the residence time of the feedstock in the pyrolysis unit. Temperature itself can have a large effect on the relative proportions of end product from a feedstock (Fig. 1.9).

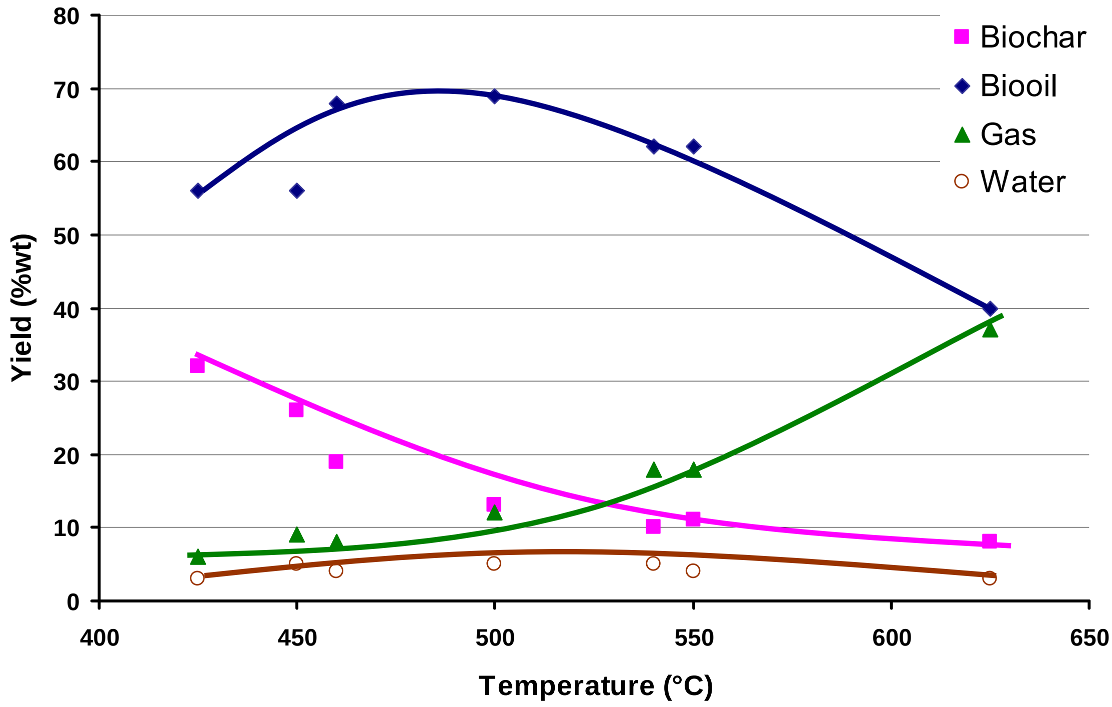

Figure 1.8 A graph showing the relative proportions of end products after fast pyrolysis of aspen poplar at a range of temperatures (adapted from IEA, 2007)

Residence times of both the solid constituents and the hot vapor produced under pyrolysis conditions can also have a large effect on the relative proportions of each end product of pyrolysis (Table 1.1). In the nomenclature, four different types of pyrolysis are generally referred to, with the difference between each being dependent on temperature and residence time of solid or vapour in the pyrolysis unit, or a combination of both. The four different types of pyrolysis are fast, intermediate and slow pyrolysis (with slow pyrolysis often referred to as "carbonisation" due to the relatively high proportion of carbonaceous material it produces: biochar) along with gasification (due to the high proportion of syngas produced).

Table 1.1 shows that different pyrolysis conditions lead to different proportions of each end product (liquid, char or gas). This means that specific pyrolysis conditions can be tailored to each desired outcome. For example, the IEA report (2007) stated that fast pyrolysis was of particular interest as liquids can be stored and transported more easily and at lower cost than solid or gaseous biomass forms. However, with regard to the use of biochar as a soil amendment and for climate change mitigation it is clear that slow pyrolysis, would be preferable, as this maximises the yield of char, the most stable of the pyrolysis end products.

Table 1.1 The mean post-pyrolysis feedstock residues resulting from different temperatures and residence times (adapted from IEA, 2007)

Mode	Conditions	Liquid	Biochar	Syngas
Fast pyrolysis	Moderate temperature, ~500°C, short hot vapour residence time of ~ 1 s	75%	12%	13%
Intermediate Pyrolysis	Moderate temperature ~500°C, moderate hot vapour residence time of 10 – 20 s	50%	20%	30%
Slow Pyrolysis (Carbonisation)	Low temperature ~400°C, very long solids residence time	30%	35%	35%
Gasification	High temperature ~800°C, long vapour residence time	5%	10%	85%

Owing to the fact that end products such as flammable gas can be recycled into the pyrolysis unit and so provide energy for subsequent pyrolysis cycles, costs, both in terms of fuel costs, and of carbon emission costs, can be minimised. Furthermore, the pyrolysis reaction itself becomes exothermic after a threshold is passed, thereby reducing the required energy input to maintain the reaction. However, it is important to note that other external costs are associated with pyrolysis, most of which will be discussed in Section 2.4. For example, fast pyrolysis requires that the feedstock is dried to less than 10% water (w w^{-1}). This is done so that the bio-oil is not contaminated with water. The feedstock then needs to be ground to a particle size of *ca.* 2 mm to ensure that there is sufficient surface area to ensure rapid reaction under pyrolysis conditions (IEA, 2007). The grinding of the feedstock, and in some cases also the drying require energy input and will increase costs, as well as of the carbon footprint of biochar production if the required energy is not produced by carbon neutral sources.

As well as different pyrolysis conditions, the scale at which pyrolysis is undertaken can also vary greatly. The two different scales discussed throughout this report are that of ‘Closed’ *vs* ‘Open’ scenarios. Closed refers to the scenario in which relatively small, possibly even mobile, pyrolysis units are used on each farm site, with crop residues and other bio-wastes being pyrolysed on site and added back to the same farm’s soils. Open refers to biowastes being accumulated and pyrolysed off-site at industrial scale pyrolysis plants, before the biochar is redistributed back to farms for application to soil. The scales at which these scenarios function are very different, and each brings its own advantages and disadvantages.

1.7 Feedstocks

Feedstock is the term conventionally used for the type of biomass that is pyrolysed and turned into biochar. In principle, any organic feedstock can be pyrolysed, although the yield of solid residue (char) respective to liquid and gas yield varies greatly (see Section 1.6.2) along with physico-chemical properties of the resulting biochar (see Chapter 2).

Feedstock is, along with pyrolysis conditions, the most important factor controlling the properties of the resulting biochar. Firstly, the chemical and