Since work is $W = F_x \Delta x$, we can define the kinetic and potential energies in the usual way for $\mathbf{E}$ fields, using $F_x = qE_x$. Then $\Delta KE = +qE_x \Delta x$ and $\Delta PE_e = -qE_x \Delta x$.

When a positive charge moves along an $\mathbf{E}$-field vector, its $KE$ increases and its $PE_e$ decreases. Similarly, when a negative charge moves along an $\mathbf{E}$-field vector in the opposite direction to the field, its $KE$ increase and its $PE_e$ decreases.

We can as usual define a conserved total energy $\mathcal{E} = KE + PE_e$.

The most useful thing to define is the electric potential, which is the potential energy per unit charge, with units of $\text{J/C} = \text{Volts}$. Note then that $\Delta V = -E_x \Delta x$. For this reason the unit of $\mathbf{E}$ is often written as $V/m$, Volts per meter.

For example, if a charge $-q$ (where $q = 1 \text{ C}$) moved from a region of zero Volts to a region of $+6 \text{ V}$, it would gain 6 Joules of $KE$, while a charge of $+q$ would lose 6 Joules of $KE$. 
Because the electrical force is so huge, in comparison to everyday forces, a potential difference of a few tens of thousands of volts will accelerate an electron to almost the speed of light!

The standard unit of energy used in physics is the electron volt, which is the energy an electron would gain in falling through a potential difference of 1 Volt. Clearly this is $1.6 \times 10^{-19}$ Joules. The most commonly encountered unit in particle physics is the MeV, which is $10^6$ eV.

**Potential of a point charge:**

$$V(r) = \frac{k_e Q}{r}.$$  

Since $V$ is a scalar, for a system of charges, $V = \sum_{i} V_i$. No worries about vectors, which is why physicists prefer to work with PE instead of forces. Note the PE between two charges, $q$ and $Q$, a distance $r$ apart, is

$$PE_e = \frac{k_e qQ}{r}.$$  

Conductors and Potential:

When we have a conductor in equilibrium, any net charge is entirely on the surface, and the field $\mathbf{E} = 0$ everywhere inside the conductor.

This means that the potential $V$ everywhere inside the conductor is a constant, and is equal to the potential on the surface of the conductor. No matter what the shape of the conducting surface, $V$ is the same at every point on the surface.
Capacitance!

\[ C = \frac{Q}{\Delta V}. \]

The unit of \( C \) is a Farad, in honor of Faraday. Since a Coulomb is an enormous amount of charge, the usual capacitors have values that are a very tiny fraction of a Farad. A microFarad capacitor is huge and very difficult to make.

**Parallel Plate Capacitor:**

\[ C = \frac{\varepsilon_0 A}{d}. \]

**Capacitors in Parallel:**

\[ C_{\text{tot}} = \sum_i C_i. \]

**Capacitors in Series:**

\[ \frac{1}{C_{\text{tot}}} = \sum_i \frac{1}{C_i}. \]
ENERGY STORED IN CAPACITOR

\[ W = E_c = \frac{1}{2} C \Delta V^2 = \frac{1}{2} \frac{Q^2}{C}. \]

EFFECT OF DIELECTRIC

\[ C = \kappa C_0. \]

\[ C = \kappa \frac{\varepsilon_0 A}{d} = \frac{\varepsilon A}{d}. \]

\( \kappa \) can range from very slightly greater than 1, to 100 or more!