Latest Developments in Low GWP Working Fluids for Heat Pump Applications

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ABSTRACT

Due to the growing global concerns around the environmental impact of use of refrigerants with relatively high global warming potential and/or ozone depletion, such as R-22, new working fluids with the positive attributes of both high thermal performance and low environmental impact are currently in development. These refrigerants exhibit promising performance when compared with refrigerants currently used in reversible AC heat pumps or in water heating heat pumps, such as R-410A and R407C. Replacements of common HFC refrigerants such as R-410A and R-407C are discussed for Air-to-Water heating and Air-to-Air reversible heat pump applications. Thermal properties as well as experimental results in such systems are presented, showing the benefits of using these new working fluids.

Keywords: Refrigerants, Global Warming, Hydro-fluoro-olefins

1 INTRODUCTION

Increasing concerns about the warming of the earth has spurred on development of working fluids that have significantly lower impact on climate change. Many fluids are being evaluated in the broad range of refrigeration and air conditioning applications. This paper will discuss very promising low global warming refrigerants for Air-to-Water heating and Air-to-Air reversible heat pump applications.

2 WORKING FLUIDS

Depicted in Table 1 are options we have identified to replace existing higher GWP refrigerants showing both single component refrigerants and blends. In the case of the blends, there are two series of products being developed, the “N” series consists of reduced GWP refrigerants that offer considerable reduction in GWP relative to the refrigerant(s) it replaces and are non-flammable. These options have the potential to be used in existing systems. Another series (“L” series) consist of the lowest GWP offerings but are mildly flammable. These might be used, for instance, in new equipment designed and installed to address any flammability issue. Among these options are both single component refrigerants and blended refrigerants.

The single component refrigerants 1234yf and/or 1234ze(E) show potential when utilized in systems that have employed R-134a. Another molecule, 1233zd(E) shows potential as a replacement for R-123 in low pressure centrifugal chillers. To better suit the operating characteristics of refrigerants such as R-404A, R-22, and R-410A, refrigerant blends were developed. These HFO/HFC refrigerant blends can provide a better performance match with existing refrigerants, and still offer a GWP reduction of 75% to 95%.

Table 1.Honeywell's Refrigerants Options

Current Product		Non Flammable (ASHRAE A1)	Mild Flammable (ASHRAE A2L)	Possible Applications
Single Component	**HFC-134a** (GWP=1300)		**1234yf** (GWP<1)	Auto AC, Vending, Refrigerators
Single Component	**HFC-134a** (GWP=1300)		**1234ze(E)** (GWP<1)	Chillers, CO_2 Cascade, Refrigerators
Single Component	**R-123** (GWP=79)	**1233zd(E)** (GWP=1)		Centrifugal Chillers
Blends	**HFC-134a** (GWP=1300)	**N-13** (GWP=547)		Chillers, Med-temp Refrigeration
Blends	**HCFC-22** (GWP=1760)	**N-20** (GWP=891)	**L-20** (GWP=295)	AC, Heat Pumps, Refrigeration
Blends	**R-404A** (GWP=3943)	**N-40** (GWP=1273)	**L-40** (GWP=285)	Refrigeration
Blends	**R-410A** (GWP=1924)		**L-41** (GWP=572)	AC, Heat Pumps

3 AIR-TO-AIR HEAT PUMP APPLICATIONS

Two series of tests were conducted. The first one tested L-41 as an R410A replacement for ductless split systems (sometimes referred to as mini-splits). The second tests evaluated L-20 as and R22/R407C replacement in a ducted split system typically used in North America.

3.1 Testing of Ductless Split (RAC) Heat Pump using R-410A

The ductless split system was a DC inverter RAC reversible heat pump unit with a nominal cooling capacity of 3587 W. The nominal heating capacity was 4995 W. The test conditions were based on ISO standard 5151 [1] and are shown in Table 3.

Table 2. RAC System Test Conditions

Operating Conditions (Cooling Mode)					
Test Condition	**Indoor Ambient**		**Outdoor Ambient**		**Compressor speed**
	DB (ºC)	**WB (ºC)**	**DB (ºC)**	**WB (ºC)**	
cool-01(T1 rating, **moderate** climate)	27	19	35	24	rated
cool-02(T1 Intermediate)	27	19	35	24	half
*cool-03(T2 rating, **cool** climate)*	*21*	*15*	*27*	*19*	*rated*
*cool-04(T3 rating, **hot** climate)*	*29*	*19*	*46*	*24*	*rated*

Operating Conditions (Heating Mode)					
Test Condition	**Indoor Ambient**		**Outdoor Ambient**		**Compressor speed**
	DB (ºC)	**WB (ºC)**	**DB (ºC)**	**WB (ºC)**	
Heat-01 (**High** Temp. rating)	20	<15	7	6	rated
Heat-02 (high Temp. intermediate)	20	<15	7	6	half
Heat-03 (**Low** Temp. rating)	20	<15	2	1	rated
*Heat-03 (**Extra Low** Temp. rating)*	*20*	*<15*	*-7*	*-8*	*rated*

This heat pump was tested at the conditions indicated above. All tests were performed inside environmental chambers equipped with instrumentation to measure both air-side and refrigerant-side parameters. Refrigerant flow was measured using a coriolis flow meter while air flow and capacity was measured using an air-enthalpy tunnel. All primary measurement sensors were calibrated to ±0.25°C for temperatures and ±0.25 psi for pressure. Experimental uncertainties for capacity and efficiency were on average ±5%. Capacity values represent the air-side measurements, which were carefully calibrated using the reference fluid (R-410A). L-41 was tested in this system along with R-410A which is used as baseline.

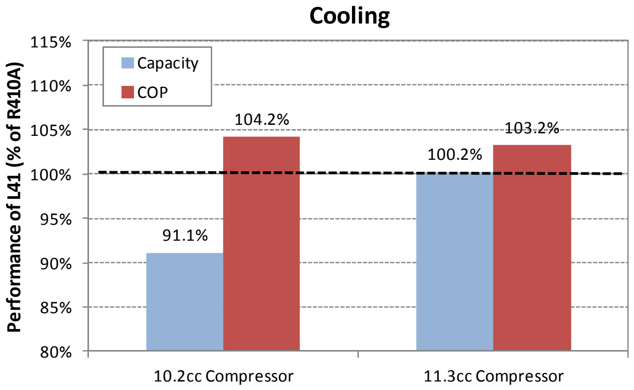

Figure 1. Cooling mode results (35°C ambient)

Figures 1 and 2 show results at two conditions: 35°C ambient for cooling and 7°C ambient for heating. The L-41 results show improved efficiency in both cooling and heating relative to the baseline refrigerant however the capacity using the nominal compressor (10.2cc displacement) was lower. Slightly increased compressor displacement would be needed for capacity to match the baseline refrigerant. To evaluate the performance with a larger displacement, we used an 11.3cc displacement compressor.
Capacity and efficiency results are shown and indicate that performance now nearly matches that of R-410A. As depicted in Figure 3, discharge temperatures are slightly higher (~11°C) still well below the maximum permissible for that compressor.

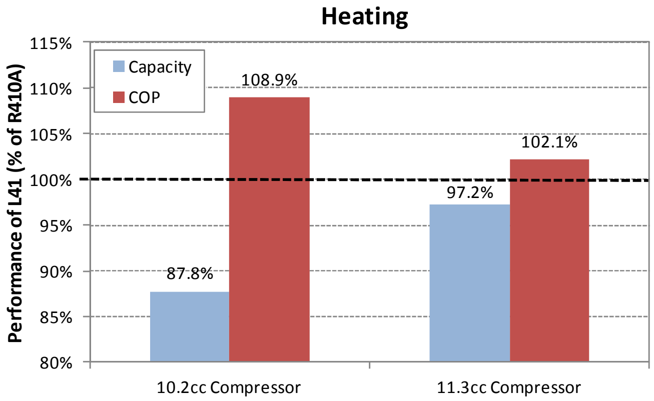

Figure 2. Heating mode results (7°C ambient).

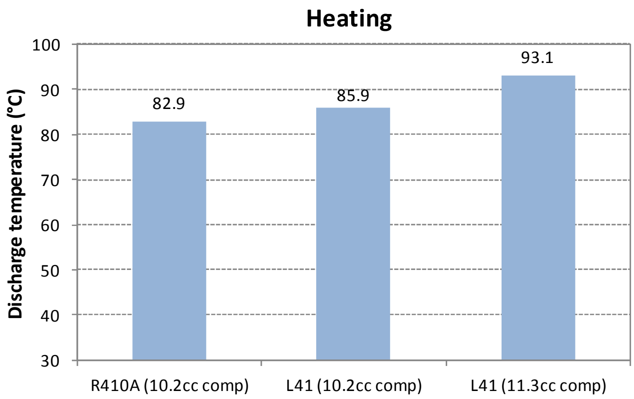

Figure 3. Discharge temperature for heating mode.

3.1.2 Refrigerant/Oil miscibility

In the system heat exchangers and connecting piping, the refrigerant is transported around the system and moves into and out of the liquid phase as it absorbs and rejects heat. Under ideal conditions, the refrigerant and lubricant are completely miscible with one another, and flow together as a single liquid phase in the liquid line, and in the suction line the refrigerant returns as a vapor with a liquid oil rich lubricant. Unfortunately, under some conditions the refrigerant and lubricant are not completely miscible and the liquid refrigerant and lubricant-rich phases separate – a condition described as immiscibility. If this immiscibility occurs in the evaporator, it is possible that the lubricant rich-phase will accumulate in void regions and may not return to the compressor, or may not return until enough oil is present that a liquid slug surges back to the compressor, potentially destroying the compressor and rendering the system inoperable. Therefore, it is desirable that any low temperature immiscibility occurs only below temperatures typically encountered in the evaporator, for instance below approximately 0°C for air conditioning applications, so that the refrigerant is able to push the lubricant through the evaporator and back to the compressor.

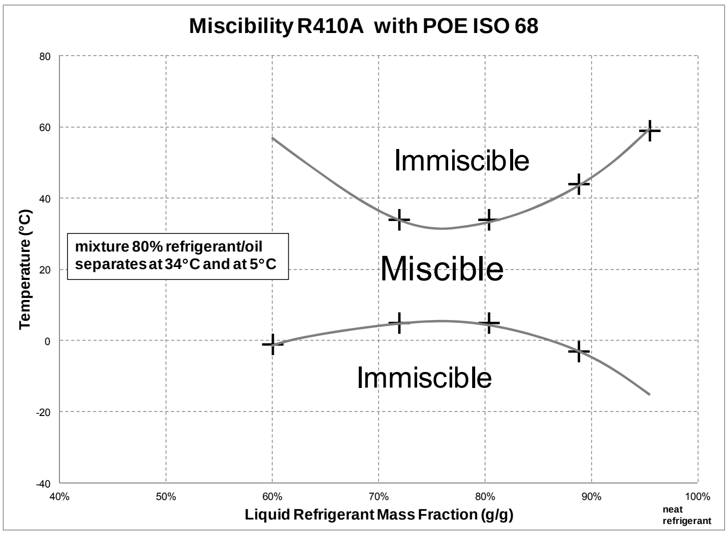

Figure 4. Miscibility of R410A with POE oil (ISO 68).

As seen in Figure 4, R410A is miscible with the POE 68 tested over a range of temperatures, and as seen in Figure 6, L-41 is miscible with POE 68 over an even wider range of temperatures. Unfortunately, Figure 5 illustrates that R32 is not miscible in the evaporator and extra safety considerations through engineering design will be necessary to properly safeguard the system.

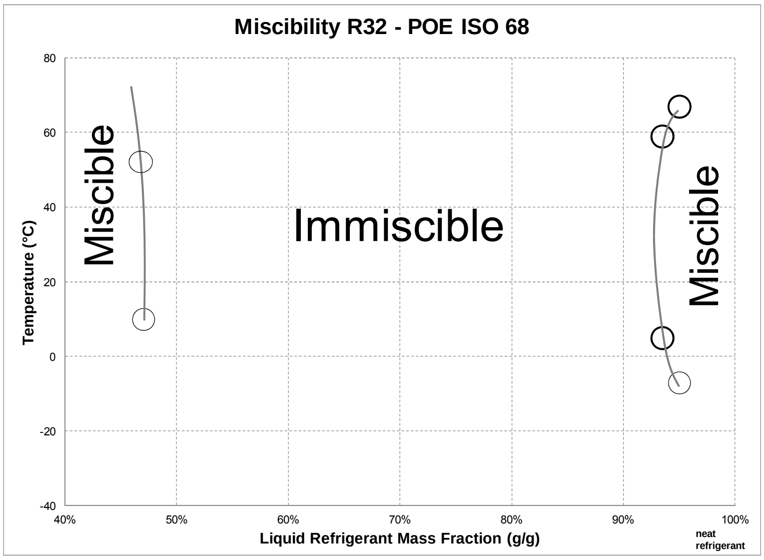

Figure 5. Miscibility of R32 with POE oil (ISO 68).

In the condenser, it is also generally desirable to have miscibility at concentrations greater than 95% refrigerant at the highest operation temperature (which can be up to 60°C for AC application), so as refrigerant condenses (for instance with an oil circulation ratio below 5%) the lubricant dissolves in the refrigerant and passes through the expansion valve and does not accumulate. If the oil circulation rate exceeds the lubricant miscibility concentration, accumulation of lubricant in the high pressure side of the system may take place and cause the lubricant level in the compressor to drop. This drop of oil level in the compressor may starve the bearings and permanently damage the compressor. Figures 4-6 show that R410A, R32 and L-41 meet the requirement for oil logging in compressors that have less than 5% OCR in AC operation.
Figure 6 shows results for L-41. There is no immiscible region for temperatures above a -20°C and below +70C. This should improve the operation of heat pumps at low ambient (winter) where such evaporation temperatures exist. On the other hand, R32 heat pumps would probably need an alternative lubricant and/or other system modification to accommodate the immiscibility, causing additional development and productions costs.

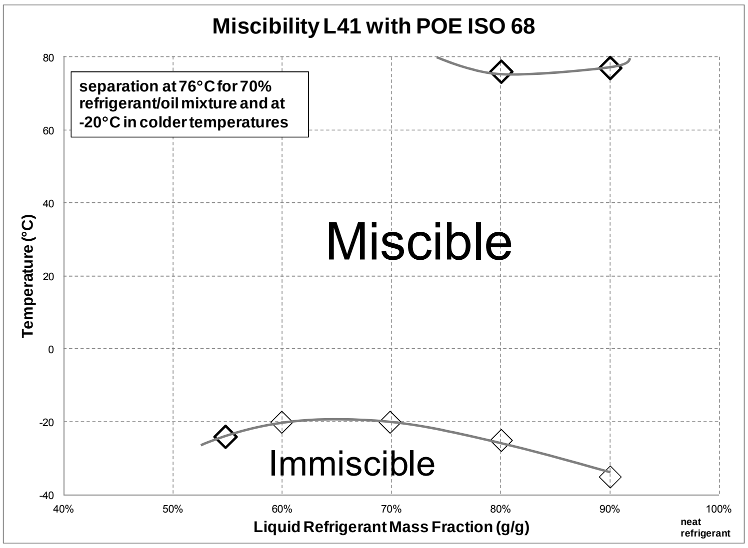

Figure 6. Miscibility of L41 with POE oil (ISO 68).

Overall, L-41 shows potential advantages and seems to be a good choice to replace R-410A as its performance is close to that of R-410A. Any slight differences seen in performance can be eliminated with minor system changes such as the slight increase in compressor displacement. This performance can be achieved without concern of high discharge temperature, and with a GWP of less than 600; this is a considerable reduction in GWP as compared to R-410A (more than 70%). In addition, it appears to have advantageous miscibility with existing POE lubricants than other alternatives discussed.

3.2 Testing of Ducted Split Heat Pump using L-20

A ducted reversible heat pump with a 3-ton (10.5 kW) cooling capacity, an efficiency rating of 13 SEER (3.8 seasonal COP), a heating capacity of 10.1 kW and an HSPF of 8.5 was used for this evaluation. This system was originally designed for R-22 but was converted to R-407C, which serves as the baseline refrigerant. R-407C was selected since R-22 has already been phased out for new equipment in many countries. No changes were made the equipment so these tests are basically drop-in ones.
In addition to R-407C, a lower GWP alternative, L-20, was evaluated. L-20 is a refrigerant blend with a GWP under 300 that is mildly flammable with an expected flammability classification of “2L”. The GWP reduction from R-407C is greater than 80% with performance characteristics nearly identical to that of R-407C.
All tests were performed inside environmental chambers equiped with instrumentation to measure both air-side and refrigerant-side parameters. Refrigerant flow was measured using

a coriolis flow meter while air flow and capacity was measured using an air-enthalpy tunnel designed according to industry standards [2],[3]. All primary measurement sensors were calibrated to ±0.27ºF (0.15ºC) for temperatures and ±0.25 psi for pressure.

Table 5 shows the results of this heat pump operating in cooling mode tested at conditions reported in Table 3. This alternative operates with cooling efficiencies at or slightly above that of R-407C with acceptably low discharge temperatures. L-20 also matches the cooling capacity of R-407C. Heating mode results are also depicted on Table 5 with basically very similar results as those seen in cooling mode. L-20 again shows nearly identical heating capacity and efficiency performance to R-407C.

Table 5. System test results.

Refrigerant	Characteristics		Cooling			Heating Rating (8°C ambient)	
	GWP	Glide (°C)	Capacity (35°C)	Efficiency (28°C)	Disch. T. (35°C)	Capacity	Efficiency
R407C	1624	4.8	100%	100%	76	100%	100%
L-20	295	7.0	101%	100%	82	102%	101%

A low global warming refrigerant candidate was evaluated with promising results. L-20 with a GWP less than 300 (>80% reduction from R-407C) achieved comparable efficiency and capacity as the baseline refrigerant. It would be considered a LGWP refrigerant option for systems that are designed to use either R-22 or R-407C and applied in locations that can safely use a mildly flammable refrigerant.

4 AIR-TO-WATER HEAT PUMP APPLICATIONS (HYDRONIC SYSTEMS)

These types of heat pumps are used for floor heating or similar applications. Current systems employ R410A as refrigerant. Typical operating conditions [1] require the water delivered at 35ºC (standard rating) with a ΔT of 5ºC after passing through the floor heating system. Outdoor ambient temperature varies from 7ºC (standard rating) to -15ºC (lowest rating value).

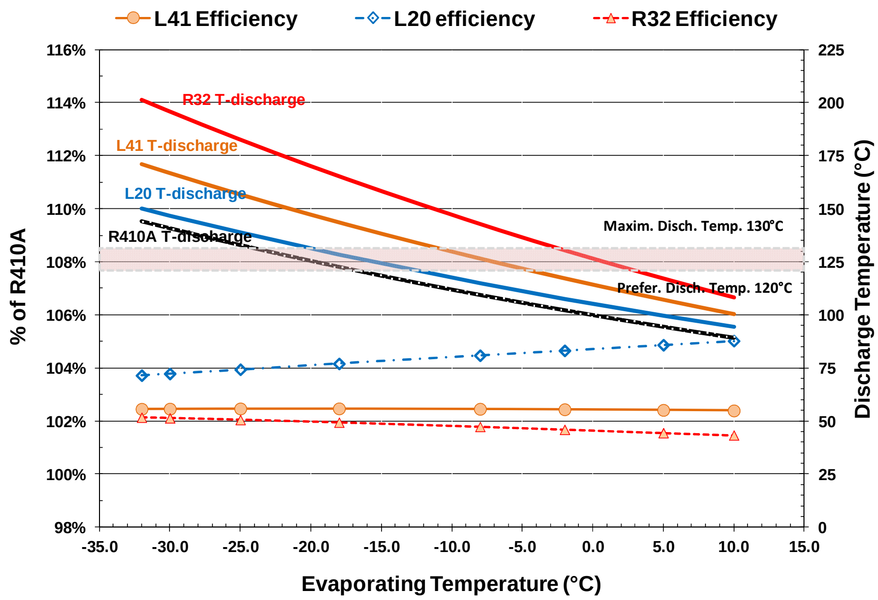

Figure 7. Standard system results

Low ambient temperatures represent a challenge for the performance (capacity, efficiency) and reliability (discharge temperature) of the system. Most compressor manufacturers have a maximum temperature limit of 130ºC with a preferred value of 110ºC.

Simulations were carried out for two types of systems: 1) A typical system with a standard compressor, 2) An advanced system equipped with a vapor injected compressor. Vapor injected systems would typically allow to extend the system operating envelope by improving efficiency and reducing discharge temperature. Refrigerants considered were R410A as baseline, R32, L-41 and L-20.

Figure 7 shows results for a standard compressor system. Condensing temperature was kept constant at 45ºC to represent a standard rating of 35ºC with 10ºC TD. Evaporating temperatures were varied from 10ºC to -30ºC which with a 6ºC TD would represent outdoor ambient temperatures of 16ºC to -24ºC. Compressor isentropic efficiency was assumed as 60%.
The results show all refrigerants providing reasonable efficiency with anadvantage for L-20 (4% better than R410A) over L-41 and R32 (2% better than R410A) in that order. Further examination of discharge temperature shows R32 limited to an evaporation temperature of -2ºC (4ºC outdoor), while L-41 goes down top -10ºC (-4ºC outdoor) and L-20 follows closely R410A with -20ºC (-14ºC outdoor). L-20 seems to be a choice that would extend significantly the operating envelope.

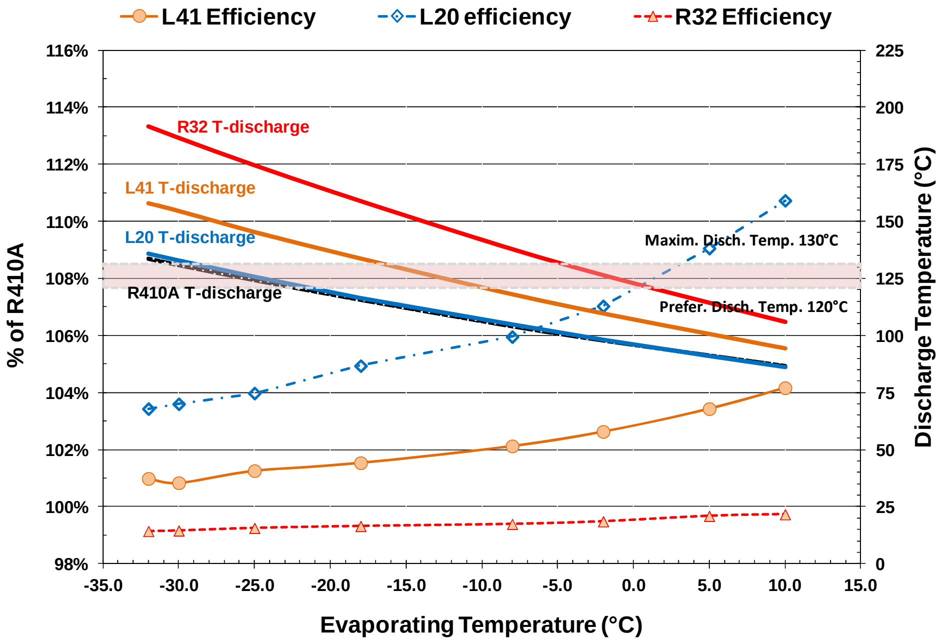

Figure 8. Evaluations for a vapor injected system.

Further evaluations of a vapor injected system are shown in figure 8. Additional assumptions were need so we used compressor isentropic efficiencies of 60% for each stage, while the heat exchanger effectiveness was of 80%. The performance of L-20 is significantly better than R410A and any other alternative (4% to 8%), while L-41 is better than R410A (1% to 4%), and R32 matches R410A. Additional examination of discharge temperature shows R32 limited to an evaporation temperature of -5ºC (1ºC outdoor), while L-41 goes down top -16ºC (-10ºC outdoor). L-20 follows closely R410A with -28ºC (-22ºC outdoor) limit. These initial evaluations show L-20 as having the largest potential not only to match operating envelope but to give better energy efficiency.

5 CONCLUSIONS

Recently developed low global warming refrigerant blends may have the potential to provide significant advantages in air conditioning heat pump systems that currently utilize current high GWP refrigerants, such as R-410, R-22 or R-407C. Comparable performance to existing refrigerants can be achieved in applications investigated to date without significant hardware modification. In addition, other aspects such as miscibility with existing lubricants and operating temperatures indicate a real advantage over other potential refrigerants

Experimental and theoretical evaluations of L-41 and L-20 show the promise of effective and efficient low GWP refrigerants for heat pumps. The reversible air-to-air heat pumps were evaluated experimentally, while the air-to-water heat pumps evaluations were done through simulations. Further work will be helpful to more fully explore options and advantages in these applications. This would include additional performance evaluations and more in depth understanding of the miscibility with lubricants, as well as conducting further flammability risk assessments where appropriate.

REFERENCES

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