The Investigation of the performance of poly(phenylene) based anion exchange membranes (AEMs) in a direct methanol fuel cell is reported. The fuel cell performances were tested with different anode gas diffusion layers as a function of concentrations of fuel and electrolyte using two commercially available platinum catalysts supported on carbon. Normalized current density values demonstrated good performance for a poly(phenylene) AEM, with a cation consisting of six methylene spacers attached to a trimethyl ammonium group, with a maximum current density of 11.8 mA cm$^{-2}$ mg$^{-1}$ in a KOH free fuel. The platinum catalyst (46%) from Tanaka showed a better performance (10.4 mA cm$^{-2}$ mg$^{-1}$) compared to the platinum catalyst from E-TEK (5.1 mA cm$^{-2}$ mg$^{-1}$) in 1M methanol fuel feed under identical conditions. We observed that the MEA with a Zoltek gas diffusion layer on the anode showed the best performance (226 mA cm$^{-2}$ and 53.8 mW cm$^{-2}$) in the presence of KOH, suggesting that a hydrophilic gas diffusion layer plays a significant role in improving the fuel cell performance. A durability test for a MEA in 1M methanol and 1M KOH for 67 h showed an overall degradation rate of 400 μV h$^{-1}$.

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compatible with TMAC6PP while allowing for greater transport of water and methanol within the electrodes. Because it is designed to transport methanol easily, TMAC6PPC6 is obviously not used as a membrane to avoid problems with methanol crossover. Like ATMP, TMAC6PPC6 is soluble in neat methanol and this helps to incorporate the ionomer in the catalyst ink.

A summary of the properties of the membranes used in this study is shown in Table I. The ionomers used in this study in membrane form, ATMP and TMAC6PP have the same IEC value, 2.4 meq/g. The two ionomers used in this study, in solution form for electrode preparation, TMAC6PPC6i and TMAC6PPC6h, are made to achieve two different IECs, Table I. The lower IEC ionomer, TMAC6PPC6i (IEC: 2.13 meq/g) with a low water uptake, 121% was synthesized for use in the cathode catalyst ink, whereas the high IEC ionomer, TMAC6PPC6h (IEC: 2.60 meq/g) with a relatively high water uptake, 190% was prepared for use in the anode catalyst ink. The chloride ion conductivities were measured in liquid water at 25°C and the values of all the four ionomers are very close. Hydroxide ion conductivity of ATMP membranes in carbon dioxide free pure nitrogen as a function of temperature showed an increasing trend with a maximum of 86 mS cm\(^{-1}\) at 90°C and 95% RH. Under similar conditions, the bromide and carbonate forms of the membrane exhibited conductivities of 13 and 16.6 mS cm\(^{-1}\) respectively. The hydroxide, bromide, and carbonate ion conductivities of TMAC6PP are 17, 29 and 34 mS cm\(^{-1}\) respectively at the lower temperature of 80°C. Interestingly TMAC6PP exhibits a very high carbonate conductivity. In this paper we now report the fuel cell performance of the characterized AEMs for an alkaline direct methanol fuel cell. In general, catalyst inks were made by mixing 50% Pt/C (TEC10E50E, Tanaka Kikinzoku Kogyo) and 20% Pt/Vulcan XC72R (E-TEK). Millipore water, isopropanol and ATMP or TMAC6PPC6 ionomer (3% solution in methanol) with a catalyst to ionomer ratio of 4:1. An ionomer solution was obtained by dissolving the membrane in methanol. Catalyst inks were painted on 5.48 cm\(^2\) GDLs to obtain a loading of 1.4 mg of Pt cm\(^{-2}\) with the E-TEK catalyst and 2.5 mg of Pt cm\(^{-2}\) with the Tanaka catalyst. The electrodes were hot pressed on ATMP or TMAC6PP membranes using a digital combo multi-purpose press, DC14, Geo Knight & Co. Inc at 66°C and 80 psig for 90s. Prior to any tests, MEAs were soaked in 1M NaOH for 2h to convert the membrane from the Br\(^{-}\) form to OH\(^{-}\) form. Following this, MEAs were subsequently soaked in water with frequent changes of water to ensure complete removal of NaOH as indicated by a neutral pH of the washings. For better understanding, the components of all four MEAs are listed in Table II.

Fuel cell testing.— Single cell hardware from fuel cell technologies, Inc with a working area of 5.48 cm\(^2\) and single serpentine flow fields was used. The supplied anodized aluminum endplates were replaced with stainless steel end plates to withstand the alkaline conditions. The effluent from the fuel cell reaches the back pressure regulators, followed by a water trap which separates out any condensed liquid in the exit lines. An isocratic HPLC pump (Chromtech)
was used to pump the methanol solution or methanol in KOH solution to the anode. Oxygen is fed to the cathode through a modular gas handling/gas metering system (Lynntech Industry, Inc.) through a humidity bottle maintained at 80°C. The purge gas N₂ and flow rate of O₂ was controlled using FC power software (Lynntech Industry, Inc.). The fuel and oxygen flow rates were set to 0.5 ml min⁻¹ and 0.2 L min⁻¹ respectively in this study.

A MSTAT4+ multi-potentiostat (Arbin Instruments) was used to conduct polarization experiments. The polarization curves were obtained by stepping down the potential from open circuit potential until the limiting current was achieved. In situ impedance spectra were measured potentiostatically at different potentials on the polarization curve using a Gamry Instruments potentiostat. The frequencies were varied between 100,000 and 0.1 Hz with the data points being 10 per decade. The ac voltage was 10 mV root mean squared.

**NMR product analysis.—** Quantitative ¹³C-{¹H}-NMR spectroscopy was performed on fuel cell effluent samples using a JEOL ECA 500 MHz spectrometer. A 150 s relaxation delay with 150 scans was used and the results were referenced to tetramethylsilane (TMS). A known concentration of 1,4 Dioxane, used as an internal standard, Chromium (III) acetylacetonate, used as a relaxation agent for quantitative results, and deuterated dimethyl sulfoxide (DMSO-D₆), used as a lock compound, were added to the sample.

**Results and Discussion**

In order to benchmark the two AEMs, we made four MEAs (MEAs: 1-4), two with the TMAC66PP membrane and two with the ATMPP membrane and investigated their methanol fuel cell performances. The fuel cell test was repeated with three sets of the same MEA¹⁻² to understand the reproducibility of the measurement. Details of the MEA components are given in Table II. The high IEC ionomer, TMAC66PPC6h and the low IEC ionomer, TMAC66PPC6l were used on the anode and cathode respectively, TMAC66PPC6h with a higher water uptake was used to increase the hydrophilicity of the anode thereby enhancing the diffusion of aqueous electrolyte and methanol; whereas the low water uptake TMAC66PPC6l was used to help reduce the flooding on the cathode.¹³¹⁴ The performance did not show significant change in magnitude when the methanol flow rate was varied from 0.5 and 1.2 ml min⁻¹. Usually, AEMs are operated at low temperatures, below 60°C to avoid any decomposition of the cationic ammonium group. For the materials studied here it has been demonstrated that the materials have adequate stability for our three day fuel cell testing protocol. The TMAC66PP did not degrade and the ATMPP polymer degraded slowly at 90°C in 4M KOH for 14 days showing 8.3% and 33% loss in conductivity after 1 and 14 days respectively.²⁶ However, the membranes remained flexible and tough throughout the test. Also, when operated at elevated temperatures, electrode kinetics can be improved with reduced thermodynamic voltage losses.³ For this reason all experiments in this study were performed at 80°C and 100% RH.

The polarization curves (I-V characteristics) and the power densities for the methanol oxidation. We used a hydrophilic Zoltek carbon cloth in MEA-1. As expected, OCV of MEA-1 improved by 20 mV, with a 1.1 fold increase in the current and power densities for the hydrophilic Zoltek anode GDL containing MEA-1 as compared to MEA-2 with a hydrophobic anode GDL (Figure 2 and Table III). The maximum current and peak power densities were 29.5 mA cm⁻² and 3.97 mW cm⁻² for MEA-1 and 26.7 mA cm⁻² and 3.6 mW cm⁻² for MEA-2. From the curves, it can also be realized that the ATMPP based MEA-3 & 4 exhibit OCVs of 0.5 and 0.46 V, which is lower than 0.56 and 0.54 V obtained for MEA-1 and 2 respectively. To see if this is an effect of the membrane, we examined MEA-2 and MEA-3 which are identical except for the polymer used (Table II). The results demonstrated a slightly higher OCV (40 mV) and better performance for the TMAC66PP containing MEA-2 than for the ATMPP MEA-3 (Table III). The peak power densities were 3.6 and 3.1 for MEA-2 and MEA-3 respectively indicating better performance for TMAC66PP over ATMPP. This result agrees with the observation from Hibbs where stable conductivity was observed for TMAC66PP with only 5% drop in conductivity over 1 week, but a gradual decrease of about 33% was observed for ATMPP.²⁰

To examine the effect of catalyst, identical MEAs (MEA-3 and MEA-4) that differ only by the catalysts were tested. It can be observed that the OCV dropped to 0.46 V; giving rise to a decreased Pt normalized current density of 5.14 mA cm⁻² for MEA-4. The Tanaka catalyst (MEA-3) achieved 10.4 mA cm⁻² which is two folds better than the E-TEK catalyst (MEA-4). In neat methanol with no hydroxide ions in the fuel, the performances appear to be unaffected by the anode gas diffusion layers. Our values are superior to the values (0.15 to 0.3 mW cm⁻²) obtained with a commercial Fumattech FAA-2 in different concentrations of methanol.¹⁵ Our MEAs also perform better than a QPVA/SiO₂/GA membrane which obtained 0.18 or 0.27 mW cm⁻² in 2M methanol.³² The maximum power data (3.97 mW cm⁻²) for MEA-1 is still lower, however, than the performance (~ 8.5 mW cm⁻²) observed for an ETFE based AEM by Varcoe and Slade at 80°C with 2 and 2.5 bar back pressures at the anode and cathode respectively.¹⁸ The best data, 3.97 mW cm⁻² and 29.5 mA cm⁻², with our current AEMs in a KOH free fuel appears better than the data obtained from a commercial Morgane, ADP-Solvay membrane which yielded a performance of 5.54 mW cm⁻² and 32.6 mA cm⁻² in 2M methanol that contained 1M NaOH.³³ In 2M Methanol, with a platinum catalyst containing NCNT of 4 mg cm⁻², a peak power

**Table II. Details of the components used in the fabrication of the MEAs.**

| MEA  | Anode Catalyst | Anode GDL  | Anode Ionomer | Cathode Catalyst | Cathode GDL  | Cathode Ionomer | AEM  |
|------|----------------|------------|---------------|-----------------|--------------|----------------|------|
| MEA-1| Pt/C, Tanaka   | Zoltek     | TMAC66PPC6h   | Pt/C, Tanaka   | E-TEK        | TMAC66PPC6l   | TMAC66PP |
| MEA-2| Pt/C, Tanaka   | E-TEK      | TMAC66PPC6h   | Pt/C, Tanaka   | E-TEK        | TMAC66PPC6l   | TMAC66PP |
| MEA-3| Pt/C, Tanaka   | E-TEK      | ATMPP         | Pt/C, Tanaka   | E-TEK        | ATMPP         | ATMPP |
| MEA-4| Pt/C, E-TEK    | E-TEK      | ATMPP         | Pt/C, E-TEK    | E-TEK        | ATMPP         | ATMPP |

**Figure 2. DMAFC performance curves for all four MEAs in 1M CH₃OH at 80°C, 100%RH:** MEA-1, MEA-2, MEA-3, MEA-4, open symbols represent power density curves.
density of 5 mW cm\(^{-2}\) and 0.217 V OCV was obtained. Our current data is certainly better for a KOH free fuel compared to this result obtained in the presence of 2M NaOH using a Nafion 117 membrane as a fuel cell separator.\(^{13}\)

In general, AEM fuel cells show improved performance in the presence of hydroxide ions in the fuel as methanol oxidation requires a stoichiometric amount of hydroxide ions (6). In addition, the presence of hydroxide ions certainly improves the conductivity and flushes out any carbonate/bicarbonate formed in the electrode from the reaction of the product carbon dioxide with the hydroxide. The aim of the paper is to baseline the performance of AEM fuel cells, and the addition of KOH to these systems is technologically important using commercially available membranes.\(^{3,11,13-16,31,34,35}\) We further studied the high performing MEA-1 & 2 for fuel cell performance studies in the presence of KOH. Figure 3 demonstrates the fuel cell performances of MEA-2 in the presence of an alkaline electrolyte as a function of methanol and KOH concentrations. We observed a significant difference in the performance when KOH is added to the fuel supply. Comparing the performance of 1M MeOH-1M KOH (Figure 3) to 1M MeOH (Figure 2) anode feed for MEA-2, the OCV increased from 0.54 V to 0.75 V with a four fold increase in the current density in the presence of 1M KOH. With a constant methanol concentration (1M) and different KOH concentrations (0.5M to 2M), the OCV remained unaltered, showing differences in the current and power densities. From 0.5 to 1 M KOH/1 M methanol, there was no difference in the performances up to 20 mA cm\(^{-2}\), but significant improvement was evident thereafter in the medium to high current density regions. The peak power densities were 16.1 and 25.0 mW cm\(^{-2}\) for 0.5 and 1 M KOH with 1M methanol respectively with the maximum current densities being 80 and 125 mA cm\(^{-2}\) for 0.5 and 1M KOH respectively. This observation agrees with the fact that increased electrolyte concentration would increase ionic conductivity in the electrode. A further raise to 2M KOH in the fuel did not yield any better performance, but the values were close to 1M KOH in 1 M methanol. The peak power densities were 16.1, 25.0, and 24.2 mW cm\(^{-2}\) for 0.5, 1, and 2M KOH respectively. The current densities were 80, 125, and 117 mA cm\(^{-2}\) for 0.5, 1, and 2M KOH respectively with 1 M methanol. The effect of electrolyte concentration has been demonstrated to attain a peak performance at a specific OH\(^{-}\) concentration by different researchers between 3 M and 8 M.\(^{36-38}\) The reason for low performance at a high OH\(^{-}\) concentration has been attributed to electrolyte viscosity, electrolyte resistance, and/or pore blockage due to K\(_2\)CO\(_3\) precipitation. In the current study, this limitation due to OH\(^{-}\) concentration is observed at with 1 M methanol at 2M KOH.\(^{36}\) With 1M MeOH-1M KOH as the baseline, increasing the fuel concentration to 2M methanol resulted in lower performance. Loss in performance and reduced OCVs (0.68 and 0.62 for the 2M-1M and 2M-2M respectively) could be related to the relatively higher methanol crossover at higher concentrations of methanol.

In their work, Scott et al. reported an increase in performance when the methanol concentration was increased from 1 to 2 M but again a drop in the performance when raised further up to 4 M using an alkaline ADP membrane.\(^{39}\) In similar work, Prakash et al. observed a decrease in performance when the methanol concentration was increased to 2 M using an alkaline Tokuyama membrane.\(^{14}\) When compared to the control 1M MeOH-1M KOH, the current and power densities of 2M MeOH-1M KOH were 2 times reduced while the 2M MeOH-2M KOH showed 1.8 times less current and power density. The OCV, maximum current density and peak power density for 2M-1M were 0.68 V, 60.0 mA cm\(^{-2}\) and 12.0 mW cm\(^{-2}\) while for 2M-2M these values were 0.62 V, 68.1 mA cm\(^{-2}\) and 13.6 mW cm\(^{-2}\). Based on the above observation, the study on the effect of fuel and electrolyte concentration demonstrated the highest peak power and maximum current densities at 1M MeOH-1M KOH with 25 mW cm\(^{-2}\) and 125 mA cm\(^{-2}\) respectively (Table IV).

We also investigated the effect of fuel and electrolyte concentrations on the performance for MEA-1 with a hydrophilic anode GDL (Figure 4). While there was only slight improvement in the use of aqueous methanol as the fuel for MEA-1 over MEA-2, in the presence of KOH, considerably higher performance was observed for MEA-1 compared to MEA-2 with a hydrophobic GDL (Table IV). While there is no significant increase in OCV when the KOH concentration was raised from 0.5 M to 1M, relatively better current and power densities were observed. The maximum current and peak power densities obtained in 1 M KOH are 226 mA cm\(^{-2}\) and 53.8 mW cm\(^{-2}\), compared

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**Table III. ADMFC performances in 1M Methanol at 80°C, 100% RH.**

| MEA  | OCV (V) | Current density at 0.1 V (mA cm\(^{-2}\)) | Current density at 0.1 V (mA cm\(^{-2}\) mgPt\(^{-1}\)) | Peak Power density (mW cm\(^{-2}\)) |
|------|---------|----------------------------------------|----------------------------------------|--------------------------|
| MEA-1| 0.56    | 29.5                                   | 11.8                                   | 3.97                     |
| MEA-2| 0.54    | 26.7                                   | 10.68                                  | 3.6                      |
| MEA-3| 0.5     | 26.0                                   | 10.4                                   | 3.1                      |
| MEA-4| 0.46    | 7.2                                    | 5.14                                   | 0.85                     |

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**Figure 3.** DMAFC performances of MEA-2 as a function of the concentrations of methanol and KOH (△: 1M-1M; ▽: 1M-0.5M; ▼: 2M-1M; ■: 2M-2M; ●: 1M-2M).

**Figure 4.** DMAFC performances of MEA-1 as a function of concentrations of methanol and KOH at 80°C, 100%RH (△: 1M-1M; ●: 1M-2M; ▽: 1M-0.5M; ▼: 2M-1M; ■: 2M-2M).
to 190.3 mA cm$^{-2}$ and 45.5 mA cm$^{-2}$ for a 0.5 M KOH. A further rise to 2 M resulted in a performance decline, with an 80 mV loss in OCV, a maximum current density of 212.9 mA cm$^{-2}$ and a peak power density of 50.4 mW cm$^{-2}$ were achieved. As observed in MEA-2, increasing the methanol concentration to 2 M resulted in poor performances with the lowest being 2 M MeOH in 2 M KOH. The OCVs, current densities and power densities were 0.84V, 166.4 mA cm$^{-2}$ and 43.4 mW cm$^{-2}$ for 2 M MeOH and 1 M KOH and 0.74V, 100.3 mA cm$^{-2}$ and 20.0 mW cm$^{-2}$ for 2 M MeOH and 2 M KOH. In the presence of KOH, the hydrophilic carbon cloth GDL (Zoltek) at the anode generated a significant improvement in the performance. The best performances of MEA-1 and MEA-2 were observed in 1 M MeOH-1 M KOH with a two-fold increase in power density for MEA-1.

In the literature, it has been demonstrated that a hydrophobic cathode and hydrophilic anode enhance the fuel cell performance. It was shown by Kim et al., that hydrophobicity decreases the methanol exposure to the catalyst.\textsuperscript{13} Similarly, in their study Suryaprakash et al., have shown that a hydrophilic anode GDL would enhance the diffusion of aqueous electrolyte and methanol and a hydrophobic cathode GDL would prevent flooding at the cathode.\textsuperscript{14} Our results agree with this observation, MEA-1 with the hydrophilic Zoltek GDL at the anode generated a significant improvement in the performance. The best performances of MEA-1 and MEA-2 were observed in 1 M MeOH-1 M KOH with a two-fold increase in power density for MEA-1.

The voltage lost after 67 h corresponded to an overall degradation rate of 400 mV h$^{-1}$. Considering the harsh chemical conditions of the test, this is still encouraging as the voltage did not degrade rapidly to zero and further refinement of operating conditions is expected to result in further improvements in stability. In comparison, Varcoe et al., demonstrated a degradation rate of 95 ± 10 mV h$^{-1}$, i.e. ca. $\frac{1}{2}$ the degradation rate of our cell for a 233h ADMFC test with a cross-linked AEM in a KOH free fuel at 50°C.\textsuperscript{21}

Nyquist plots of the fuel cell as a function of potential were produced from electrochemical impedance spectroscopy (EIS) performed in situ under fuel cell operation (Figure 6). Impedance spectra studied on MEA-1 in a KOH free methanol fuel at 80°C as a function of d.c. potentials at OCV, ca. 0.3 V, and 0.2 V is shown in Figure 6. The data did not appear to be Kramers-Kronig consistent,\textsuperscript{41} presumably because even though the voltage degradation rate appears manageable, the baseline of the EIS measurement was changing over the time scale of the experiment, 2-3 hours. We were able to measure the internal cell resistance and charge transfer resistances from the EIS.\textsuperscript{12,37} The internal cell resistance that includes ohmic resistances from the membrane, electrode, and their interfaces are measured from the high frequency x-axis intercepts.\textsuperscript{25} The charge transfer resistances ($R_{ct}$) have been calculated from the intercept of the arc and the real impedance axis. At all potentials, one large arc was seen, that was shallower than a perfect semicircle indicating that the electrodes are micro porous which would approximate a constant phase element in an equivalent circuit. The potential dependent arc tends to reach the x-axis as the cell potential is decreased down from open circuit voltage (OCV) to 0.2 V. Except the cell potential, all other components and conditions are the same for all the plots. Hence, this can be attributed to the charge transfer resistance on the electrodes as a function of the cell potential. At open circuit voltage, when no current is drawn, as
anticipated the charge transfer resistance was at its maximum, 3.0 \( \Omega \text{ cm}^{-2} \). When the cell potential was stepped down, due to increasing current density and decreasing overpotential, the charge transfer resistances decreased down from 3.0 \( \Omega \text{ cm}^{-2} \) at OCV to 0.8 \( \Omega \text{ cm}^{-2} \) at 0.2 V. The second aspect examined from all the spectra is the cell resistance at the high frequency intercept; this is an indication of the ohmic internal resistance of the fuel cell. The ohmic internal resistance is a sum of resistances from various fuel cell components. It was observed to be almost the same at all potentials (Table V). This is to be expected owing to identical components in the fuel cell at all potentials.

\(^{13}\)C\(^{1}\)H\(^{1}\)-NMR liquid state spectroscopy on the fuel cell effluent (Figure 7) with an anode solution containing 1M Methanol and 1M KOH shows that CO\(_3^{2-}\) is the only product of the methanol oxidation detected in the fuel cell effluent under these conditions. The overall fuel cell reaction (Equation 3) in an alkaline direct methanol fuel cell can be determined by the anode (Equations 1) and cathode (Equation 2) half reactions 3.

**Anode**: \( \text{CH}_3\text{OH} + 6\text{OH}^- \rightarrow \text{CO}_2 + 5\text{H}_2\text{O} + 6\text{e}^- \) \[1\]

**Cathode**: \( \frac{3}{2}\text{O}_2 + 3\text{H}_2\text{O} + 6\text{e}^- \rightarrow 6\text{OH}^- \) \[2\]

**Overall cell reaction**: \( \text{CH}_3\text{OH} + \frac{3}{2}\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O} \) \[3\]

The carbonate we observed in the product is a result of reaction in [Equation 4], where CO\(_2\) reacted with OH\(^-\) resulting in carbonate formation.

**Carbonate formation**: \( 2\text{OH}^- + \text{CO}_2 \rightarrow \text{CO}_3^{2-} + \text{H}_2\text{O} \) \[4\]

A galvanostatic fuel cell test using MEA-2 with 100 mL of 1M MeOH-1M KOH analyte solution was run at a potential of 400 mV until all of the reactant solution had passed through the fuel cell in ca. 1h.\(^{43}\) Quantitative NMR analysis on the effluent using 1,4 dioxane as an internal reference, was used to close the mass balance to 95%, indicating that a total of 13.5% of the methanol was converted to carbonate. The gaseous CO\(_2\) from the effluent is probably not fully accounted for in this NMR study. In the liquid effluent, NMR has detected only 13.5% of CO\(_2\) which was converted to CO\(_3^{2-}\). Further diagnostics are required to account for the gaseous products. Future work will include a detailed study on methanol oxidation products from this DMAFC work using online GC and more optimized MEAs with non-precious metal catalysts.

### Table V. Resistance values from Impedance spectra for MEA-1 in a KOH free methanol fuel at 80°C.

| Cell Potential (V) | High Frequency Intercept (m\(\Omega\) cm\(^{-2}\)) | \(R_d\) (\(\Omega\) cm\(^{-2}\)) |
|------------------|---------------------------------|-----------------|
| OCV              | 28.6                            | 3.0             |
| 0.4              | 26.6                            | 1.7             |
| 0.3              | 26.1                            | 1.0             |
| 0.2              | 26.4                            | 0.8             |

**Conclusions**

The current work was focused on benchmarking the DMFC performances of two AEMs and a new ionomer developed at Sandia National Laboratories using commercial platinum catalysts. Preliminary studies using these newly developed AEMs suggest that they are potential candidates for ADMFCs. Normalized current density values demonstrated good performance for the poly(phenylene) AEM, with a cation consisting of six methylene spacers attached to a trimethyl ammonium group, with a maximum current density of 11.8 mA cm\(^{-2}\) mg\(^{-1}\) in a KOH free fuel. However, the use of KOH free fuel and these AEMs in ADMFCs was not sufficient to achieve practical levels of performance. Additions of KOH lead to significant improvement in the performance. Study of the performance of the fuel cell as a function of GDL hydrophobicity was investigated with two different GDLs. The results demonstrated that a hydrophilic anode GDL and hydrophobic cathode GDL give the best performance. We observed that the MEA with a hydrophilic Zoltek gas diffusion layer on the anode showed the best performance (226 mA cm\(^{-2}\) and 53.8 mW cm\(^{-2}\)) in the presence of KOH, suggesting that a hydrophilic gas diffusion layer plays a significant role in improving the fuel cell performance. While the fuel cell still showed a measurable rate of degradation under these conditions, an overall degradation rate of 400 \(\mu\)V h\(^{-1}\) during a durability test for a typical MEA in 1M methanol and 1M KOH was observed over 67 h. These results are encouraging.

**Figure 7.** \(^{13}\)C\(^{1}\)H\(^{1}\) NMR spectra of the anode solution of a DMFC after running a galvanostatic experiment at a voltage of 400 mV using 1M MeOH-1M KOH.
for further developments in this technology using these AEM and ionomer chemistries.

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