The floating zone image furnace is an ideal tool to grow micrometre to millimetre sized metal-oxide crystals. During crystal growth there is no contact with crucibles or quartz/platinum tubes, minimising the formation of impurities. The rapid cooling of the melt produces quenching conditions, allowing synthesis of crystals that do not form with slow cooling; e.g. crystals within the solid-solution range. Here we report the use of the floating zone image furnace technique to grow single crystals of the δ-Bi$_2$O$_3$-related solid-solution phases of nominal composition Bi$_8$Nb$_2$O$_{17}$, Bi$_{5.6}$WO$_{11.4}$, Bi$_{16}$Ta$_2$O$_{19}$ and Bi$_{38}$Mo$_7$O$_{78}$. The Bi$_{5.6}$WO$_{11.4}$ and line phase Bi$_{38}$Mo$_7$O$_{78}$ single crystals were analysed with synchrotron and laboratory based X-ray diffraction to determine metal cation positions and neutron diffraction to determine the oxygen anion positions. The diffraction methods are also applied to the 3-D incommensurately modulated structures of Bi$_8$Nb$_2$O$_{17}$ and Bi$_{16}$Ta$_2$O$_{19}$. There are challenges encountered in these latter complicated structures; e.g. integration of the collected ‘6-D’ data and subsequent refinements. Each sample studied presents different methods of approaching the structural solutions. The ability to grow single crystals of the Bi-rich transition-metal oxides and solve these structures, highlight the potential for the exploration of phase diagrams by the use of the floating zone technique.