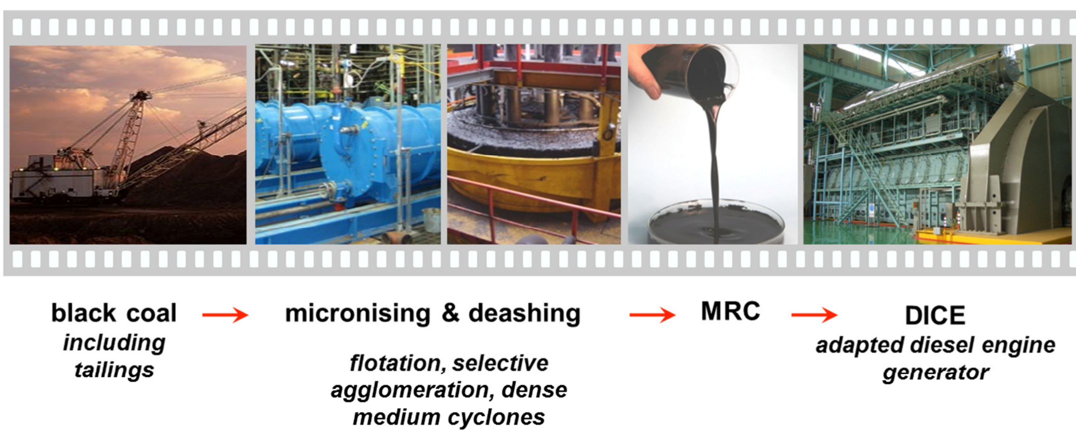

Figure 3 - DICE Fuel Cycle with Black Coal

Figure 4 - DICE Fuel Cycle with Brown Coal

Deployment of MRC-DICE technology could create new markets for brown and black coals, as an alternative fuel for diesel-based applications.

The commercialisation of the MRC-DICE technology is proposed to occur in three broad stages: Research and Development (R&D), Demonstration and Commercialisation. The diagram in Figure 5 shows the three stages and possible timelines and estimated budgets for each stage from discussions at the workshops.

Figure 5- MRC-DICE Commercialisation Stages

2.1 R&D plan

A three stage plan is currently under development for the R&D stage of the MRC-DICE commercialisation. The three stages of this plan are:

1. Stage P1 - Fuel development and logistics
2. Stage P2 – Test programme
3. Stage P3 – Logistics, guidelines and R&D fundamentals

Stage P1 – Fuel development and logistics

Two MRC-DICE fuels will be produced, one based on black coal and one based on brown coal. These fuels will be analysed prior to use in injection tests and engine tests in a 1MW engine. A fuel preconditioning system will also be developed to extract the fuel from the containers used for transport and prepare the fuel for use.

Stage P2 – Test programme

Two tests will be undertaken on each MRC-DICE fuel: a 20 hour injection test and a 20 hour combustion test in a 1MW, single cylinder engine.

Stage P3 – Logistics, guidelines and R&D fundamentals

During this stage a techno-economic model will be developed that will guide the commercialisation of the MRC-DICE technology. Research and develop of fundamental issues and other tasks will be undertaken in response to actions identified during stages P1 and P2.

2.2 MRC Fuel

DICE requires cost-effective production of ultra-low ash coals. Although the cleaner the better, detailed coal specifications for large diesel engines remain unclear. The earlier USDOE work concluded that coal with less than 1.8% ash was suitable for DICE. The ash target is currently 1–2%, but will be a trade-off between processing cost, and engine and maintenance costs. Depending on engine speed, MRC should have a top size of around 50 µm, a coal concentration of at least 55%, and enable effective pressure atomisation. However, it is likely that, as DICE develops, coarser and higher solids MRC will be preferred – reducing processing and transportation costs, and improving engine efficiency and output.

For all coals, formulation may then be required with small amounts of dispersant/stabiliser to obtain the required rheological properties (low viscosity, high stability). The stability specification will depend on the transportation and storage requirements, and end application (for example, for captive MRC-DICE plants, fuel stability is unlikely to be an issue). The amount of dispersant required varies greatly with the coal and dispersant used, and is typically 0.05-0.5wt%.

The production of MRC fuels from biomass, including algal soups, is also being investigated.

Bituminous coals

For black coal, the MRC process can use a variety of technologies all commercially available and well known to the industry. All involve micronising to increase mineral liberation, followed by flotation/selective agglomeration or dense medium separation.

These processes have been used in a number of studies since 1990. While in the past there was no ready market for ultra-fine wet coal (dewatering to product normal moisture specifications being uneconomic), with DICE, ultrafine wet coal is a suitable fuel.

Note that micronising before de-ashing also avoids needing to micronise clean product MRC before the engine, thereby avoiding fuel contamination by the grinding media. Overall, this approach gives an improvement over the processes used for the USDOE program.

In practice, there will be many options for producing MRC, including starting with washed coals through to scavenging MRC from tailings streams, and blending of biochars, for example as shown in Figure 6.

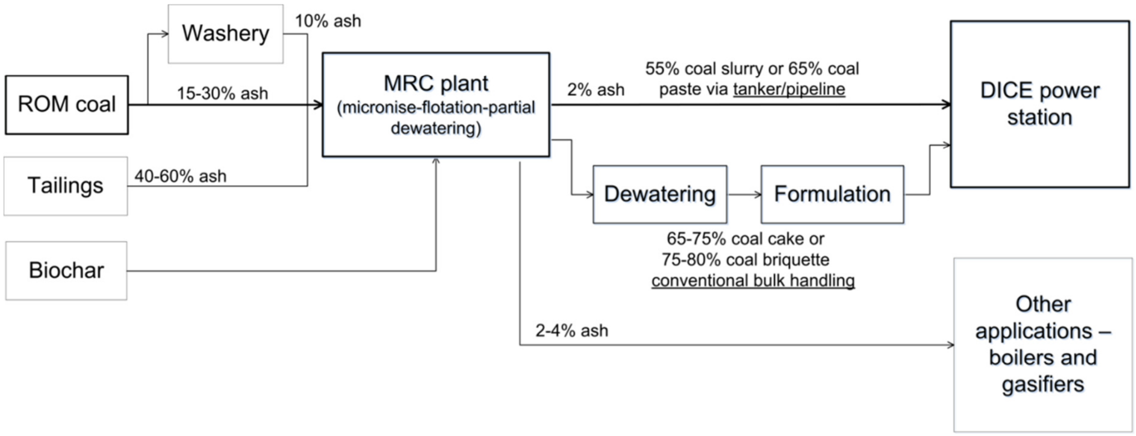

Figure 6 - Options for Black Coal MRC Production

MRC is somewhat similar to the coal water fuel produced for boilers and gasifiers in China, where conversion of combustion equipment to use cleaner and more efficient coal water fuel receives a range of subsidies, leading to rapid growth of the industry over the last few years to over 100 Mtpa. Although similar, MRC has a finer grind, lower ash specification, and slightly lower solids content. The Chinese boiler fuel is significantly more viscous than that specified for DICE – at least with conventional pressure atomization. See Figure 7.

Figure 7 - Left, coal water fuel for a boiler by JGC; right, MRC for DICE

Low Rank Coals

Low rank coals have received far less attention for DICE. It is generally assumed that processing will need to reduce the porosity of the coal (eg by hydrothermal processing, roller/press compaction, or both). As it is unlikely that surface selective separation techniques (eg flotation or selective agglomeration) will be suitable for low rank coals, especially Victorian brown coals, size/density separation would be used for a de-sanding step.

These processes have been successfully tested by Exergen, Ignite Energy Resources, JGC Corporation and in the current Brown Coal Innovation Australia (BCIA)-CSIRO R&D project. It is noted that most of the ash formed from Victorian coals is from organically bound elements in the coal, and not mineral ash (this can be as low as 0.3%), and that the de-sanding step is mostly to remove relatively coarse sand entrained during mining operations.

After de-ashing/de-sanding and hydrothermal treatment, it is necessary for partial dewatering of the fuel to achieve the required solids concentration, followed by micronisation.

2.3 Engines

Although a wide range of engines have been used to fire MRC, including up to 1900 rpm, it is generally accepted that the lower speed engines are more suitable and somewhat less sensitive to coal fuel characteristics than higher speed engines. These lower speed engines include low-speed two-stroke marine type engines (10–100 MW at 90–120 rpm) and the largest four-stroke medium-speed engines (20 MW at 400-500 rpm). This is due to their longevity (due to less wear and tear at lower speeds) and tolerance to lower quality fuels (such as residual fuel oils which contain up to 0.15% of highly abrasive corundum-like catalyst fines), to allow easier MRC fuel specifications – higher mineral ash content, coarser coal top size, higher viscosity. The choice of engine will be site and application dependent: while the low-speed engine has slightly higher efficiency and lower maintenance costs, the cost of these engines is higher at around \$1.8 M/MW compared to \$1.2 M/MW for medium-speed engines.

Despite being a mature technology, these engines continue to undergo development that will further improve their suitability for MRC firing (eg higher firing pressure, electronic control, more efficient turbochargers, new materials and adaptations to enable the use of alternative fuels such as biofuels and bitumen water fuels). The new electronically controlled (ME) variants are being implemented as “intelligent engines” with auto-tune ability – perfect for maximising efficiency with MRC.

Figure 8 - A mid-size low speed engine with generator by MAN (55 MW, 120 rpm)

The use of bitumen water emulsions and slurries in diesel engines provides a good analogue for MRC. Over the last 20 years there have been a number of initiatives to produce bitumen water fuels to replace HFO in boilers, and these fuels have also been used in diesel engines. Such fuels include Orimulsion produced from natural bitumen, and MSAR (multiphase superfine atomised residue) produced from refinery residue (an extremely heavy tar).

Wärtsilä has extensive experience with firing Orimulsion into medium-speed engines (including a 40 MW demonstration power plant at Vaasa and a 150 MW power plant in Guatemala). Wärtsilä expect that MRC will need similar adaptations.

MSAR was developed as an Orimulsion replacement, and is an MRC of solid bitumen particles in water. While it is a very difficult fuel, giving both poor atomisation and ignition, and contains highly abrasive catalyst fines, it is being used in adapted engines. It is of note that recent CSIRO work shows that, given reasonable atomisation, MRC from coal has superior combustion characteristics to MSAR (and also is superior to many heavy fuel oils).

Another interesting possibility is the potential to adapt dual fuel low- and medium-speed gas reciprocating engines to future DICE operation, an adaptation that is not possible with gas turbines: the choice of appropriate reciprocating engines to burn gas now, may provide the future option to convert to MRC if higher gas prices eventuate.

A number of engine manufacturers are currently interested in DICE for applications ranging from new base load capacity, down to 5 MW backup capacity. MAN Diesel and Turbo have engaged with a number of MRC proponents and are the industry leaders. MAN has also established a staged program to assess DICE, complete with a specially adapted low-speed 1 MW single cylinder test engine. While all manufacturers have some previous negative experiences with coal fuelling of engines, all acknowledge that the previous work was undertaken without a high level of commitment, and none of the programs were completed because the expected scenario of oil shortages did not materialise or funding ceased. Future developments will clearly benefit from recent experience with Orimulsion and MSAR, the extensive experience from the USDOE program for black coals, and more recently by CSIRO's R&D for both black and brown coals and chars.

Figure 9 - A large medium speed engine by MAN (20 MW, 500 rpm)

Components Subject to Wear

Testing by the USDOE and CSIRO have identified a number of components that have been subject to wear during tests and are likely to require the application of specialist hardened materials or coatings to provide reasonable engine durability.

- Fuel injection pump system and nozzle tip

- Piston rings and liners
- Exhaust gas valves and seats
- Turbocharger rotors and blades
- Crankshaft bearings

To achieve a viable commercial engine, DICE stakeholders have suggested that at least 8000 hours of reliable operation is required between overhauls.

It should also be noted that significant quantities of ash will need to be captured in the exhaust system with a baghouse (i.e. fabric filter) or other gas cleaning device. For a full scale 50 MW engine this could be in the order of several tonnes per day.

Suitable adaptations have been considered by two large engine manufacturers, noting that several of these have already been developed for bio-oils. A fuel testing program with an engine manufacturer is planned to develop fuel specifications, and to identify a suitable engine for a demonstration plant.

3 METHODOLOGY

The MRC-DICE risk review was undertaken in two stages; an initial desktop risk review and a subsequent workshop stage with stakeholders.

3.1 Desktop Risk Review

To complete the desktop review, WorleyParsons has assembled a team of specialists that cover each block of the MRC-DICE value chain.

Each specialist reviewed key documents from the DICE-NET website and documents submitted to WorleyParsons by CSIRO and other stakeholders. Our team took the points identified by the stakeholders in the scope of works to develop a list of risks for the MRC-DICE technology. Each risk was scored on the consequence (Table 2) and likelihood (Table 3) scale to produce a risk rating.

Table 2 - Consequence matrix

	Consequences				
	1 - Insignificant	**2 - Minor**	**3 - Moderate**	**4 - Major**	**5 - Catastrophic**
1 Feedstock	Suitable feedstock available in target regions with simple processing requirements using proven technology	Suitable feedstock available in adjacent regions with simple processing requirements using proven technology	Suitable feedstock not identified but expected to exist in target regions.	Feedstock for MRC-DICE expensive or requires high levels of processing	Suitble feedstock not available for MRC-DICE
2 Slurry Preparation	Suitable MRC-DICE fuel produced to agreed standard using proven technology for low cost and production can be scaled to suit market demand	Suitable MRC-DICE fuel produced to agreed standard for moderate cost and production can be scaled	Suitable MRC-DICE fuel can be produced but R&D required to confirm cost and scalability	Suitable MRC-DICE fuel can be produced but is expensive and cannot be produced at large scale	Suitable MRC-DICE fuel cannot be produced
3 Transport	MRC-DICE fuel or feedstock can be transported using existing infrastructure at low cost	MRC-DICE fuel or feedstock can be transported using existing infrastructure at moderate cost	MRC-DICE fuel or feedstock can be transported using new infrastructure using proven technology at moderate cost	MRC-DICE fuel or feedstock can be transported using new infrastructure but technology is unproven and cost is unknown	No infrastructure in place or planned and no proven technology to transport MRC-DICE fuel
4 Storage	MRC-DICE fuel or feedstock can be stored using existing infrastructure at low cost	MRC-DICE fuel or feedstock can be stored using existing infrastructure at moderate cost	MRC-DICE fuel or feedstock can be stored using new infrastructure using proven technology at moderate cost	MRC-DICE fuel or feedstock can be stored using new infrastructure but technology is unproven and cost is unknown	No infrastructure in place or planned and no proven technology to store MRC-DICE fuel
5 Power Gen	MRC-DICE generators operate reliably c.f. diesel with comparable O&M costs and are fully compatible with electricity networks and markets	MRC-DICE generators operate reliably c.f. diesel with higher O&M costs and are fully compatible with electricity networks and markets	MRC-DICE generators operate reliably c.f. diesel with higher O&M costs and are only suitable for niche applications on electricity networks and markets	MRC-DICE generators operate at lesser reliability c.f. diesel with higher O&M costs and are only suitable for niche applications on electricity networks and markets	MRC-DICE generators cannot operate with acceptable reliability and/or cannot be used on electricity networks and markets
6 Commercialisation	Impact can be absorbed through normal activity	An adverse event which can be absorbed with some management effort	A serious event which requires additional management effort	A critical event which requires extraordinary management effort	Disaster with potential to lead to collapse of the project
7 Project Execution	Impact can be absorbed through normal activity	An adverse event which can be absorbed with some management effort	A serious event which requires additional management effort	A critical event which requires extraordinary management effort	Disaster with potential to lead to collapse of the project

Table 3 - Likelihood matrix

Likelihood Category				
E	**D**	**C**	**B**	**A**
Rare	**Unlikely**	**Moderate**	**Likely**	**Almost Certain**
Highly unlikely to occur on this project	Given current practices and procedures, this incident is unlikely to occur on this project	Incident has occurred on a similar project	Incident is likely to occur on this project	Incident is very likely to occur on this project, possibly several times

For each risk that is considered significant, a high or extreme risk rating, a brief description of that risk was included in the desktop risk review report.

The desktop risk review report was reviewed by the key funders of the engine test programme and comments were incorporated into the final version of the report.

The desktop study formed the basis for discussion of risks during the two subsequent workshops held in Newcastle and Melbourne.

The risk map from the desktop review is shown in Figure 10. More detail on the risks identified can be found in the Desktop Study Report 201020-06973-SR-REP-0001.

Risk Map **Before Treatment**			Consequence				
			Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
Likelihood	A	Almost Certain	10	26 27	24		
	B	Likely			7 22 28 35 63 68 84	82 85 86	
	C	Moderate	16	2 3 13 14 71	4 5 8 9 19 20 21 30 61 62 65 67 69 73 74 77 81 89	31 60 64 66 70 75 87 88 90 91 93 92	
	D	Unlikely	17	25	6 11 12 15 23 32 33 34 36 37 40 48 49 52 53 54 55 56 75 76	72 78 79 80 83	
	E	Rare	18 29		1		

Low	Moderate	High	Extreme
5	26	33	16

Figure 10 - Desktop Risk Review Risk Map

3.2 Risk Review Workshops

During the workshop stage, two workshops were held for stakeholders to discuss the risks to the MRC-DICE technology, rate the risks against the criteria described in Section 3.1 and suggest control measures to treat the extreme and high risks. Control measures identified will be considered for inclusion in the project plan and the engine test programme.

The first workshop, held in Newcastle, focused on technical risks and showstoppers in the context of the planned engine test programme. The second workshop, held in Melbourne, focused on commercialisation and project execution risks looking forward to actions post the engine test programme.

Risk and Showstoppers Workshop, Newcastle, 30 August 2014

The purpose of this workshop was to:

- review the risks identified during the desktop risk review;
- identify existing controls to manage the risk;
- focusing on the high and extreme risk ratings, suggest controls to mitigate the risks; and
- determine if any of these risks constitute a showstopper for the commercialisation of the MRC-DICE technology.

The context of the workshop was the currently planned engine test programme with MAN.

The workshop was hosted by CSIRO at the Energy Centre in Mayfield, Newcastle. WorleyParsons facilitated the workshop and provided inputs from key personnel on the blocks of the supply chain via remote presentations. The full workshop agenda is contained in Appendix 2, and includes the list of attendees.

After review of each block of the value chain, a revised risk map was developed as shown in Figure 11.

The results of the Newcastle workshop were carried over to form the starting point for the Melbourne Workshop.

Risk Map
Before Treatment

Likelihood			Consequence: Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
	A	Almost Certain		26 27	24	95	
	B	Likely			7 22 28 35 63 68 84	86 82 85	
	C	Moderate		2 3	10 19 20 21 61 62 65 67 69 73 74 77 89 81	31 91 60 64 75 87 88 90 93	
	D	Unlikely		4	6 8 30 76	70 66 72 78 79 80 83	
	E	Rare	29		1 5 9	92	

Low	Moderate	High	Extreme
2	9	31	14

Risk Map
After Treatment

Likelihood			Consequence: Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
	A	Almost Certain		26	24		
	B	Likely			22 28 35 63 68 84	86 82 85	
	C	Moderate		27 2 3	61 62 65 67 69 73 74 77 89 81	95 60 88	
	D	Unlikely		4	7 10 19 20 6 8 76	64 75 90 93 70 72 78 79 80 83	
	E	Rare	29		21 30 1 5 9	31 91 87 66 92	

Low	Moderate	High	Extreme
2	15	32	7

Figure 11 - Risk Map Outputs from Risk and Showstopper Workshop

Commercialisation Workshop, Melbourne 14 August 2014

The purpose of this workshop was to:

- review the risks resulting from the Risk and Showstopper Workshop with a commercialisation lens;
- Identify existing controls to manage the risks;
- focusing on the high and extreme risk ratings, suggest controls to mitigate the risks;
- highlight the top 10 risks to commercialisation; and
- identify the key questions that could be answered by the engine test programme to reduce these risks.

The context of the workshop was beyond the planned engine test programme with MAN.

The workshop was hosted by WorleyParsons at its Collins Street office in Melbourne. WorleyParsons facilitated the workshop. The full workshop agenda is contained in Appendix 3, and includes the list of attendees.

The final results of the risk review after the Commercialisation workshop are contained in the remaining sections of this report.

4 RISKS SUMMARY

4.1 Risk Register

Sixty five Risks have been identified in the risk review, ranging from “extreme” to “low” in their ratings.

Figure 12 shows the mapping of the risks on the likelihood and consequence scales, both before treatment and after treatment.

A listing of the risks that have been identified as having “extreme” or “high” ratings is shown in Appendix 1, along with the estimate of the risk rating before and after treatment.

Section 4 (this section) summarises the key risks and risk treatments. Sections 5 to 11 discuss the key risks in more detail, arranged under the blocks of the value chain.

Risk Map
Before Treatment

Likelihood		Consequence: Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
A	Almost Certain		26 27			
B	Likely			99 7 28 63 68 22 84	86 108 110 82 85 129	
C	Moderate		2 3 96	100 19 21 20 61 62 65 67 69 73 74 77 89 10 81	112 60 64 75 87 88 90 93 95	111
D	Unlikely		4	6 8 102 24 30 76 109	101 70 104 66 72 78 79 80 83	
E	Rare	29		1 5 9	92	

Low	Moderate	High	Extreme
2	13	34	16

Risk Map
After Treatment

Likelihood		Consequence: Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
A	Almost Certain					
B	Likely			99 28 63 68 22 84	85	
C	Moderate		27 2 3 96	100 61 62 65 67 69 73 74 77 89 81	82 112 60 88 129	
D	Unlikely		26 4	7 19 20 10 6 8 102 24 76 109	86 108 110 64 75 90 93 101 70 104 72 78 79 80 83	111
E	Rare	29		21 30 1 5 9	87 95 66 92	

Low	Moderate	High	Extreme
3	19	36	7

Figure 12 - MRC-DICE Risk Review

4.2 Key Risks and Risk Treatments

Before treatment, sixteen risks have been rated as "extreme" with another thirty four rated as "high". A further fifteen risks have been identified that have rated as "moderate" or "low" risk.

After treatment, there are seven risks that are rated as "extreme" with another thirty six are rated as "high". The remaining twenty two risks are rated as "moderate" or "low" risk.

None of the risks identified were considered "showstoppers" that would otherwise indicate that the MRC-DICE development programme should be halted immediately.

From Figure 12 it can be seen that there are no risks in the upper right-hand corner of the risk map before or after treatment, having catastrophic consequences and being almost certain to occur.

The treatment measures were developed during discussions with stakeholders at the two workshops to try to reduce the severity of the risks rated as "extreme" and "high". Appendix 1 contains a full listing of these risks and their treatment plans.

Extreme risks after treatment

Of the seven risks identified and rated as "extreme" after treatment:

- four are related to commercialisation:
  - 111 - MAN contract and timing restrictions
  - 129 - $40m required for the demonstration phase
  - 60 - Competing technologies develop more quickly
  - 88 - Non-commercial funding not available
- two are related to project execution:
  - 82 - Financial market uncertainty
  - 85 - Due Diligence information requirements
- one is related to power generation:
  - 112 - Engine durability for 8,000 hrs running

During the Melbourne commercialisation workshop it was agreed with MAN to combine all the engine durability related risks into 112.

The concentration of risks in the commercialisation, project execution and engine technology areas suggests that the technical aspects of MRC-DICE fuel have been well explored and the risks managed to a greater degree than the engine, commercialisation and project execution risks.

Further discussion of the individual risks is contained in Section 5 to Section 11.

High risks after treatment

Thirty six risks identified are rated as "high" risks after treatment and can be broken down as follows:

- twenty two are related to commercialisation
- seven are related to project execution
- three are related to feedstock

- two are related to power generation
- two are related to slurry preparation
- none are related to transport
- none are related to storage

As for the risks rated “extreme”, commercialisation and project execution risks are well represented. This list suggests that although the risks associated with the engine technology have been mitigated with controls, there is still a significant area of risk for the commercialisation of MRC-DICE.

Further discussion of the individual risks is contained in Section 5 to Section 11.

4.3 Breakdown of risks by commercialisation stage

Many of the risks identified are not related to the current R&D stage of the commercialisation pathway. As noted in Section 2, the commercialisation of MRC-DICE technology is expected to progress through three stages:

1. Research and Development (R&D)
2. Demonstration
3. Commercialisation

The figures on the following pages show the risk maps broken down into these stages.

Risk Map
Before Treatment

Likelihood		Consequence: Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
A	Almost Certain		26			
B	Likely					
C	Moderate		2 3	21 20 10	75 87	111
D	Unlikely		4	8 102 109	70 104 66	
E	Rare					

Low	Moderate	High	Extreme
1	5	7	3

Risk Map
After Treatment

Likelihood		Consequence: Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
A	Almost Certain					
B	Likely					
C	Moderate		2 3			
D	Unlikely		26 4	20 10 8 102 109	75 70 104	111
E	Rare			21	87 66	

Low	Moderate	High	Extreme
2	8	5	1

Figure 13 - Risk map R&D stage

Risk Map
Before Treatment

Likelihood			Consequence: Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
	A	Almost Certain					
	B	Likely				85 129 86	
	C	Moderate		96	67 81	112 88 90 95	
	D	Unlikely					
	E	Rare				92	

Low	Moderate	High	Extreme
0	1	3	7

Risk Map
After Treatment

Likelihood			Consequence: Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
	A	Almost Certain					
	B	Likely				85	
	C	Moderate		96	67 81	112 88 129	
	D	Unlikely				86 90	
	E	Rare				95 92	

Low	Moderate	High	Extreme
0	1	6	4

Figure 14 - Risk map demonstration stage

Risk Map
Before Treatment

Likelihood			Consequence: Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
Likelihood	A	Almost Certain		27			
Likelihood	B	Likely			99 28 63 68 22 84 7	82 108 110	
Likelihood	C	Moderate			100 61 62 65 69 73 74 77 89 19	60 64 93	
Likelihood	D	Unlikely			6 24 30 76	101 72 78 79 80 83	
Likelihood	E	Rare	29		1 5 9		

Low	Moderate	High	Extreme
1	7	24	6

Risk Map
After Treatment

Likelihood			Consequence: Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
Likelihood	A	Almost Certain					
Likelihood	B	Likely			99 28 63 68 22 84		
Likelihood	C	Moderate		27	100 61 62 65 69 73 74 77 89	82 60	
Likelihood	D	Unlikely			7 19 6 24 76	108 110 64 93 101 72 78 79 80 83	
Likelihood	E	Rare	29		30 1 5 9		

Low	Moderate	High	Extreme
1	10	25	2

Figure 15 - Risk map commercialisation stage

Summary of Risk Treatments

To arrive at the final risk rating, each risk that is rated “extreme” has been reviewed and a risk treatment plan suggested. This has also been done with some of the risks rated “high”. The full list of “extreme” and “high” risks after treatment, including their treatment plans, are shown in Appendix 1.

As noted in Section 4.2, none of the risks identified are considered “showstoppers” by the stakeholders.

One of the important considerations when developing the treatment plan is the ability to influence. Figure 16 shows the ability to influence for each of the thirty one risks treated based on their initial risk rating. As a guideline during the workshops, “low / none” equates to no change in the consequence or likelihood rating, “moderate” reduces the consequence or likelihood by one step and “high” changes the combined consequence and likelihood score by two steps.

It can be seen from Figure 16 that only six of the “extreme” risks can be influenced to a “high” degree with a treatment plan, seven risks can be influenced to “moderate” degree and for two we have “low / none” ability to influence. For these two risks where there is low ability to influence, Risk 112 relates to engine durability and risk 60 relates to the development of other competing technologies.

Risk / Influence Matrix		**Ability to Influence**		
		Low / None	Moderate	High
Risk	Extreme	112 60	111 129 64 75 88 90 93	86 108 110 82 87 95
	High	101 104 92 99 100	66 20 10	7 19 21 26 27
	Moderate	102 24		30
	Low			

Figure 16 - Ability to Influence Risk Rating

Table 4 summarises the actions to mitigate the risks as detailed in Section 4.3.

Table 4 - Risk treatment plans

No,	Risk treatment title	Description	Risks treated	Stage
1	Engine test project plan	Clear and articulated project plan for MAN engine test programme to secure support from MAN, confirm outcomes particularly with respect to	111, 112, 87, 66, 92, 7, 19, 61,	R&D

No,	Risk treatment title	Description	Risks treated	Stage
		durability and protect IP aspects. Ensure this aligns with Glencore XT plant operational constraints imposed by plant relocation. Consider combined business case fuel and engine.	10	
2	Develop a fuel specification for MRC-DICE fuel	The 20 hour injection test and the 20 hour engine test being undertaken by MAN will provide valuable information to support the development of a draft fuel spec by June 2016. Spec should include as a minimum: • particle size distribution • particle top size • maximum ash content • ash mineralogy • slurry density (% solids) • ignitability / combustibility energy content	70,	R&D
3	Develop fuel preconditioning system	Development of a small skid (pallet size) to precondition fuel and supply it to an engine fuel tank. Includes procuring suitable tanks for transporting fuel to MAN. April 2015	26,27	R&D
4	Develop consortium approach for demonstration phase	$40m is estimated to be required for the demonstration phase of MRC-DICE. A consortium approach is required and could involve a number of different government agencies in a range of countries including Australia, Japan, Germany, Indonesia etc. Engagement has already started	129	Demonstration
5	Next stage commercialisation plan	Develop a plan that includes funding requirements for the next stage of investment and development. Should include strategies for: 5. Timing of development to suit appropriate market and investment conditions 6. Development of information appropriate for investors 7. Consideration of all non-financial factors e.g. social license to operate, exhaust emissions, transport of fuel MSDS etc 8. Timing of fuel production, transport	86,108,82, 85,60,75,8 8,90, 93, 95, 104, 99, 63, 21	Commercialisation

No,	Risk treatment title	Description	Risks treated	Stage
		infrastructure and standards development to match engine development programme •		
6	Develop a communications strategy	2. "Build the story" for MRC-DICE e.g. lower emissions coal, support renewables, CCS, cogeneration applications, biomass blending etc. Target potential investors and international governments.	110, 63, 100	Commercialisation

4.4 Key Findings

Though there remains a significant area of risk for the commercialisation of MRC-DICE technology, it has the potential to be successful if the risk treatments summarised above are implemented expeditiously.

After treatment, none of the risks identified were considered "showstoppers" by stakeholders that would otherwise indicate that the MRC-DICE development programme should be halted immediately.

5 MRC FEEDSTOCK

The alternative feed stocks such as brown coals, coal tailings and other materials introduce considerable additional complexity, technical huddles and unknowns in the required beneficiation stages for the preparation of the fuel for the DICE. This is in addition to those which would be encountered with high-quality, low-ash feed stocks.

These issues associated with the beneficiation and preparation of poorer quality feed stocks represent significant additional complexity and development risks beyond the development and commercial scale demonstration of robust, reliable and efficient engine(s) operating on MRC-DICE fuel.

No feedstock related risks have been rated as “extreme” and three risks have been rated as “high” risk after treatment. Figure 17 contains the risk map for MRC feedstock.

99 Don't understand commercialisation pathways

Rating – High

Consequence – Moderate Likelihood - Likely

This risk relates to how the technology will be adopted during the commercial roll-out. There are a range of possible coal fuel specifications and engine modifications. Do mines need to be matched to a specific engine like coal fired power stations or should the fuel specification be sufficiently rigid that any MRC-DICE fuel can be used on any DICE engine?

It is possible that engines will be matched to very specific fuel requirements during the early phases but over time fuel requirements may be relaxed as confidence in engines by manufacturers and operators increases.

The current treatment for this risk is to ramp up MRC manufacturing in modules to match the incremental engine capacity installed. XT is to develop a skid mounted design for an MRC plant that matches the fuel requirements for a single MRC-DICE engine.

100 Getting approvals for MRC manufacture could be difficult

Rating – High

Consequence – Moderate Likelihood - Moderate

Manufacture and transport of MRC-DICE fuel is a new development for coal resources in Australia and elsewhere.

There are some issues that will need to be considered as MRC plants are planned, including the environmental impact of building and operating the plant, storage and transport risks and impacts of spillages. Also important is the “social license to operate” for this technology. There are individuals and groups who oppose investment in further coal development to lower emissions rather than investment in zero emission technologies. MRC fuel must also deal with the political issues surrounding previous incarnations of low ash "supercoal" in Australia and media interest in the commercialisation potential of DICE. In China and elsewhere it may be necessary to highlight the benefits of MRC to differentiate from coal water fuel

The treatment plan to overcome these issues is to develop the story for MRC-DICE, focusing on:

- lower emissions than existing coal fired stations
- flexibility to support renewables
- agreed and funded development programme with MAN
- potential for further emissions reductions with cogen, CCS and biomass blending
- broader applications than coal water fuel

101 Is MRC-DICE a cost competitive use of coal?

Rating – High

Consequence – Major Likelihood - Unlikely

To be competitive, MRC-DICE will need to be able to provide a fuel and engine total cost of ownership that is competitive with existing and future competing technologies. At the moment these technologies are large diesel or heavy fuel-oil fuelled reciprocating engines or small open cycle and combined cycle gas turbines. It is a low fuel cost that is likely to drive uptake against these competitors, so the total cost of fuel manufactured, delivered to site and injected into the engine will be very important. This has been quantified for use of black coal tailings, which would otherwise be a waste product, and the results look promising.

Coal for use in MRC-DICE will need to represent an opportunity in the market vs other potential uses for coal. For brown coal resources it is not yet clear what the competitiveness of MRC-DICE is vs coal-to-liquids or coal-to-chemicals uses.

More work needs to be done in this area to assess the trade-off between fuel cost and other costs of ownership for MRC-DICE engines.

Risk Map
Before Treatment

			Consequence				
			Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
Likelihood	A	Almost Certain					
	B	Likely			99		
	C	Moderate		2 3 96	100		
	D	Unlikely		4	6	101	
	E	Rare			1 5		

Low	Moderate	High	Extreme
1	6	3	0

Risk Map
After Treatment

			Consequence				
			Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
Likelihood	A	Almost Certain					
	B	Likely			99		
	C	Moderate		2 3 96	100		
	D	Unlikely		4	6	101	
	E	Rare			1 5		

Low	Moderate	High	Extreme
1	6	3	0

Figure 17 - MRC feedstock risk map

6 SLURRY PREPARATION

Slurry (MRC-DICE fuel) properties are crucial to the reliable, efficient and cost effective operation of the DICE. MRC-DICE fuel must be able to be manufactured cost effectively to be a competitive technology in the market.

No risks have been rated “extreme” and two risks have been rated “high” after risk treatment for slurry preparation. Figure 18 shows the full risk maps, before and after treatment, for slurry preparation.

70 The suitable "commercial" fuels not able to be engine tested as it falls outside the test spec

Rating – High

Consequence – Major Likelihood - Unlikely

During the MAN engine test programme, MRC-DICE fuels will be tested to see if they can be used as a fuel by first being injected using a test rig in Copenhagen and then see if they can be combusted using a 1 MW test engine in Japan. MAN wants to ensure the highest possibility of success in these tests and hence requires an MRC-DICE fuel specification that is not the most cost-effective fuel to manufacture due to low ash content.

For commercial applications of the MRC-DICE technology, there will be a trade-off between the cost of fuel and the extent and cost of engine modifications to arrive at the best combination that supports the business case for MRC-DICE.

Maximum particle top size needs to be further explored as this dictates the energy needed for grinding. The grinding energy requirement, and therefore operating cost, increases exponentially as particle size decreases. However coarse particles, particularly coarse non-combustibles, will likely create significant wear issues in heavy diesel engines. A technical and financial trade-off between particle size and operating cost should be undertaken.

It is expected finer average particle size will reduce issues with wear, slurry settling and line clogging. Additionally, finer particle sizing is expected to improve atomisation and combustion efficiency. These benefits must be balanced against increased grinding costs and increased difficulties in solids/liquid separation.

Both ash content and ash mineralogy are expected to impact wear. Generally the ash minerals are expected to be harder and more abrasive than the combustible components, resulting in the ash tending to be coarser than the bulk of the MRC product, exacerbating wear issues due to ash.

The fuel specification may be outside that specified by MAN for the engine tests and should cover as a minimum:

- particle size distribution
- particle top size
- maximum ash content
- ash mineralogy

- slurry density (% solids)
- ignitability / combustibility
- energy content

To mitigate this risk, the intention is for the contract with MAN for the engine test programme to include testing of any MRC-DICE fuel that is provided.

92 Inability to provide a suitable fuel within MAN's fuel specification

Rating – High

Consequence – Major Likelihood - Rare

MAN may develop a fuel specification for the MRC-DICE engine that is not able to be met by some or all feedstocks and/or fuel preparation processes. This could be due to specific characteristics of the feedstock or equipment constraints. The current project plan includes for draft fuel standards to be in place by June 2016 based on the results of the injector and engine tests.

If these standards cannot be met then fuel may not be available for demonstration and commercial operation of an MRC-DICE engine.

As discussed for risk 70, it is intended to mitigate this risk by requiring that the testing of any fuel provided to MAN be included in the contract.

Risk Map
Before Treatment

Likelihood			Consequence				
			Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
Likelihood	A	Almost Certain					
	B	Likely			7		
	C	Moderate					
	D	Unlikely			8 102	70	
	E	Rare			9	92	

Low	Moderate	High	Extreme
0	3	3	0

Risk Map
After Treatment

Likelihood			Consequence				
			Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
Likelihood	A	Almost Certain					
	B	Likely					
	C	Moderate					
	D	Unlikely			7 8 102	70	
	E	Rare			9	92	

Low	Moderate	High	Extreme
0	4	2	0

Figure 18 - Slurry preparation risk map

7 TRANSPORT

Transport covers the movement of MRC-DICE feedstock, intermediate product or fuel from its place of production to the end user site.

For black coal, transport of feedstock in the form of lump coal is proven with well-developed existing infrastructure within Australia and other countries. Transport of black coal tailings or intermediate product such as filter cake is not technically or economically proven and may require significant effort to test and develop this infrastructure.

For brown coal, transport of run of mine coal could be cost prohibitive due to the high moisture content and therefore low energy density and there are potential technical issues related to materials handling of a sticky material using existing infrastructure. For an intermediate product such as filter cake the issues are similar.

Transport of MRC-DICE slurry is possible using established technology used for mineral slurry transport but there may be issues with wear and power requirements for significant distances if pipelines are used. Heavy fuel oil is currently transported using tankers and pipelines and this technology and some existing infrastructure may be appropriate for MRC-DICE fuel.

Taking the supply chain as a whole, optimising one aspect can result in inefficiencies within another component. For example, a substantial investment in rapid loading facilities may not be required in a situation where transport costs are relatively inexpensive. Hence, transport cannot be considered in isolation, most commodity based operations also consider the transport interface points such as storage, loading and unloading facilities.

Within any supply chain, the availability of an appropriate amount of capacity to deliver product to end users in a timely manner that protects the environment from fugitive emissions is fundamental to successful performance. This section considers the key risks associated with this objective.

The following underlying assumptions were used as a basis for considering risks:

- Proven and reliable supply chain technologies are only considered – for example road and rail transport.
- Product is sourced from locations that are close to existing transport (road/rail) transport infrastructure.
- Product is produced at a reasonably steady rate, with no significant inter or intra year variations.
- Tonnages are small relative to existing coal mining operations. A train consisting of 40 wagons and 2 locomotives would have an acquisition cost of between $12 million - $20 million, the price variation driven by the type of wagon used. To justify this cost, the annual haulage task would need to of a reasonable magnitude in both distance travelled and volume carried. For example, similar size grain trains operating in the Hunter Valley would haul around 250,000 - 300,000 tonnes annually over an average haulage distance of 350 kilometres.

- If product is transported as filter cake or slurry it can use existing transport infrastructure.

Figure 19 shows the risks for Transport before and after treatment. No Risks have been identified that are rated “extreme” or “high” after treatment.

Two risks were identified that were “high” before treatment, related to 19 settlement and segregation during pumping and transport and 21 failure to deliver product to end users during the testing, demonstration and commercialisation phases.

With treatment these risks were reduced to “moderate” in each case. For risk 19 the mitigation measure was to ensure the test programme tests settling and segregation of fuel during transport and for risk 21 to develop a Material Safety Datasheet (MSDS) and review transport regulation related to dangerous goods.

Risk Map
Before Treatment

			Consequence				
			Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
Likelihood	A	Almost Certain					
	B	Likely					
	C	Moderate			19 21		
	D	Unlikely			24		
	E	Rare					

Low	Moderate	High	Extreme
0	1	2	0

Risk Map
After Treatment

			Consequence				
			Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
Likelihood	A	Almost Certain					
	B	Likely					
	C	Moderate					
	D	Unlikely			19 24		
	E	Rare			21		

Low	Moderate	High	Extreme
0	3	0	0

Figure 19 - Transport risk map

8 STORAGE

Storage of MRC-DICE fuel is essential to ensure owners of MRC-DICE engines have reliable fuel supplies.

MRC-DICE fuel is a slurry of solid particles suspended in water. Over time, these solid particles can settle in the storage vessel and potentially aggregate into a solid layer at the bottom. Chemicals are added to increase the storage time but it is likely that mechanical means such as stirring of vessels will be required to keep the solids in the slurry in suspension.

Figure 20 shows the risk maps for storage of MRC-DICE fuel. No risks have been identified that are "extreme" or "high" after treatment.

Two risks have been identified that are rated "high" before treatment. 26 settling and segregation during storage and 27 additional infrastructure required at the site to maintain fuel quality.

Risks 26 and 27 have been mitigated through the development of a skid mounted preconditioning system to treat the fuel prior to supply to the engine fuel tank and identification of suitable tanks for transporting fuel. After treatment these risks are rated as "low" and "moderate" respectively.

Risk Map
Before Treatment

Likelihood			Consequence: Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
Likelihood	A	Almost Certain		26 27			
	B	Likely					
	C	Moderate					
	D	Unlikely					
	E	Rare					

Low	Moderate	High	Extreme
0	0	2	0

Risk Map
After Treatment

Likelihood			Consequence: Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
Likelihood	A	Almost Certain					
	B	Likely					
	C	Moderate		27			
	D	Unlikely		26			
	E	Rare					

Low	Moderate	High	Extreme
1	1	0	0

Figure 20 - Storage risk map

9 POWER GENERATION IN DICE GENERATORS

MRC-DICE fuel is a new application for engine manufacturers and potential purchasers.

There are many uncertainties involved in the use of this fuel, many of which have been identified by the stakeholders and are being mitigated through further Research and Development (R&D) and test work.

Included in the activities to achieve commercialisation are a number of Go/No Go decision points. At these points, if the technology has not proven itself to meet the requirements, the project will not progress further.

Figure 21 shows the risk map before and after treatment for power generation. One risk is rated “extreme” and two risks rated as “high” after treatment. This is a significant reduction in number of risks since the desktop review and Newcastle workshop as all the risks relating to engine durability have been combined under risk 112 Engine durability to survive 8000 hours between overhauls.

112 Engine durability to survive 8000 hours between overhauls

Rating – Extreme

Consequence – Major Likelihood - Moderate

8000 hours Mean Time Between Overhauls (MTBO) is considered the minimum for a practical application of MRC-DICE engines and equates to approximately 1 year of service. This is compared to MTBO of around 24,000 hours for an engine running on Heavy Fuel Oil (HFO).

There has been success in the USDoE trials of four stroke diesel engines but until the two stroke designs are tested by MAN it is unknown if this work can be directly translated to the large two stroke engines being considered for commercialisation.

As part of the engine test programme with MAN, a 20 hour test on a 1 MW one cylinder low speed test engine with MRC fuel capability will be conducted. The engine will include current dual fuel capability to enable use of MRC, and comprise state of the art electronic control to enable optimisation for MRC. Subject to successful injector testing, black and brown coal derived fuels will be tested.

The 20 hour tests will not provide a definitive answer on whether an engine running on MRC-DICE fuel will be durable. The tests will confirm combustion characteristics and could potentially highlight engine areas that will require design changes for subsequent demonstration engines leading to increased chances of success during the demonstration phase.

28 Australian electricity markets not suitable

Rating – High

Consequence – Moderate Likelihood - Likely

Low electricity wholesale prices, the removal of the carbon pricing mechanism and the oversupply of generation capacity in the Australian NEM will make it difficult for generators to invest in any new capacity, particularly a new technology.

This may create an opportunity in the market for MRC-DICE if a wave of investment occurs as the technology is proven and becomes commercially available.

The treatment plan is to explore markets off the NEM or in countries other than Australia. This raises the question of whether the current, Australian based, funders of the MRC-DICE development programme would still find the technology attractive to invest in if it was going to be applied in other countries using non-Australian sources of coal.

Further treatment of this risk could be possible through mapping out the likely regions for application of MRC-DICE, analysing the supply chain for each region and engaging with the stakeholders that have the most to gain from commercialisation.

104 Uncertain whether economics of the engine will be indicated from initial engine tests

Rating – High

Consequence – Moderate   Likelihood - Likely

It is unlikely that the initial 20 hour engine tests will indicate the potential for an economic MRC-DICE engine in commercial applications. Any issues that are identified during these tests that have a technical solution may turn out to be too expensive to solve for the demonstration and commercial phases.

To mitigate this risk, the targets for the 20 hours tests will need to be agreed. These could include:

- exhaust emissions including CO_2, NOx and other pollutants
- operability to support renewables
- economic viability - maintenance period, cost of engine, cost of fuel

Risk Map
Before Treatment

Likelihood			Consequence				
			Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
Likelihood	A	Almost Certain					
	B	Likely			28		
	C	Moderate			20	112	
	D	Unlikely			30	104	
	E	Rare	29				

Low	Moderate	High	Extreme
1	1	3	1

Risk Map
After Treatment

Likelihood			Consequence				
			Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
Likelihood	A	Almost Certain					
	B	Likely			28		
	C	Moderate				112	
	D	Unlikely			20	104	
	E	Rare	29		30		

Low	Moderate	High	Extreme
1	2	2	1

Figure 21 - Power generation risk map

10 COMMERCIALISATION PATHWAY

The paths to commercialisation and execution depend to some extent on the aims of the originator. For example:

- Does the originator want to retain control of the technology and/or the incubator business that utilises it?
- Does the originator want to derive profit from the development process?
- Is the technology to be closely held or publicly available?
- Is the originator prepared to invest for other than a financial return i.e. if the intention is to create an alternative energy source for social, policy and environmental reasons is the originator prepared to invest for other than a financial return and in effect subsidize the early stages of implementation?

These alternatives all point to different paths for funding and commercialisation and different levels of risk that the private sector might analyse in its investment decision – which in turn may feed into different levels of risk and therefore feasibility from a financing point of view.

The background to the industry may cause relatively poorly informed investors likely to have a preconceived concept of the risks in this sort of technology and feedstock, and depress initial investor interest.

Figure 22 shows the commercialisation risk map before and after treatment. After treatment there are four risks rated as “extreme” and twenty two risks rated as “high”.

60 Competing technologies

Rating – Extreme

Consequence – Major Likelihood - Moderate

During the development and early commercialisation phases of the DICE technology, competing technologies such as gas turbines will improve their competitiveness as their costs track down the Experience Curve. The longer it takes the DICE technology to achieve critical commercial mass, the harder it becomes to compete with such existing technologies.

In other words, the goal posts for competitiveness are always moving, making it harder for the DICE technology to catch up. External shocks to existing technologies can give DICE a “foothold”. In the case of gas turbines, this may initially be rapidly rising gas prices. However, such effects are unlikely to be long-lived as the laws of supply and demand come into play and more gas supply comes on-line, typically in “lumpy” quantities, to meet demand, so reducing gas prices.

To mitigate this risk, the key for DICE is to establish a commercial foothold as quickly as possible. To do this a commercialisation plan needs to be developed to target market niches and review Experience Curves for existing technologies in the market.

88 Non-commercial funding not available

Rating – Extreme

Consequence – Major   Likelihood - Moderate

If non-commercial (Commonwealth, State or International government) funding is not available during the demonstration stage of the MRC-DICE technology, it is unlikely that commercial investors will support the first non-commercial plant. If the demonstration plant is not developed it is highly unlikely that the MRC-DICE technology will be commercialised.

To treat this risk it will be necessary to consider next phase funders and their information requirements for a decision. Lobbying of Australian and International government agencies may be required. Stakeholders need to make a plan of who should be targeted which would include companies that may benefit from increased sales of coal for MRC-DICE. Matching funds are likely to be required from the private sector. In Australia it may be possible to get some support for making MRC-DICE a project of national significance.

111 MAN have timing restrictions

Rating – Extreme

Consequence – Catastrophic Likelihood - Unlikely

MAN has timing restrictions with respect to commencing the engine test programme. A contract needs to be agreed by the end of September. At the moment there is not a firm proposal with schedule and details in place.

The BCIA Funding agreement is in place subject to the risk review. Terms are not yet agreed between MAN and CSIRO. ANLEC and CSIRO have agreed terms. IP ownership issues are clear; from the fuel tank onwards the IP belongs to MAN.

To treat this risk, the project plan for the engine tests is to be finalised in the next two weeks.

129 $40m required for the demonstration phase

Rating – Extreme

Consequence – Major   Likelihood - Moderate

The demonstration phase of the MRC-DICE commercialisation will require investment of around $40 million to fund engine and fuel equipment. If these funds are not available the technology will not be commercialised.

The commercialisation of the MRC-DICE technology is different to the approach normally taken by MAN to commercialise a new fuel for their engines. Generally an engine owner, such as a shipping company, will approach MAN with a proposed alternative fuel and pay MAN for the development costs and provide their own engine as a demonstration unit. A current example is the development of methanol as a fuel for ship engines where the carrier of this cargo is looking to take advantage of a source of cheap fuel.

For MRC-DICE, the stakeholders will need to fund the purchase of a new engine or existing engine and the adaptations required to allow running on MRC-DICE fuel. This phase is unlikely to be a commercially attractive investment so it will need funds from non-commercial funders, such as governments, and those looking to take advantage of a high risk / high growth opportunity.

61 Natural gas prices fall

Rating – High

Consequence – Moderate   Likelihood - Moderate

In the time period it takes for MRC-DICE to be commercialised, natural gas prices may fall due to oversupply as a response to high short term gas prices. This will reduce MRC-DICE fuel's competitive position as a low cost, natural gas alternative.

As for risk 60, the treatment plan is to move quickly to commercialise while developing a plan to target niche markets and track the experience curves of competing technologies.

62 Unit Size Too Small for Mainstream Grid Market

Rating – High

Consequence – Moderate   Likelihood - Moderate

There are few fossil fuel units connected to the National Electricity Market (NEM) in Australia that are less than about 150 MW in capacity. This is typically the entry level for open cycle gas turbines (OCGTs) for meeting peak demand. Typically two such units are combined with a heat recovery steam generator (HRSG) to provide steam for a turbine-generator of about the same capacity for base-load combined cycle operation of typically 450 to 650 MW.

To effectively penetrate the NEM, the DICE units are likely to need to have capacities around 100 to 150 MW or higher. If not, the high capital cost of grid connection in the form of transformers, switchgear and connections could reduce or eliminate any operational savings from lower fuel costs. Economies of scale are critical to success in the grid connected market.

Reaching such unit capacities will be a challenge for the DICE technology given current projections of up to 50 MW or so. Such sizes may be commercial as embedded generation within the distribution network or as network support in weak areas of the transmission network, typically in smaller regional areas. Smaller unit sizes may also be competitive in developing countries but this is a market that is difficult for a new technology such as DICE to penetrate because of the lack of technology support in the early phases of its commercialisation in such markets.

63 GHG intensity regulations lower than MRC-DICE can achieve

Rating – High

Consequence – Moderate   Likelihood - Likely

As has occurred in the USA, the introduction of emissions intensity regulated limits for new electricity generation could mean that MRC-DICE cannot meet these limits without the use of Carbon Capture and Storage or biomass co-firing. This would significantly increase the development time and cost for the MRC-DICE technology.

To treat this risk, studies are required on cogeneration, CCS and biomass blending to estimate their likely cost and time to market. High exhaust temperatures provide an advantage vs conventional gas and coal fired Power Stations.

64 Infrastructure for fuel supply chain

Rating – High

Consequence – Major Likelihood - Unlikely

Infrastructure for the MRC-DICE fuel supply chain does not exist at a scale to supply commercial customers. The development of this infrastructure needs to be committed early enough to ensure that it is in place so that commercial customers can confidently install MRC-DICE engines.

Treatment for this risk is to explore markets other than Australia where infrastructure or government support is available. To ensure infrastructure requirements do not get left behind, the fuel development program must be concurrent with the engine development program.

65 Consortium approach to infrastructure

Rating – High

Consequence – Moderate Likelihood - Moderate

No single entity is likely to commit to funding the entire MRC-DICE fuel supply chain. This leaves individual proponents to fund section of the supply chain or a consortium of investors to finance the entire supply chain. In either case, there is significant risk of conflict with respect to timing, appropriate levels of investment and return.

To treat this risk, DICE-NET has been established to engage stakeholders. Some infrastructure exists for black coal that could be used or adapted.

66 Inadequate funding for R&D

Rating – High

Consequence – Moderate Likelihood - Major

Funding has been sought for the research and development phase of the MRC-DICE development. This funding only covers the activities already identified and does not include contingency for additional tasks or unforeseen costs such as damage to key equipment like a test engine.

To mitigate this risk, a detailed project plan is being developed that sets out key activities, timeframes, budgets, IP management and reports for the research investment committee. The contract terms will be drawn up to limit the liability of funders and contingency will be included in the budget. The budget amount includes for engine rebuilds at the end of the 20 hour tests should there be a catastrophic failure of the test engine.

67 Social licence to operate

Rating – High

Consequence – Moderate Likelihood - Moderate

Coal generation may not be an acceptable technology for government, stakeholders and the public to support. Demonstration of the benefits compared to other new coal technologies, as a supporting technology for renewable generation and paths to further emissions reductions through cogeneration, CCS and biomass blending may reduce concerns. This would need to be part of a well-developed communications plan for the technology.

68 Genset capacities too small for the grid

Rating – High

Consequence – Moderate Likelihood - Likely

If genset capacities cannot be scaled up to commercial generation sizes, 100-150 MW, then grid connection costs compared to gas turbines of 150MW plus will be higher. Similar to risk 62 above.

69 CCS application to MRC-DICE

Rating – High

Consequence – Moderate Likelihood - Moderate

If CCS application to MRC-DICE is difficult, too expensive or not possible, this may reduce the future potential for stationary generation applications when compared to other lower GHG emission technologies.

As for risk 63, the treatment plan is to study cogeneration, CCS and biomass blending to estimate their likely cost and time to market. High exhaust temperatures provide an advantage vs conventional gas and coal fired Power Stations.

72 Fuel substitution

Rating – High

Consequence – Major Likelihood - Unlikely

MRC-DICE fuel quality could be compared to alternative sources, and if it easily substituted with a higher quality feed without significant cost, customers may switch and reduce demand for MRC-DICE fuel.

If the commercial arrangements acknowledge the potential for alternative feed, either MRC-DICE from other suppliers or other fuels, this could support investment by engine manufacturers who want a range of fuel options but could discourage investment by MRC-DICE fuel suppliers.

73 Generation cost

Rating – High

Consequence – Moderate Likelihood - Moderate

The perceived cost of generation compared to competing technologies – which quartile is this likely to fall into on a cost curve comparing like with like, will strongly influence the uptake with potential generation customers. Customers will need to consider whether MRC-DICE generation can be competitive across the market, competitive in an existing niche market or create a new market niche. For example, what are the price outcomes for the generated power – is there benefit in analysing this on the ability to supply peaking power rather than base load – are there alternatives where the power is fed into the grid or on remote sites that affect potential returns and therefore financial viability?

74 Stranded assets

Rating – High

Consequence – Moderate Likelihood - Moderate

There is potential for stranded asset risk for R&D investment and components such as the win, pulverising, slurry transport, dewatering and generation. Are these better to be in one corporate and financed structure or several with different technology and risk aspects? If they are separate how are the financial interdependencies dealt with?

75 Balance between fuel spec and engine innovation

Rating – High

Consequence – Major Likelihood - Unlikely

A very stringent fuel specification with respect to particle size and ash content is likely to result in a more conventional engine design but will increase the cost of fuel preparation. Conversely, an engine design that accepts a wider range of particle sizes and ash contents is likely to require more advanced engineering of components to achieve expected levels of operability and reliability resulting in a more expensive engine. A balance needs to be agreed that maximises the attractiveness of the business case for MRC-DICE overall.

To mitigate this risk, appropriate tests need to be included in the engine and fuel test programme and the demonstration phase to allow discovery of commercial fuel and engine development together. The plan for value chain for fuel production needs to match the engine development and commercialisation. There are common aspects for black/brown coal, although fuel production aspects may be different. Time and budget need to be allowed in the project programme for these tests.

77 Technology leadership

Rating – High

Consequence – Moderate Likelihood - Moderate

Is there any benefit in leading the field in development of this technology or is the better approach to stimulate competition in the open market by releasing the technology which could relieve the originator of financial risk other than the cost of developing the technology? At what stage of development would the technology be viable for the investor market? If the technology is off the shelf for example, or an aggregation of off the shelf technologies, there is less need for a pilot – which can be very expensive in terms of cost of finance.

What is the background to the industry – are relatively poorly informed investors likely to have a preconceived concept of the risks in this sort of technology and feedstock, and depress initial investor interest?

86 Insufficient investment to prove technology

Rating – High

Consequence – Major Likelihood - Unlikely

Investors in the commercialisation of MRC-DICE must be confident that the technology is sufficiently proven and ready for commercial applications. If insufficient investment is committed to prove the technology, investors may want to wait for further evidence or demand a risk premium on their investment.

As for risk 88, to mitigate this risk it will be necessary to consider next phase funders and their information requirements for a decision. Lobbying of Australian and International government agencies may be required. Stakeholders need to make a plan of who should be targeted. Matching funds are likely to be required from the private sector. In Australia it may be possible to get some support for making MRC-DICE a project of national significance.

87 IP loss if MAN decide not to pursue MRC-DICE

Rating – High

Consequence – Major Likelihood - Rare

MAN are investing a significant amount of resources in the development and proving of the MRC-DICE technology. If the testing and demonstration programme are successful but MAN decides not to pursue the technology on a commercial scale, the IP developed could be lost to the MRC-DICE stakeholders.

This risk will be treated through contract terms with MAN and having CSIRO participating in the test programme. If MAN chooses not to proceed then they will be required to hand over the technology.

89 Mismatch between engine and fuel development

Rating – High

Consequence – Moderate Likelihood - Moderate

Fuel production, specifications and testing processes may not be ready in time to provide MRC-DICE fuel to operating engines for commercial operation, reducing the commercial attractiveness to purchasers.

90 Fuel not available to run demonstration

Rating – High

Consequence – Major   Likelihood - Unlikely

During the demonstration phase, significant quantities of MRC-DICE fuel will be required to run the demonstration engine for long periods to gain experience with operations. If the fuel supply cannot be maintained the engine testing will be delayed which will delay the commercialisation of the technology.

As for risk 75, to mitigate this risk, the plan for value chain for fuel production needs to match the engine development and commercialisation. There are common aspects for black/brown coal although fuel production aspects may be different.

93 Lack of wrap-around guarantee for engine and fuel

Rating – High

Consequence – Major   Likelihood - Unlikely

The lack of a wrap-around engine and fuel guarantee may cause users not to adopt the technology due to concerns with split responsibility from engine manufacturer and fuel producers.

As for risks 75 and 90, to mitigate this risk, the plan for value chain for fuel production needs to match the engine development and commercialisation. There are common aspects for black/brown coal although fuel production aspects may be different.

95 Infrastructure not available for fuel supply chain during pre-commercial phase

Rating – High

Consequence – Major   Likelihood - Rare

As for risk 90, this risk relates to being able to reliably supply fuel to an operating engine during the demonstration phase.

In addition to the mitigation measures suggested for risk 90, stakeholders may have to commit to the development of infrastructure during the development of the engine if it is to be available to supply fuel to the demonstration engine.

108 commercialisation non-technical barriers

Rating – High

Consequence – Major   Likelihood - Unlikely

To achieve commercialisation, a number of non-technical barriers will need to be addressed. These include regulatory impact, community engagement, social license to operate covering production, transport, storage, combustion etc. It is risky to assume because coal is well understood that MRC-DICE fuel will have no problems.

To mitigate this risk and independent review, like an Environmental Impact Statement (EIS) should be performed as part of the feasibility study. This should be included in the work plan and budget.

110 Lack of communication during demonstration and commercial phases

Rating – High

Consequence – Major Likelihood - Unlikely

A lack of communication with governments and the public during the demonstration and commercialisation phases could lead to a lack of success of MRC-DICE by failing to sell the story.

To mitigate this risk, a targeted communications and engagement strategy is required providing all stakeholders with consistent messages to communicate.

Risk Map
Before Treatment

Likelihood			Consequence: Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
	A	Almost Certain					
	B	Likely			63 68	86 108 110 129	
	C	Moderate			61 62 65 67 69 73 74 77 89	60 64 75 87 88 90 93 95	111
	D	Unlikely			76 109	66 72	
	E	Rare					

Low	Moderate	High	Extreme
0	2	13	13

Risk Map
After Treatment

Likelihood			Consequence: Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
	A	Almost Certain					
	B	Likely			63 68		
	C	Moderate			61 62 65 67 69 73 74 77 89	60 88 129	
	D	Unlikely			76 109	86 108 110 64 75 90 93 72	111
	E	Rare				87 95 66	

Low	Moderate	High	Extreme
0	2	22	4

Figure 22 - Commercialisation risk map

11 PROJECT EXECUTION

It is also important to consider in the early stages of commercialisation when working through the pathway to implementation of the technology and process, how robust in financial terms both the process and eventual operating business is to external impacts. This is often dealt with via modelling and scenario analysis – either stochastic or probabilistic.

After treatment, two project execution risks are rated as “extreme” and seven are rated as “high”. Figure 23 shows the project execution risk maps before and after treatment.

82 Financial uncertainty

Rating – Extreme

Consequence – Major Likelihood – Moderate

Movement in interest rates over time, change to attitudes to tenor of financial instruments requiring refinancings, access to different forms of finance such as bank debt as opposed to public raisings and private placements can all change over time. These can impact both the availability and cost of finance and can have a significant cost impact on project execution.

To mitigate this risk the stakeholders will need to carefully consider the timing of commercialisation and whether an opportunity exists to lobby non-commercial funders to access finance and grants. A plan needs to be developed for commercialisation that includes actions to track financial conditions and select the appropriate time for commercialisation.

85 Due Diligence

Rating – Extreme

Consequence – Major Likelihood – Likely

If the previous stage were to be treated as part of a financial feasibility study that optimised the development pathway including pertinent issues that reduce risks to an acceptable level, then for full investment, sufficient information has to be provided to debt and equity by way of an objective assessment to attract them.

The market must have an opportunity for independent due diligence which should be based on thorough due diligence and independent reports by the originator. Otherwise initial interest will not be stimulated as there is no evidence to support the technology implementation.

To mitigate this risk a thorough costing of implementation and operation would be needed with sufficient scenario analysis, including:

- Offtake markets would need to be assessed for appetite and size
- Legal and potential documentation risk would need to be assessed

- Legal and tax risk would have to be considered – have R&D grants been considered, Foreign Investment Review Board (FIRB) limitations, regulatory compliance requirements and risks, planning risks, community inputs and objections etc.
- Have the stakeholders been prepared so there is no risk of material third party intervention in implementation?
- Is there sufficient and long term margin between costs of production and price of offtake that is sustainable through downside analysis and is this evidenced sufficiently
- Has the legal structure been made investor ready in terms of attractiveness to different forms and sources of finance and availability of appropriate security?

In addition, to gain support for the MRC-DICE technology, lobbying of potential funders and governments in Australia and internationally will be required.

22 Over-investment in transport / supply chain capacity

Rating – High

Consequence – Moderate Likelihood – Likely

As mentioned in risk 64, investment in infrastructure is required ahead of the demonstration and commercial engines being in place to ensure a supply of fuel is available for the MRC-DICE engines. This risk is that too much investment is made in infrastructure ahead of engines being installed and the infrastructure does not get fully utilised. This could be caused by lack of demand for MRC-DICE engines or the uptake of engines not being in the geographic location anticipated.

78, 79, 80 Early Commercial Failures

Rating – High

Consequence – Major Likelihood – Unlikely

The financial pressures to accelerate develop to establish a commercial foothold can result in early failures in the field. At one end of the spectrum, failures can increase the cost of the technology through recalls, modifications and a slowing in market acceptance until the technology is fully proven. At the other end of the spectrum, catastrophic failures can result in the end of the technology as occurred with airship transport following the crash of the Hindenburg and the Comet jet airliner following four crashes due to a technology flaw.

A key mitigation strategy is extensive field testing in commercial environments following the demonstration phase, but this need to be balanced against the cost and time required.

81 No agreement of project objectives

Rating – High

Consequence – Moderate Likelihood – Moderate

Stakeholders cannot agree on the objectives and the way forward for the MRC-DICE project and therefore funding fails. The DICE-NET has been established to engage stakeholders in the process

83 Market uncertainty

Rating – High

Consequence – Major Likelihood – Unlikely

Economic shocks such as financial market collapses which give rise to a loss of confidence in investors can increase costs to execute the project and put the execution of the project at risk if investors withdraw their support. Financial market requirements for flexibility and exit strategies from investment are likely to increase this risk.

Financial markets can also impact demand for electricity generation technologies and electricity demand and MRC-DICE may no longer meet the required equity yields compared to alternative investments. Investors will also need sufficient information to be able to make the investment decision?

84 Investment profile

Rating – High

Consequence – Moderate Likelihood – Likely

Different types of finance have different risk appetite – whether venture, development, project or corporate finance, the risk profile needs to suit the chosen path way and the returns need to be commensurate.

Risk Map
Before Treatment

			Consequence				
			Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
Likelihood	A	Almost Certain					
	B	Likely			22 84	82 85	
	C	Moderate			10 81		
	D	Unlikely				78 79 80 83	
	E	Rare					

Low	Moderate	High	Extreme
0	0	8	2

Risk Map
After Treatment

			Consequence				
			Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrophic 5
Likelihood	A	Almost Certain					
	B	Likely			22 84	85	
	C	Moderate			81	82	
	D	Unlikely			10	78 79 80 83	
	E	Rare					

Low	Moderate	High	Extreme
0	1	7	2

Figure 23 - Project execution risk map

12 GLOSSARY

Abbreviation	Meaning
Cogen	Cogeneration of electricity and heat
DICE	Direct Injection Carbon Engine
DICEnet	DICE network – group of stakeholders interested in the development of DICE technology
EIS	Environmental Impact Statement
FIRB	Foreign Investment Review Board
HFO	Heavy Fuel Oil
MAN	Specialist engine manufacturer
MRC	Micronised Refined Carbons
MSDS	Material Safety Datasheet
MTBO	Mean Time Between Overhauls
R&D	Research and Development
USDoE	United States of America Government Department of Energy

13 REFERENCES

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Appendix 1 Risk register and treatments, “extreme” and “high” risks

R&D Stage risks and risk treatments

Number	Ranking	Risk Description (Event and Consequence OR Cause	Category	Existing Controls	Risk Severity Before Treatment	Risk Treatment Plan	Ability to Influence	Action Plan Type	Risk Severity After Treatment
111	1	MAN timing restrictions; agreeing contract, by end of September. Not a firm proposal with schedule and details in place.	6 Commercialisation	BCIA Funding agreement in place subject to risk review. Terms not yet agreed with MAN and CSIRO. ANLEC and CSIRO have agreed terms. IP clear. From fuel tank onwards MAN IP.	*Extreme*	Clear and articulated project plan to be finalised in next two weeks.	Moderate	Reduce likelihood	*Extreme*
75	11	Correct balance between engine innovations and fuel quality not achieved reducing the attractiveness of the MRC-DICE business case overall.	6 Commercialisation	Technology development programme is in place and needs to be agreed with all stakeholders.	*Extreme*	Include appropriate tests to allow discovery of commercial fuel and engine development together. Plan for value chain for fuel production matches engine development and commercialisation. Common aspects for black/brown coal, fuel production aspects may be different. Allow time for these tests.	Moderate	Reduce likelihood	*High*
87	12	Knowhow loss to other stakeholders if MAN prove the technology but decide not to commercialise it.	6 Commercialisation	None known	*Extreme*	Contract terms, personnel to attend testing. If MAN does not proceed then hand over technology.	High	Reduce likelihood	*High*

Number	Ranking	Risk Description (Event and Consequence OR Cause	Category	Existing Controls	Risk Severity Before Treatment	Risk Treatment Plan	Ability to Influence	Action Plan Type	Risk Severity After Treatment
70	18	The suitable "commercial" fuels not able to be engine tested as it falls outside the test spec	2 Slurry Preparation	Version 1 fuel specifications and suitable tests, draft standards by June 2016. 20 hr test at CSIRO prior to providing sample to MAN. Use mechanical not UCC. New injector design.	*High*	20 hr injection test by MAN in modified injector before it goes into the engine in Japan. Develop new fuel spec.			*High*
104	19	Uncertainty over whether economics of the engine will be indicated from initial engine test if survives first 20 hours. Could be a technical solution but too expensive.	5 Power Gen	Order of magnitude estimates from 20 hr tests. If MAN thought impossible wouldn't be doing it.	*High*	Targets of the 20 hr tests from Denemark. Emissions, CO2, operability to support renewables Economic viability. Do these address the risks? Look at the potential market then, consider maint period, cost of engine, cost of fuel.	Low / None		*High*
66	20	Cost estimates for R&D stages are not adequate, unforseen impacts such as damage to test engine not allowed for	6 Commercialisation	Detailed project plan setting out key activities, timeframes, budgets, IP management, and project management framework and reporting for research investment committee. Rebuild included in programme cost.	*High*	Contract terms to reduce liability of funders. Contingency included in the budget.	Moderate	Reduce likelihood	*High*
21	36	Product not delivered to end user. Test fuel to MAN.	3 Transport	Shared infrastructure with fuel oil?	*High*	Transport regulations WRT dangerous goods. MSDS developed	High	Reduce likelihood	*Moderate*

Number	Ranking	Risk Description (Event and Consequence OR Cause	Category	Existing Controls	Risk Severity Before Treatment	Risk Treatment Plan	Ability to Influence	Action Plan Type	Risk Severity After Treatment
20	37	Significant wear issues in pumping, slurry lines and slurry metering/injection systems - from fuel tank to injector.	5 Power Gen	Tests to show relative effects of coal, minerals amount and size on atomiser wear (test nozzle) and cylinder abrasive wear (HFRR tests with contaminated lubricants). Data required for specifications/standards work and MAN developments.	*High*	CSIRO to review design and visit MAN	Moderate	Reduce likelihood	*Moderate*
10	47	Project starting late, Pilot plant unit moving to a new site at the end of the year so can't produce material. Order needed by end of Aug 2014.	7 Project Execution	Schedule published that meets requirements	*High*	Communication with funders and Glencore so plan movement of pilot plant, terms and conditions in contract in parallel with commercial discussions.	Moderate	Reduce likelihood	*Moderate*
26	49	Settling and segregation during storage	4 Storage	Target fuel stagnant settling rate of <5mm of soft pack cake/month controlled by combination of PSD and additives. Report.	*High*	Development of a small skid (pallet size) to precondition fuel and supply it to an engine fuel tank. Includes procuring suitable tanks for transporting fuel to MAN. April 2015	High	Reduce likelihood and consequence	*Low*

Demonstration stage risks and risk treatments

Number	Ranking	Risk Description (Event and Consequence OR Cause	Category	Existing Controls	Risk Severity Before Treatment	Risk Treatment Plan	Ability to Influence	Action Plan Type	Risk Severity After Treatment
85	6	The MRC-DICE proponents need to perform adequate due diligence to encourage investors to consider financing the development.	7 Project Execution	None known	*Extreme*	Due dilligence and considering next phase funders and their information requirements for a decision. Lobbying required? International govts?			*Extreme*
112	8	Engine durability to survive 8000 hours of running between overhauls. This is considered the minimum for a practical applicaton and equates to approx 1 year of operation. C.f. Heavy Fuel Oil engine ~ 24,000 hrs. Success in US DoE work with 4 stroke engines, does this directly apply to 2 stroke engines being tested by MAN?	5 Power Gen	Construction of a 1 MW one cylinder low speed test engine with MRC fuel capability. The engine will include current dual fuel capability to enable use of MRC, and comprise state of the art electronic control to enable optimisation for MRC. This provides a facility for subsequent coal tests on an operating cost/refurbishment basis. Nominal 20 hour engine tests. Report detail performance and issues. Data for full size prototype engine. Two tests planned based on chemically cleaned black coal MRC and brown coal MRC. Third test on physically cleaned black coal MRC subject to additional funding.	*Extreme*	Test programme is supposed to test this assumption. Ensure the programme does this.	Low / None	Reduce likelihood	*Extreme*

Number	Ranking	Risk Description (Event and Consequence OR Cause	Category	Existing Controls	Risk Severity Before Treatment	Risk Treatment Plan	Ability to Influence	Action Plan Type	Risk Severity After Treatment
88	13	If non-commercial funding (Commonwealth and State government) is not available during the demonstration stages the MRC-DICE technology is unlikely to be commercialised.	6 Commercialisation	Australian government agencies are engaged in the project. Seek funding in other countries?	*Extreme*	Due dilligence and considering next phase funders and their information requirements for a decision. Lobbying required? International govts? Make a plan of who want to target. Matching funding required. Project of national significance?	Moderate	Reduce likelihood	*Extreme*
129	7	The demonstration phase will require around $40m. Funds are not available and technology is not commercialised.	6 Commercialisation		*Extreme*	A consortium approach is required and could involve a number of different government agencies in a range of countries including Australia, Japan, Germany, Indonesia etc. Engagement has already started.	Moderate	Reduce likelihood	*Extreme*
86	2	Insufficient investment in the pilot and demonstration phases to provide investors with confidence to commercialise the MRC-DICE technology	6 Commercialisation	Costed project plan in place to prove technology, needs to be agreed with all stakeholders.	*Extreme*	Due dilligence and considering next phase funders and their information requirements for a decision.	High	Reduce likelihood	*High*
90	14	Fuel not available to run demonstration	6 Commercialisation	Undertake fuel development program concurrent with engine development program Contemplate transportation of bulk fuel for demonstration	*Extreme*	Plan for value chain for fuel production matches engine development and commercialisation. Common aspects for black/drown coal, fuel production aspects may be different.	Moderate	Reduce likelihood	*High*

Number	Ranking	Risk Description (Event and Consequence OR Cause	Category	Existing Controls	Risk Severity Before Treatment	Risk Treatment Plan	Ability to Influence	Action Plan Type	Risk Severity After Treatment
95	16	Infrastructure not available for production, storage and transport of MRC-DICE fuel in quantities required for the pre-commercial phase	6 Commercialisation		*Extreme*	Plan for value chain for fuel production matches engine demonstration. Commitment to fund early development. Common aspects for black/brown coal, fuel production aspects may be different. Build infrastructure as part of the development project.	High	Reduce likelihood	*High*
92	26	Inability to provide a suitable fuel within MAN's fuel specification. Relationship between feedstock and engine. Not standardised fuel. May need to customise each engine to run on a particular feedstock. Design Engines to handle a range of feedstocks?	2 Slurry Preparation	Version 1 fuel specifications and suitable tests, draft standards by June 2016	*High*	MAN will test whatever fuel spec you provide and whatever coal source.	Low / None		*High*
67	41	Social License - coal generation not acceptable to public, government and other stakeholders	6 Commercialisation	None known	*High*				*High*
81	48	Agreement on project objectives cannot be reached by stakeholders	7 Project Execution	DICE-NET has been established to engage stakeholders	*High*				*High*

Commercialisation stage risks and risk treatments

Number	Ranking	Risk Description (Event and Consequence OR Cause	Category	Existing Controls	Risk Severity Before Treatment	Risk Treatment Plan	Ability to Influence	Action Plan Type	Risk Severity After Treatment
82	5	Financial terms, such as interest rates, access to finance can change the ability to finance and the cost of finance. NEXT PHASE	7 Project Execution	None known	*Extreme*	Timing of commercialisation, ability to lobby non-commercial funders, grants. Track and select timing for commmercialisation.	High		*Extreme*
60	9	By the time DICE is commercialised, experience curve effects for competing technologies such as GTs will mean DICE is non-competitive and can't catch up	6 Commercialisation	None known	*Extreme*	Move quickly, develop commercialisation plan to target niches and review learning curves for existing technologies in the market.	Low / None		*Extreme*
108	3	COMMERCIALISATION Regulatory, lifecycle assessment, community engagement, social license to operate. Consolidate here from all sections. Production, transport, combustion e.g. coal transported, so this can be transported DO NOT ASSUME!	6 Commercialisation	Is the project plan sufficient to cover this?	*Extreme*	Independent review e.g. like EIS, as part of feasibility. Include in work plan and work out how to fund.	High	Reduce likelihood	*High*
110	4	Lack of communication, demonstration and commercial phases	6 Commercialisation		*Extreme*	Targeted engagement, communication and engagement strategy, consistent approach.	High	Reduce likelihood	*High*

Number	Ranking	Risk Description (Event and Consequence OR Cause	Category	Existing Controls	Risk Severity Before Treatment	Risk Treatment Plan	Ability to Influence	Action Plan Type	Risk Severity After Treatment
64	10	Infrastructure not available for production, storage and transport of MRC-DICE fuel in quantities required for the market	6 Commercialisation	Explore markets other than Australia. Undertake fuel development program concurrent with engine development program.	*Extreme*	Plan for value chain for fuel production matches engine development and commercialisation. Common aspects for black/drown coal, fuel production aspects may be different.	Moderate	Reduce likelihood	*High*
93	15	Lack of wrap-around engine and fuel guarantee. Users will not adopt the technology due to concerns with split responsibility from engine manufacturer and fuel producers.	6 Commercialisation	Undertake fuel development program concurrent with engine development program.	*Extreme*	Plan for value chain for fuel production matches engine development and commercialisation. Common aspects for black/brown coal, fuel production aspects may be different. Specifications, standards and commercial terms.	Moderate	Reduce likelihood	*High*
101	17	What is the cost position of brown, black MRC vs other fuels? Including logistics, processing etc. What is the market opportunity for use of coal to highest value use?	1 Feedstock	Already quantified to some extent, looks promising.	*High*		Low / None		*High*
72	21	Fuel substitution from MRC-DICE conventional or alternative fuels reduces fuel demand.	6 Commercialisation	None known	*High*				*High*

Number	Ranking	Risk Description (Event and Consequence OR Cause	Category	Existing Controls	Risk Severity Before Treatment	Risk Treatment Plan	Ability to Influence	Action Plan Type	Risk Severity After Treatment
78	22	Field applications in the early commercialisation phase will show up significant technology flaws adding to the cost and slowing deployment	7 Project Execution	Well considered demonstration programme	*High*				*High*
79	23	There is a "Comet jet/Hindenburg airship-like" disaster in the early days of the commercialisation (e.g. fuel explosion)that kills the technology	7 Project Execution	Well considered demonstration programme	*High*				*High*
80	24	Technology is commercialised before it is fully proven and fails requiring recalls	7 Project Execution	Well considered demonstration programme	*High*				*High*
83	25	Market changes, such as financial collapse, can reduce the appetite of investors for risk taking and may cause withdrawal of finance during the project to seek alternative investments.	7 Project Execution	None known	*High*				*High*
99	27	Don't understand commmercialisation pathways; matched set of mine and engine or tight fuel specification?	1 Feedstock	Derisked through tests with MAN and development of fuel spec.	*High*	Part of next phase of the project. Engines can be ramped up in modules. Fuel production can also be modular.	Low / None		*High*

Number	Ranking	Risk Description (Event and Consequence OR Cause	Category	Existing Controls	Risk Severity Before Treatment	Risk Treatment Plan	Ability to Influence	Action Plan Type	Risk Severity After Treatment
28	29	MRC-DICE is not a suitable electricity market entrant due to low prices and over capacity on the NEM in Australia. Are alternatives attractive to current stakeholders Govt and private.?	5 Power Gen	Explore markets other than Australia	*High*				*High*
63	30	Emissions intensity regulations introduced that are too onerous for MRC-DICE without CCS or biomass co-firing	6 Commercialisation	None known	*High*	Cogen, CCS studies, biomass blending. High exhaust temperature. Advantage vs conventional gas fired Power Station.			*High*
68	31	Genset capacities cannot be scaled up to commercial sizes (say 100 MW) to offset grid connection costs compared to gas turbines (150+MW) for same grid connection costs	6 Commercialisation	None known	*High*				*High*
22	32	Over investment in transport/supply chain capacity. NEXT PHASE	7 Project Execution	None known	*High*				*High*

Number	Ranking	Risk Description (Event and Consequence OR Cause	Category	Existing Controls	Risk Severity Before Treatment	Risk Treatment Plan	Ability to Influence	Action Plan Type	Risk Severity After Treatment
84	33	The investment profile of MRC-DICE needs to match the appetite of investors, with risk being rewarded with commensurate returns.	7 Project Execution	None known	*High*				*High*
100	34	Manfacturing of MRC - getting approvals could be difficult	1 Feedstock	Additives used low toxicity, many advantages from risk point of view vs heavy fuel oil and diesel. Still using coal and emissions no better than open cycle gas turbines.	*High*	Build the story support renewables etc	Low / None		*High*
61	38	By the time DICE is commercialised, natural gas prices will have fallen due to over-supply as a response to higher gas prices in the short to medium term	6 Commercialisation	None known	*High*	Move quickly, develop commercialisation plan to target niches and review learning curves for existing technologies in the market.			*High*
62	39	The DICE technology cannot be scaled up to competitive-sized generators for mainstream grid use, restricting their applications to off-grid and niche grid-support at the end of weak network lines	6 Commercialisation	None known	*High*				*High*

Number	Ranking	Risk Description (Event and Consequence OR Cause	Category	Existing Controls	Risk Severity Before Treatment	Risk Treatment Plan	Ability to Influence	Action Plan Type	Risk Severity After Treatment
65	40	Consortium approach is required to build infrastructure but stakeholders may not be willing to invest in shared infrastructure	6 Commercialisation	DICE-NET has been established to engage stakeholders. Infrastructure exists for black coal that could be used or adapted.	*High*				*High*
69	42	CCS application to MRC-DICE is difficult / not possible / expensive	6 Commercialisation	None known	*High*				*High*
73	43	Generation cost does not suit existing electricity markets and becomes a niche technology.	6 Commercialisation	None known	*High*				*High*
74	44	If uptake is not as high as projected, investment in R&D and assets could be stranded.	6 Commercialisation	None known	*High*				*High*
77	45	Should the MRC-DICE be the technology leader or wait for others to develop the technology	6 Commercialisation	None known	*High*				*High*

Number	Ranking	Risk Description (Event and Consequence OR Cause	Category	Existing Controls	Risk Severity Before Treatment	Risk Treatment Plan	Ability to Influence	Action Plan Type	Risk Severity After Treatment
89	46	Mismatch between engine and fuel technology development	6 Commercialisation	Undertake fuel development program concurrent with engine development program	*High*				*High*
7	28	Difficulty keeping the fuel dispersed and in suspension	2 Slurry Preparation	Target fuel stagnant settling rate of <5mm of soft pack cake/month controlled by combination of PSD and additives. Report.	*High*	Test programme is supposed to test this assumption. Ensure the programme does this.	High	Reduce likelihood	*Moderate*
19	35	Settling and segregation during pumping/transport	3 Transport	Target fuel stagnant settling rate of <5mm of soft pack cake/month controlled by combination of PSD and additives. Report.	*High*	Test programme is supposed to test this assumption. Ensure the programme does this.	High	Reduce likelihood	*Moderate*
27	50	Additional infrastructure required at the test site to store and maintain the quality of the MRC-DICE fuel,	4 Storage	Development of a small skid (pallet size) to precondition fuel and supply it to an engine fuel tank. Includes procuring suitable tanks for transporting fuel to MAN. April 2015	*High*	Development of a small skid (pallet size) to precondition fuel and supply it to an engine fuel tank. Includes procuring suitable tanks for transporting fuel to MAN. April 2015	High	Reduce likelihood	*Moderate*

Appendix 2 Risk and Showstoppers Workshop - Agenda

WorleyParsons
resources & energy

AGENDA

Project No: 201020-06973

Project: MRC-DICE RISK REVIEW

Risk and Showstoppers Workshop, Newcastle

PARTICIPANT NAME AND ORGANISATION			
CSIRO:	James McGregor Louis Wibberley Bruce Fox	**DATE**	30 July 2014
		TIME START	10:00
WORLEYPARSONS:	Phil O'Neil Joe Micallef Ian Waterman	**TIME FINISH**	16:00
		LOCATION	CSIRO Energy Centre
STAKEHOLDERS:	Martin Oettinger - ACALET Steve Malss - ACALET Noel Simento - ANLEC R&D Phil Gurney - BCIA Barry Isherwood - Carbon Connections Melissa Round - Dept of Industry Geoff Bongers - GAMMA ENERGY TECHNOLOGY Angus Ikin - XT Dave Osborne - XT	**DOC NO**	SR-AGD-0001
		FILE LOC	\\Aunewwpfil02v\shr\Jobs\20 020\06973 - MRC DICE Rick Reveiw\3.0 Reports\3.02 MoM - Customer
		PROJ REF	

AGENDA

ITEM	ITEM DETAILS	PRESENTER	TIME
1.	**OneWay Moment**	Phil O'Neil	10:00
2.	**Workshop Introduction** -housekeeping -purpose -agenda	Phil O'Neil	10:05
3.	**MRC-DICE Introduction** -brief overview of the technology and work to date	Louis Wibberley	10:15
4.	**Lab tour** -brief tour of the CSIRO MRC-DICE facilities	Louis Wibberley	10:35
5.	**Risk Assessment Introduction** -showstopper definition -methodology -existing controls -risk ratings -control measures -final risk ratings	Phil O'Neil / Joe Micallef	11:20
6.	**Desktop Risk Review** -Presentations on risk topics -Comments received on the desktop report	WorleyParsons	11:35

AGENDA

ITEM	ITEM DETAILS		PRESENTER	TIME
7.	**Lunch**			12:20
8.	**Risk review – MRC-DICE Feedstock**		Joe Micallef	12:50
9.	**Risk review – Slurry preparation**	**Risk review – Power generation**	Joe Micallef / Phil O'Neil	13:10
10.	**Risk review – Transport**	**Risk review – Commercialisation pathway**	Joe Micallef / Phil O'Neil	13:40
11.	**Risk review – Storage**	**Risk review – Project execution**	Joe Micallef / Phil O'Neil	14:10
12.	**Risk summary**		Joe Micallef	14:40
13.	**Workshop wrap and next steps**		Phil O'Neil	15:00
14.	**Commercialisation discussion (optional)** -introduction -brainstorming of issues that stand in the way of commercialisation		Phil O'Neil	15:10

END OF RECORD

Appendix 3 Commercialisation Workshop - Agenda

WorleyParsons
resources & energy

AGENDA

Project No: 201020-06973

Project: MRC-DICE RISK REVIEW

Commercialisation Workshop, Melbourne

PARTICIPANT NAME AND ORGANISATION		DATE	14 August 2014
CSIRO:	James McGregor Louis Wibberley Bruce Fox	**TIME START**	10:00
WORLEYPARSONS:	Phil O'Neil Peter Tolé Jeremy Brasington Peter Lawley	**TIME FINISH**	16:00
		LOCATION	Level 12, 333 Collins St, Melbourne
STAKEHOLDERS:	Lewis Jeffery, Kinerja Geoff Bongers, GAMMA ENERGY TECHNOLOGY Rick Fowler, Coal Innovation NSW David McManus, Brown Coal Innovation Australia Phil Gurney, BCIA Barry Isherwood, Carbon Connections P/L Angus Ikin, XT Bruce Murphy, Dept of Industry Claude Morson, Dept of Industry John White, Ignite Energy Resources Limited Jeffrey Moloney, MAN Larry Silva, MAN Roland Davies, AGL Geoff Gay, Energy Australia Stephen Malss, ACALET Martin Oettinger, ACALET Jane Burton, Clean Coal Victoria	**DOC NO**	SR-AGD-0002
		FILE LOC	\\Aunewwpfil02v\shr\Jobs\201 20\06973 - MRC DICE Rick Review\3.0 Reports\3.02 MoM - Customer
		PROJ REF	

AGENDA

ITEM	ITEM DETAILS	PRESENTER	TIME
1.	**OneWay Moment**	Phil O'Neil	10:00
2.	**Workshop Introduction** -housekeeping -purpose	Phil O'Neil	10:05

AGENDA

ITEM	ITEM DETAILS	PRESENTER	TIME
	-agenda		
3.	**MRC-DICE Introduction** -brief overview of the technology and work to date	Louis Wibberley	10:15
4.	**Newcastle Workshop feedback**	Phil O'Neil	10:35
5.	**Commercialisation Assessment Introduction** -setting the objective -workshop methodology	Phil O'Neil / Peter Tolé	11:00
6.	**Commercialisation review – MRC-DICE Feedstock & licensing**	Peter Tolé	11:15
7.	**Commercialisation review – Slurry preparation**	Peter Tolé	11:45
8.	**Commercialisation review – Transport & Infrastructure**	Peter Tolé	12:15
9.	**LUNCH**		12:45
10.	**Commercialisation review – Storage**	Peter Tolé	13:15
11.	**Commercialisation review – Power generation options**	Peter Tolé	13:30
12.	**Commercialisation review – Commercialisation pathway**	Jeremy Brasington	14:00
13.	**Commercialisation review – Project execution**	Peter Tolé	14:30
14.	**Commercialisation feasibility review** -business case imperatives, risks & financial considerations -discussion of top 10 risks -key questions to be answered by engine test programme to de-risk investment -holistic view of commercialisation pathway and end -to-end warranties	Jeremy Brasington	15:00
15.	**Workshop wrap and next steps**	Phil O'Neil	15:45
16.	**Close**		16:00

END OF RECORD

Appendix 4 DICE Frequently Asked Questions

Direct Injection Carbon Engine

Summary

- Size-for-size, DICE is the most efficient means of converting carbon-based fuel energy to electricity which gives a significant reduction in carbon footprint. DICE also enables cost effective management of the carbon foot print via the fuel, fuel utilisation, and flue gas. These advantages are due to the high thermodynamic efficiency of the diesel engine, high fuel flexibility, high efficiency at part load, and more efficient adaptation for carbon capture.
- DICE has lower capital cost at $1200–2000/kW (about half that of supercritical pulverised fuel plants), and together with tolerance to load changes, DICE makes stop-start operation for peak and backup duty a practical and economic option for coal-based generation. Unlike natural gas turbines, this flexibility can be provided without losing efficiency or increased maintenance.
- Development of MRC fuel for DICE (as refined coal product) allows coal to match fossil energy competitor performance in the electricity market. Other advantages include:
  - being cost competitive with conventional coal-fired generation.
  - likely to retain a cost advantage over gas for base-load power at forecast gas and coal prices.
  - would have performance capability advantage compared to conventional coal-fired generation (rapid start/stop capability), and match or better performance capability of gas for base-load power and peaking power.
  - gives the ability to underpin intermittent renewables (Direct Action).
  - for carbon capture to have 40% advantage over competing coal and gas technologies (Direct Action).
  - ability to drastically improve on current remote area (or off-grid) power generation status quo (for coal mines and mines).
- There is an opportunity for black coal sector to obtain significant additional profit margin on value-add of black coal to produce MRC. High quality MRC (1.5% ash) can be produced from a wide range of black coals (including tailings with >50% ash) for around $1.5-1.75/GJ.
- The increased cost of coal processing is offset by a range of the benefits that a more refined coal product attracts.
- Technical issues to produce commercial DICE, underpinned by specification MRC, are deemed manageable via modern engineering. However this requires the commitment of an engine OEM, which in turn requires the commitment of the broader coal industry.
- In contrast with previous work, the main R&D objective has been to produce low cost MRC with sufficient quality to enable DICE to compete with new base load pf power plants, and with an expected thermal efficiency of 50% (HHV) at 50 MW unit capacity.
- While there has been excellent progress towards commercialisation of the new fuel cycle, there is now an opportunity to replace current parallel black and brown developments with a more detailed, cost effective and integrated program. This will substantially de-risk the development - across the entire fuel cycle, and without increasing the overall development time.
- Broad industry support is critical to establishing this integrated development program, and to ensure increased commitment by MAN and other manufacturers (this is not only about $ - which are small compared with other low emission coal technologies).

List of frequently asked questions

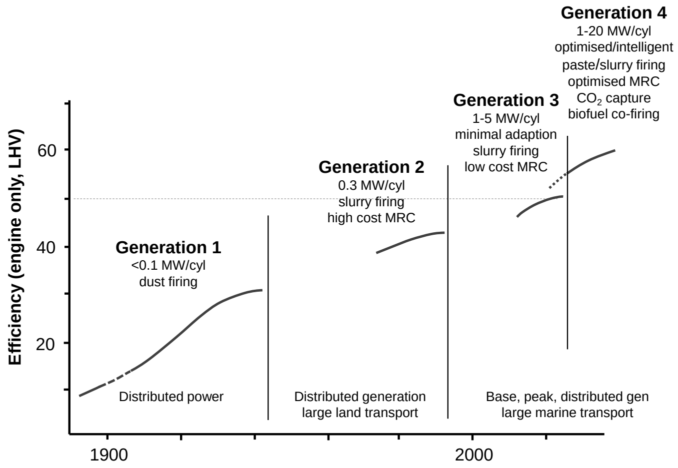
1. What does DICE stand for?
2. What does MRC stand for?
3. What are the properties of MRC?
4. What chemical additives are used, rates and toxicity?
5. What is the required ash content and how it is achieved
6. How is the concentrate dewatered?
7. How is MRC to be transported?
8. What are the implications of mineral matter content and composition?
9. What are the implications of coal type?
10. Opportunities to value-add coal?
11. Market potential?
12. What is the difference between black and brown coal based CWS?
13. What is the difference between coal water fuel, coal water slurry and MRC?
14. What is the difference between UCC and MRC?
15. Doesn't water in fuel reduce thermal efficiency?
16. Doesn't micronising of the carbon fuel use a lot of energy?
17. What is the recovery of coal during the cleaning step?
18. Why has the meaning of DICE and MRC been changed to refer to carbon fuels?
19. Why is DICE being redeveloped when development was terminated in the early 1990s?
20. What are the main technical challenges for DICE and how are they being de-risked?
21. What about fouling?
22. Is MRC or DICE subject to IP constraints?
23. What is DICEnet?

1. What does DICE stand for?

Direct injection carbon engine; a diesel engine which uses water-based slurry of micronised refined carbon fuel (MRC). The MRC fuel is injected as a liquid spray into the cylinders a few milliseconds before combustion is required to start.

DICE has been investigated several times over the last 100 years, starting with dust engines using pulverised coal. Whilst good results were obtained for these "dust engines", feeding dry dust is both technically very difficult and potentially dangerous, and for some fuels there is the additional penalty of drying. With dust aspiration, there is also more tendency for the fuel dust to contaminate the oily cylinder surfaces, than occurs in the direct injection of slurry fuels pioneered in the 2nd generation engines.

The present program involves generation 3 and 4 engine technology.



2. What does MRC stand for?

Micronised refined carbons. These include a range of carbon-based fuels (coal, lignite, biomass, biochars, and tar) that are finely ground, refined to improve certain properties (de-ashing and densification) to enable mixing with water to produce stable, low viscosity slurry with a high solids content. The specific energy is typically 15-25 MJ/L

3. What are the properties of MRC?

	Black coal	Brown coal
HHV (MJ/L)	21-25	16-19
Viscosity (mPa.s) @100/s (pumping) @100,000/s (injection)	 200-500 100-300	 400-700 200-400
Unstirred settling rates (mm/month)	1-5	1-5
Particle size d50 μm* d95 μm*	10-15 40	10-15 50

* current specification, expect that coarser grinds will actually perform better in large engines

4. What chemical additives are used, rates and toxicity?

Stage	Additive	Rate kg/t dry coal	Cost $/GJ	Comments
Flotation	Diesel	0.1-0.2	0.004-0.009	Amount required depends on coal hydrophobicity and extent of micronising
	MIBC	0.1	0.006	Low because micronizing increases froth stability
Formulation	PSSNa	1.2-2*	0.15-0.24	Cost based on LION data
	CMC	0-1*	0.003	
Total cost of additives			0.16-0.26	

* of active ingredient (added in aqueous solution)

Overall, no toxicity issues, with additives being used in affordable quantities.

Alternative dispersants to PSSNa include ammonium lignosulphonate and NSF. Both are used commercially in the minerals industry and in China for coal/water mixtures. More is required, offsetting the lower cost.

MIBC is methyl isobutyl carbinol (a standard frother for coal flotation).

PSSNa is polystyrene sulphonate sodium salt (an excellent anionic dispersant); not hazardous, many uses including pharmaceuticals.

CMC is carboxy methyl cellulose sodium salt (can act as both a dispersant and stabiliser); only used with a dispersant, if required; not hazardous – used in pharmaceutical industry as a thickening agent.

Ammonium lignosulphonate; non-hazardous - lignosulphonates are widely used in dust suppression on unpaved roads, in drilling muds and for coal/water mixtures in China.

NSF is naphthalene sulphonate formaldehyde condensate sodium salt; classed as hazardous chemical by OSHA, but used widely without problems (including for coal/water mixtures in China).

5. What is the required ash content and how it is achieved

The present requirement is to produce MRC with <2% mineral ash, and this specification is mostly based on targets used by the USDOE. As this is 10 times the ash content of normal fuel oil, MAN would prefer 1% ash, but this requirement was largely driven by the desire to undertake engine trials with the absolute minimum of engine modifications.

MRC can be produced from black coal by a range of commercial processes, all well known to the coal industry and not subject to IP constraints.

One suitable process is by micronising followed by flotation. The actual process configuration will depend on the properties of the feed coal, and how the MRC process is integrated into the value chain. When tailings are used as the feed, the MRC process would be undertaken in 2 or more stages to minimise micronising ash.

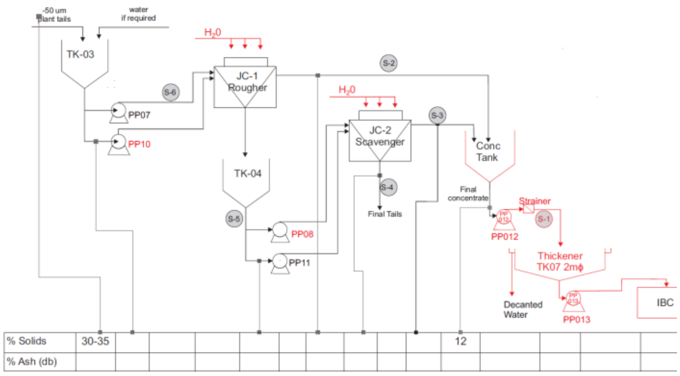
This process is similar to that also proposed by Yoon (Virginia Tech, USA), differing only in the choice of equipment supplier.

The laboratory test work to assess the effectiveness of flotation has been recently confirmed at the pilot scale (1 tonne/day) at Bulga.

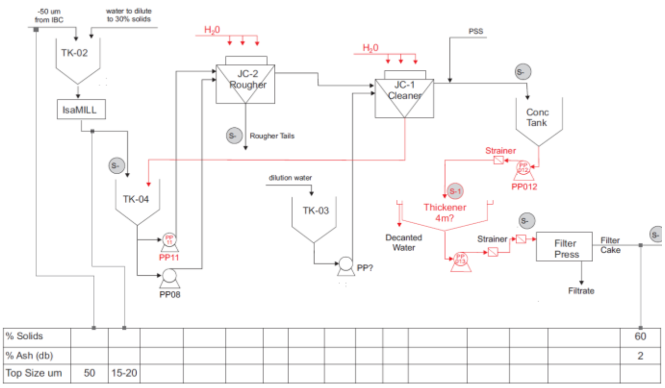
It is also acknowledged that previous work by the Japanese produced slurry fuel for boilers with down to 2% ash using spirals and hydroclones, and some of the earlier work by the DOE used selective agglomeration.

For low rank coals, flotation can used after suitable hydrothermal treatment (a commercial process involving heating a coal slurry to around 320C for several minutes to reduce coal porosity and achieve surface modification). This also increases the hydrophobicity of the coal. When flotation is unsuitable, spirals can be used for de-sanding as most of the extraneous minerals in Victorian coals are relatively coarse (~0.5mm) inclusions from sand beds.

The figures below show the current configuration of the Bulga Pilot Plant by Glencore Xstrata Technology, which involves a 2-stage flotation process to produce 2% ash MRC from tailings (~54% ash).



Stage 1 – rougher-scavenger



Stage 2 – cleaner

6. How is the concentrate dewatered?

The concentrate is presently dewatered using a short thickening stage followed by filtration. The hydrophobicity of the MRC concentrate results in rapid thickening, and filtration is readily achieved with an ultra-clean filtrate stream (which is recycled).

Tests have shown that centrifuges may also be used.

Both equipment is used for large scale commercial dewatering of coal fines. MRC dewatering may be significantly easier despite its finer size, due to lower clay content.

7. How is MRC to be transported?

MRC has similar rheological properties to coal water mixtures for boilers, and it is therefore assumed that it can be reliably stored and shipped. Like all slurries, some settling will occur given sufficient time, and therefore all tanks are required to be equipped with low intensity tank agitators (for example as used for heavy fuel oil storage).

It is envisaged that MRC would be mostly transported as slurry, however it would also be possible to transport the concentrate as a cake or briquette. To produce MRC from cake, only a small addition of water and dispersant is required in a mixer. Briquettes would also require remilling.

Overall logistics will depend on the feed coal and market. For example, if MRC is to be produced from tailings, it would be produced at the washery and shipped as slurry or briquette. If MRC is to be produced from an export coal, then it could be produced by a MRC plant that is nearby the end user, and so transportation of MRC, and long term storage would be minimised.

These logistics arrangements are contemporary with existing practices for fuel oils.

Examples of fuel handling demonstrations are given below.

Japan COM-Joban Power

Up to 500,000 t per year were produced in Japan (including from Saxonvale coal) to part fuel a 600 MWe boiler at Nakoso power station (12x11 t/h burners for CWF). Transportation was via 9 km pipeline of 350 mm diameter.

The project terminated in 2003 due to low fuel oil prices. At that stage LION Japan were producing the PSSNa dispersant from a pilot plant in Singapore (now used for other chemicals).

Note that LION are presently collaborating with CSIRO to develop new dispersants, and have costed a new and larger PSSNa production facility should DICE proceed.

Japan – China project

This project involved the world's first commercial trade in coal water fuel.

300,000 t per annum capacity

Production in China, storage in a 10,000 m^3 tank.

Transportation to Japan over 1100 km in a modified fuel oil tanker of 5000 DWT

Coastal transportation in Japan over 400 km via a new coal water fuel tanker of 700 DWT

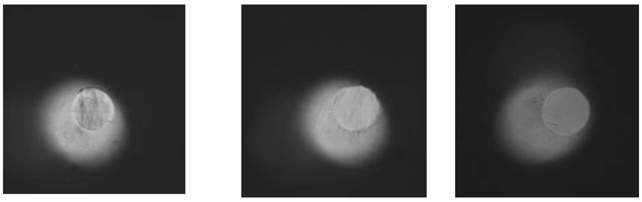
8. What are the implications of mineral matter content and composition?

Mineral matter has the potential for abrasive wear of the cylinder components (rings and liner) from hard flyash particles. Wear of the exhaust valve and turbocharger turbine/inlet is deemed to be manageable with current best practice (ref MAN, USDOE).

Despite the excellent USDOE program, there is little or no information in the literature on the effect of specific minerals, with most previous USDOE work reporting only total ash, and without details on mineral occurrence either in the fuel and the morphology of the resulting flyash.

Extraneous quartz, pyrites and titania minerals are likely to cause most of piston ring and liner abrasive wear due to their high hardness. Quartz and zircon minerals are also likely to be less spheroidised during combustion. However, this is highly dependent on the materials of construction of these components, and to some extent the size of the mineral particles as flyash residue.

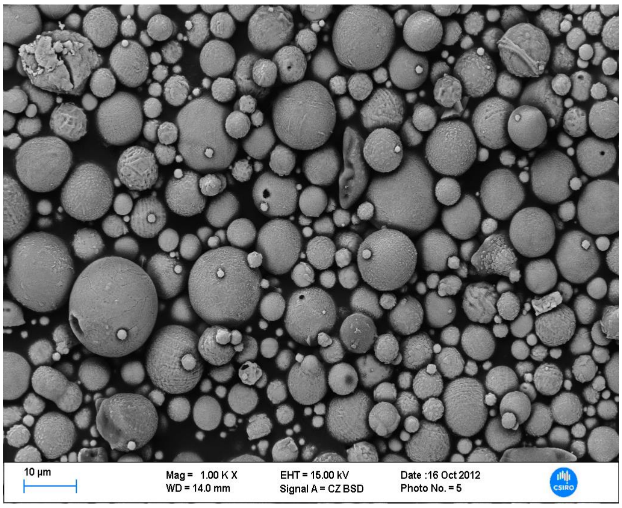
During wear tests using a laboratory reciprocating rig at contact pressures up to 200 MPa, the use of carbide coated surfaces (which are 50% harder than quartz), has been found to eliminate wear rates from ash contaminated cylinder oil.



Wear scars from clean cylinder oil (left), and contaminated by brown MRC ash (centre), black MRC ash (right)

Lubricant contamination (5 wt%) by clean particles of black and brown coal, and brown coal ash actually reduces wear by acting as a solid lubricant and preventing scuffing wear due to lubricant breakdown.

Most of the mineral matter will be spheroidised during combustion, with only the larger and higher melting minerals such as quartz or zircon remaining unfused. Typically quartz <20μm will spheroidise - with most black MRC the quartz is below 5μm.



Iron rich flyash cenospheres formed during combustion of brown coal MRC under engine conditions (combustion at 12 MPa, duration ~60ms)

It is speculated that particles between 5-30μm will cause more wear due to their ability to enter the ring-cylinder oil film.

Experiments show that inherent ash is likely to fuse and form cenospheres.

The amount and size of the minerals in MRC from brown coals are very different: the extraneous ash is generally much coarser due to the inability for efficient removal by flotation. Also, the organically bound ash forming elements in brown coal for a ultra-fine soft sulphatic ash that acts as a lubricant.

The USDOE researchers showed that ring life of at least 8,000 hours was possible with a medium speed engine. Note that the rings typically wear 4-10x faster than the liner.

The effect of cylinder wear decreases linearly with engine bore size.

In engines, accelerated cylinder wear (noting that a low rate of wear is essential to prevent glazing) is due to abrasion from particles harder than the cylinder components, scuffing (micro-seizing due to local lubricant breakdown) and corrosion (due to acid formation – especially in heavy fuel engine burning up to 5% S fuel). With most fuel oils, scuffing and corrosion are usually greater than abrasive wear – but not with some residual fuels.

9. What are the implications of coal type?

In summary, all coals tested to date (range of black and brown) gave good ignition and combustion.

Although wide variation was speculated (there is no information on this in the literature), CSIRO have found that providing atomisation of the fuel is suitable (say producing a spray with a mean size of 75μm), all coals will give good ignition and combustion. Ignition delays at 600°C are typically 5-7ms, which is very acceptable.

Fuels tested ranged from Bulga, Wambo, Lithgow, Moolarbin, Loy Yang, Yallourn, Kalimantan, Rhenisch coals, and high temperature carbonised eucalyptus charcoal.

Only charcoal water mixtures was found to give slower ignition, requiring a chamber temperature of 700°C to match the ignition of black coal at 600°C. Ignition can be greatly improved by the blending of a proportion coal – say 20%. This implies that anthracite would have similar behaviour.

The water content of the fuel (over the range 40-60 wt%) has little effect, presumably because a higher water fuel has a lower viscosity and provides better atomisation.

It is speculated that the extremely high heating rates in a diesel engine (around 100,000°C/s, or 10-20x faster than in pf boilers or gasifiers), and the high pressure (around 120-150 bar) results in both enhanced volatiles formation and hindered release, resulting in combustion of a more homogenous fuel droplet.

10. Opportunities to value-add coal?

For black coals, MRC provides an opportunity for a 20% value-add of coal via production of a refined specification product for higher value applications - power generators (utilities) require flexibility from their generation assets in current and future on-grid electricity markets, and MRC products are able to provide power generators with required flexibility to operate the required generation assets in on-grid electricity markets or off-grid.

Traditional generation assets using coal do not provide the full flexibility required by power generators (utilities) from their generation assets in contemporary and future on-grid electricity markets. There is limited or no opportunity to value-add unrefined specification coal for these applications.

For brown coals, MRC offers much greater opportunities to value-add. In addition to providing brown coal with a lower

CO_2, more flexible generation technology, it also provides new opportunities for brown coal slurry exports to Asia in competition with LNG. LNG in Asia cost more than $15/GJ and is likely to increase as demand in Japan. Hydrothermally treated brown coal suitable for DICE and gasification could be landed for less than 1/3rd of the LNG price. An export HTD product based on a brown coal mine about the same size as the current Loy Yang mine would be expected to have a value to Victoria of about $2B pa (and employ many hundreds of workers).

11. Market potential?

In summary, the international market potential is large (well over 175 GW), with significant upside both nationally and internationally.

The market potential of fuel for DICE is effectively any coal-based generation, with the easiest market entry being replacement of smaller/old inefficient capacity and large remote diesel fuelled capacity (eg mine sites), followed by incremental new capacity and marine applications.

Using IEA data (growth estimate below), the current small scale/old capacity is around 175 GW (~508 Mtpa). Current remote generation (off-grid) capacity is estimated at around 3% of the total generation worldwide. Marine capacity is estimated at an equivalent 85 GW (250 Mtpa coal equivalent).

CO_2 emission limits, such as the recent USDOE limit of 1100 lb/MWh (burner tip) would prevent new DICE generation unless biomass MRC was co-fired with coal MRC, or partial (say 20%) CCS was used. DICE could achieve around 1400 lb/MWh now, and 1250 lb/MWh in the future.

	2009	2020	2035
China	650	984	1159
USA	333	366	314
EU	177	180	108
East Europe/Eurasia	103	98	81
India	92	201	325
Russia	47	48	41
Japan	46	46	39
Africa	41	55	68
Others (Australia 45%)	92	155	228
World total	**1581**	**2133**	**2353**
Coal use (Mtpa)	**4585**	**6186**	**6824**

Estimates for coal generation capacity (data extracted from IEA data base)

12. What is the difference between black and brown coal based CWS?

MRC from brown coal has a lower specific energy mostly due to a higher oxygen content, and contains significantly different ash forming constituents. Although the brown coal MRC contains higher water content, its ignition and combustion is significantly better than that from black coal, though this advantage is offset by the increased difficulty in atomisation.

	Black MRC	Brown MRC
SE (MJ/L)	21-25	16-19
Oxygen content (% db)	5	22-24
Mineral ash (% db)	1-2 (quartz and clay <5μm)	0.1-2 (quartz, siderite 0-200μm)
Non-mineral ash	minor	1-2% (Ca, Mg, Fe, Na forms sulphate fume)
Ignition delay (ms @ 600°C)	5	3-5
Effect on efficiency relative to diesel (% HHV)	-1%	-2-3%
Abrasive wear relative to oil steel-steel	2x	1.2x
carbide-carbide	1x	1x

13. What is the difference between coal water fuel, coal water slurry and MRC?

Coal water fuel is a generic term for water-based slurry fuels containing coal. Other terms include coal water slurry (CWS) and coal water mixtures (CWM).

The term MRC has been used to differentiate higher quality fuel for DICE from the higher ash, higher viscosity coal water fuels and slurries produced for boilers and gasifiers.

14. What is the difference between UCC and MRC?

Yancoal's UCC is also an MRC, but one with a lower mineral ash content. This fuel is produced by chemical cleaning (which is very effective in removing silica based minerals) and was originally for gas turbines. Although more costly to produce, it is likely to have a higher value by being more suitable for smaller and higher speed engines (eg the smaller medium speed engines).

15. Doesn't water in fuel reduce thermal efficiency?

In summary, the effect is a slight reduction.

Water either in the fuel, or produced from the combustion of the hydrogen in the fuel, always decreases the achievable thermal efficiency due to the latent heat of the steam in the exhaust gases. However, the overall effect of added water on efficiency can be significantly minimised in internal combustion engines.

It is noted that water is routinely added to diesel engines for NOx emissions control – up to 50% by weight of the fuel (equivalent). Methods include adding water to fuel to create oil-water emulsions, direct injection of water into the cylinder, or even more effectively by scavenge air moisturisation (ie evaporating salt water into the inlet air to feed the cylinders with relatively warm (70°C) saturated air). The effect on efficiency is small, usually less than 0.5% points, and in the case of scavenge air moisturisation, nil.

For MRC, given a modest fuel preheat (and taking into account the higher hydrogen content of fuel oil relative to coal and other carbons, and the higher oxygen content of coal), the efficiency penalty is expected to be between 1-2% points relative to diesel fuel. This still provides DICE with a step increase in efficiency over conventional coal steam plants.

It is noted that the previous USDOE program fuelling medium speed 4-stroke engines with MRC containing 50% water showed little or no measurable effect on thermal efficiency compared to diesel fuel.

16. Doesn't micronising use a lot of energy?

In summary, the energy penalty is small, with significant potential for this to be reduced.

Nearly all solid fuels are micronised to some degree before combustion (eg coal is milled to a mass mean size of around 65-70 μm for boilers). For DICE, extra fine micronising is required, with a mass mean size of around 15 μm being required. This increases the energy penalty for milling and results in a loss of thermal efficiency of around 0.6% points due to micronising – about 3x that for coal fired boilers.

It is expected that future DICE will accept a coarser grind (especially for brown coals) which should reduce this penalty by as much as 50%.

Given other process penalties, the micronising energy penalty for DICE is considered acceptable. For example, current dry cooling of pf steam generation plant reduces the efficiency by 1.5-2% points, and a similar efficiency penalty can accrue from emissions control.

17. What is the recovery of during the coal cleaning?

In summary, the recovery is high, and MRC can be produced from current waste products.

Coal recovery is dependent on the cleaning methods used, and the overall production mix of the preparation plant. For flotation, a combustible recovery of around 85% is achievable in producing MRC. However, this does not necessary mean a loss of 15% of the recoverable coal, as the tailings streams from the MRC cleaning steps can be utilised for higher ash products. In addition, MRC can also be produced from tailings, which effectively increases the overall grade recovery.

The reason for the increase in combustibles recovery is due to micronising, which significantly increases the separation of mineral matter from the coal.

Overall combustibles recovery should therefore be higher for MRC production than from the production of conventionally washed coal products.

18. Why has the meaning of DICE and MRC been changed to refer to carbon fuels?

A key advantage of DICE is the potential to efficiently utilise a range of biomass, which could include treated biomass, biochars and algal residues. Acceptable ignition of biochar has been confirmed in recent tests by the CSIRO, especially if ignition is sweetened with a small addition of coal. Therefore, as DICE has the potential to use a range of coals, lignites, biomasses, together with tar residues, the original terminology of "coal engine" has been broadened to include any solid carbon-based fuel to become the "carbon engine".

19. Why is DICE being redeveloped when development was terminated in the early 1990s?

Earlier development of DICE was driven by the cost and availability of diesel fuel for heavy transportation and small scale generation, using relatively small medium-high speed engines. This is a difficult application leading to increased technical issues and higher fuel processing costs, which became marginal when the diesel price dropped in the early '90s. DICE is being redeveloped with new environmental, economic and energy security drivers, and with technology not available to the earlier developments.

The present interest is DICE has many advantages over the earlier USDOE program.

- Better and much larger mills (halves milling cost)
- Fine coal cleaning technology
- New dispersants (more effective)
- Larger engines (3x larger)
- New materials and manufacturing methods
- Electronic engine control (easier to optimise for different fuels, including auto tuning ability of individual cylinders).
- Many new drivers, including willingness to pay more for higher efficiency, changes to the supply industry, gross changes to the demand profile, water constraints.

DICE also has greater development potential than pf technology which is has reached the metallurgical limits even with large amounts of exotic alloys. Large engine design is presently limited by the market for marine engines – very low speed to drive single propellers and be speed flexible.

20. What are the main technical challenges for DICE and how are they being de-risked?

The USDOE program clearly demonstrated that the main technical issues were providing efficient and consistent atomisation of MRC, and armouring the engine against abrasive wear. Engineering solutions were demonstrated for both of these issues for medium speed 4-stroke engines with over 1,000 hours of engine operation, and over 100 hours of continuous operation, without any indication of potential longer term issues such as engine fouling by ash. The success of the earlier developments has been acknowledged by the main engine companies MAN and Wärtsilä, who strongly believe that DICE can be commercialised, given the appropriate resources to implement improved engineering solutions.

De-risking is being achieved by a staged development program starting with atomisation and pilot engine tests prior to small scale demonstration.

It has been deemed by a wide range of experts in MAN, Wärtsilä, RWE, and the USDOE that the technical issues around DICE can be solved by suitable engineering. Useful recent examples include:

- The injection valves for gas engines initially had a service life of only 1-2,000 hours (around 2005) - after several years of development these valves now achieve over 16,000 hours (the standard time between engine freshening services); a 8x improvement.
- The atomiser nozzles for slurry fed gasifiers originally had a service life of only a few hundred hours – current GE designs last over 1,200 hours; a 3x improvement.
- At the beginning of the DOE DICE program an injector tip would last less than an hour – within a few years this life had been extended to over 2,000 hours; a 2000x improvement.

However, this requires the commitment of an engine OEM, which in turn requires the commitment of the coal industry.

21. What about fouling?

This has received scant attention, probably because ash fouling has not been reported as an issue. A complete lack of fouling is unexpected, as coal cleaning processes only remove the extraneous mineral components in coal, leading to flyash with proportionally higher amounts of deleterious elements (Na, K, S, Cl, Ca, Mg) from the original coal – a condition certain to cause fouling in combustion devices (and which does occur in boilers using coal water mixtures). However, past engine tests totalling several thousand hours, including continuous operation periods of over 100 hours, have not observed cylinder or turbocharger fouling. Compared to boilers (and gas turbines), the lack of fouling has generally been attributed to the highly cyclic heat flux within reciprocating engines: cylinder surfaces are only exposed to gases (say above 800°C) for ~10% of the cycle, and the temperature of the metal surfaces is lower (mostly below 300°C). It is also noted that the lack of fouling from coal in diesel engines was the main reason for terminating development of the coal fired gas turbine in favour of the diesel engine in the late 1970s - which resulted in the comprehensive USDOE coal engine program (see extract below):

Clean-Coal Diesel Development at Cooper-Bessemer leading to this Demonstration Project

From 1985 to 1993, Cooper-Bessemer conducted extensive research and development work to burn coal-based fuel in a diesel engine, under the sponsorship of Morgantown Energy Technology Center (now part of NETL) of the U.S. Department of Energy, and in cooperation with Arthur D. Little, Inc., and other leading U.S. companies. The research work on a single-cylinder research engine between 1985 and 1988 firmly established the feasibility of burning Coal Water Fuel (CWF), which is a mixture of equal parts by weight of finely powdered coal and water. This led to undertaking a five-year project in 1988 to develop a six-cylinder 1800 kW pre-production version of the diesel engine to operate on CWF. This project which was completed in 1993 yielded very encouraging results:

- Cooper's 1800 kW and 200 kW research engines were operated for over 1200 hours, developing full power with good fuel consumption, without any deposits inside the engine. Fuel injectors performed flawlessly on the very challenging coal slurry fuel.
- New technologies were developed to protect sensitive engine components such as piston rings, valves and turbocharger rotors from the wear due to constituents in the coal.
- A full scale emissions control system demonstrated the ability to reduce NO_x, SO_x, and particulate emissions to levels significantly below current and anticipated future regulatory limits.

22. Is MRC or DICE subject to IP constraints?

No. MRC can be produced from black coal by a range of commercial processes, all well known to the coal industry and not subject to IP constraints. Similarly for the engine: while there are many patents concerning engine technology from the USDOE program over 1978-94, all are expired.

However, it is expected that new IP will be developed for technology across the fuel cycle as DICE is commercialised under the current range of new drivers.

23. What is DICEnet?

DICEnet (www.dice-net.org) is an umbrella organisation which supports the development of DICE as the internationally preferred stationary electricity generation technology, via the:

- Development of DICE fuels utilising abundant and low-cost coal reserves and biomass.
- Demonstrating low market entry cost through modularisation and using standard engine technology.
- Demonstrating the CO_2 emissions and other environmental credentials of DICE.
- Demonstration of DICE as a complementary generation partner with load variable and distributed renewable energy sources.