# Biomass Process Flow Calculations

by

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1.0    PURPOSE

1.1    The purpose of this Design Course is to provide a systematic method for process flow design calculations for biomass and similar projects. This guideline is mainly applicable to the dry processing portion of a project.  For example, on a biomass to liquids project, it would be applicable only to the delivery, storage and preparation of biomass and may not be applicable to the fuel conversion process.  For a wood pellet plant, it would be applicable from start to finish of the process.  These calculations are intended to be done on Excel spreadsheets.

2.0    ABSTRACT

2.1    Biomass projects require specialized calculations to determine expected and design flowrates for overall process design and for sizing of equipment.  The calculations are complicated by the fact that moisture contents, bulk densities and operating hours may vary as material moves through the process.

2.2    The process may be schematically represented as a "Block Flow Diagram", or as a "Process Flow Diagram".  In the case of the Block Flow Diagram, the diagram may be part of the Excel spreadsheet, and the entire task is performed by an engineer. In the case of the Process Flow Diagram, the engineer will perform the calculations, to be inserted into the drawing by the designer or drafter, generally in the lower area of the drawing.  The spreadsheet is inserted as a "live" document that is, automatically updated when the drafter opens the drawing.

3.0    BLOCK DIAGRAMS VS. PROCESS FLOW DIAGRAMS

3.1    The difference between block flow diagrams and process flow diagrams is mainly one of detail.  The process flow diagram will have more detail than the block flow diagram.

3.2    Block Flow Diagram (BFD)

3.2.1  Purpose is to represent the client's wishes in an easily understood diagram.

3.2.2  Processing centers are grouped into blocks.  Conveyors are not shown.

3.2.3  Flow between blocks and branch flows are shown with labeled flow identifiers.

3.2.4 Input at each flow identifier:

    a.     Annual Uptime Hours—This is scheduled time minus expected downtime. See Discussion in Section 5.

    b.     Bulk Density—Preferred density is on oven-dry basis. See discussion in Section 5.

    c.     Moisture Content—Normally biomass companies use wet-basis moisture content. See discussion in Section 5.

3.2.5 Calculated values at each flow identifier:

    a.     Annual Fiber Flow
    b.     Annual Wet Basis Flow
    c.     Hourly Dry Basis Flow
    d.     Hourly Wet Basis Flow
    e.     Hourly Volumetric Flow
    f.     Storage Weight and Volume where Required

3.3 Process Flow Diagram (PFD)

3.3.1 Purpose is to identify each major piece of equipment and to provide enough data to size the equipment. This approach allows systematic and easily identified equipment sizing criteria.

3.3.2 Each piece of equipment including conveyors is shown in symbolic form. Normally the symbols are the same as would be used on a Piping and Instrument Diagram (P&ID) and are pre-drawn as autocad blocks.

3.3.3 Flow identifiers between equipment are shown to verify flows, to parse out flows between processing units and as a calculation aid.

3.3.4 Flow identifiers attached to the equipment are for sizing equipment.

3.3.5 Input at each flow identifier:

    a.     Annual Uptime Hours—This is scheduled time minus expected downtime. See discussion in Section 5.

    b.     Bulk Density—Preferred density is on oven-dry basis. See discussion in Section 5.

      c.      Moisture Content—Normally biomass companies use wet-basis. See discussion in Section 5.

      d.      Design Factor—This is a multiplier that is applied to the average calculated flow that is used to specify the equipment. See discussion in Section 5.

    3.3.6  Calculated values at each flow identifier:

      a.      Annual Fiber Flow
      b.      Annual Wet Basis Flow
      c.      Hourly Dry Basis Flow
      d.      Hourly Dry Basis Flow, Design
      e.      Hourly Wet Basis Flow
      f.      Hourly Wet Basis Flow, Design
      g.      Hourly Volumetric Flow
      h.      Hourly Volumetric Flow, Design
      i.      Storage Weight and Volume where Required

3.4    Drawing Sequence

    3.4.1  The Block Flow Diagram should be performed and approved by the Client before any other drawings are started. It will be started after a Design Criteria is created.

    3.4.2  The Process Flow Diagram will be done somewhat concurrently with the General Arrangement Drawings as they affect each other.

4.0    <u>DESIGN PROCESS</u>

4.1    Usually, the material balance calculation will begin at the end of the process, or close to the end where a single stream of finished product can be identified. This is because the Client has identified a process goal in terms of finished product output, and it is the Engineer's job to help him to achieve this and to identify material inputs and equipment requirements to achieve this goal. The annual production flow is normally given by the client on a wet basis. It must be shown as wet basis, but corrected to oven-dry basis.

4.2    The material balance calculations are done on an annual, oven-dry basis. Changes in moisture content and uptime hours are accounted for separately at each flow identifier. This renders material balances generally very straight forward, easy to check, and easy for the client to follow.

4.3    All calculations at each flow identifier are based on the annual oven-dry flow and are all done the same way.  Therefore, each column, headed by a flow identifier can be simply copied to an adjacent column.  The material balance calculation is adjusted as required by the process.  Then the input variables (annual uptime hours, bulk density, moisture content and design factor) are adjusted appropriately.

EXAMPLE:

| Flow Identifier: | | | 2 |
|---|---|---|---|
| Annual Uptime Hours: | hr | | 7500 |
| Bulk Density, Dry Basis: | PCF | | 9.0 |
| Moisture Content | % | | 8.0% |
| Design Factor | | | 1.33 |
| | | | |
| **Annual Flow, DB** | **MT/YR** | | **520,353** |
| Annual Flow, WB | MT/YR | 520,353/(1-.08)= 565,560 | |
| Hourly Flow   , DB | MT/HR | 520,353/7500 = | 69.4 |
| Design Flow, DB | MT/HR | 69.4 X 1.33 = | 92.3 |
| Hourly Flow   , WB | MT/HR | 565,560/7500 = | 75.4 |
| Design Flow, WB | MT/HR | 75.4 X 1.33 = | 100.3 |
| Volumetric Flow, Design | CF/HR | 92.3 x 2204 / 9.0 = 22,603 | |

Notes:
- Metric tons (2204 pounds/ton) are often used by clients with European delivery contracts.
- DB means "Dry Basis", WB means "Wet Basis".
- Volumetric flow is the same whether calculated wet basis or dry basis as long as bulk density basis is consistent.  This is because the moisture has minimal effect on volume.
- Fiber flow represents flow on an oven-dry basis.  Wet flow is fiber flow with moisture included.
- The calculations above are done as formulas in Excel spreadsheet cells.  The Annual Flow, DB is calculated as a multiple of another cell and is the basis of the material balance.  Cells below this are calculated based on the Annual Flow, DB and the data above this cell.  As a result, columns can be copied and only the Annual Flow, DB calculation changed.  The input data is changed to reflect characteristics of the process at the particular flow location.

4.4    Storage:  There will usually be several places in the process where material is temporarily stored in open piles, silos, bins, etc.  The storage requirement is usually provided by the Client in terms of hours or days of storage.  The block flow or

process flow diagram should identify these and include a calculation of total volume and weight of material stored. The Client should clarify whether his storage requirement is "full-to-empty" or if it is between two operational points in the storage unit. Calculation columns for storage are handled separately in the spreadsheet.

4.5    Dryers: Dryers are handled somewhat differently. Here, the main problem is usually to predict the fuel flow to the dryer. Often, when tree stems are being processed, this will be supplied partly from bark from the debarker and partly from purchased fuel. The oven-dry flow of dryer furnish into the dryer is equal to the flow leaving the dryer. The wet-basis flow is reduced however, due to elimination of water. The difference in annual wet-basis flow represents the annual moisture removal. Dryer suppliers will normally provide a rating in terms of Btu, hot gas entering the dryer, per pound of moisture evaporated. This is usually about 1600 to 1700 for Btu/pound for green wood chips dried in rotary drum dryers. The flow of bark to the dryer is calculated based on the oven-dry heating value of the bark, corrected for moisture content. Annual purchased fuel becomes the difference between fuel requirement and fuel supplied by the debarker from purchased tree stems.

EXAMPLE:

| | | |
|---|---|---|
| Fuel Higher Heating Value | BTU/LB | 8,900 |
| Loss due to Hydrogen Combustion | BTU/LB | 660 |
| Fuel Lower Heating Value (typ. For pine bark) | BTU/LB | 8,240 |
| Fuel Moisture Content | % | 50% |
| Heat to Evap Fuel Moist | BTU/LB | 1116 |
| Effective Heat Value | BTU/LB | 8,240-(1-.5)/.5x 1116 = 7,124 |
| Dryer Heat Required (Provided by Dryer Mfg) | BTU/LB | 1600 |
| | | |
| Flow to Dryer , Wet | MT/YR | 940,000 |
| Flow from Dryer, Wet | MT/YR | 522,222 |
| Bark Fuel to Dryer, Dry | MT/YR | |
| | (940,000-522,222) x 1600/7124 = | 93,829 |

Notes:
- Lower heating value of fuel is used. This is because the dryer temperature remains above the temperature required to condense water vapor formed in

combustion of hydrogen in the fuel. To understand the difference between lower and higher heating values, consider that the combustible elements in most fuel are mainly carbon and hydrogen. To test for heating value, a sample of the fuel is burned in an oxygen bomb calorimeter. The amount of heat released is determined by the temperature rise of a water jacket surrounding the sample. Since the final temperature is only a few degrees above the initial temperature, the water formed in the combustion of the hydrogen portion of the fuel must condense and in doing so, release its heat of vaporization to the water jacket. The resulting calculation yields the "higher heating value", and this is the value that is often found in fuel tables. The "lower heating value" is calculated from a knowledge of the fraction of the total sample weight that is comprised of hydrogen. In most dryer applications, the water formed in combustion of hydrogen does not condense, and therefore the associated heat of vaporization is not available for drying.

- Calculation assumes a direct-fired dryer. All of the heat from fuel combustion enters the dryer.
- Heat to evaporate moisture includes heat to raise water temperature from initial fuel temperature to dryer exit temperature cannot be recovered. Assuming initial fuel temperature of 80F and dryer exit of 240F, then:

$$(212-80)1 + 970 + (240-212).49 = 1116$$

Where 1.0 and 0.49 are the heat capacities of water and steam, respectively. The heat required to evaporate water at atmospheric pressure is found in steam tables to be 970 BTU/LB.

## 5.0   NOTES ON INPUT DATA

### 5.1   Uptime Hours

5.1.1   Typical Calculation

| | |
|---|---|
| Days per year available: | 365 |
| Less Holidays: | -7 |
| Less Planned Down Days | -7 |
| Planned Operating Days | 365 -7 -7 = 351 |
| Planned Hours per Day | 24 |
| Planned Hours per Year | 351x24 = 8,424 |
| Expected Uptime Rate | 0.9 |
| Expected Uptime Hours | 8,424x.9 = 7,582 |

5.1.2  Typical Processing Center Rates

|  | Hours/Day | Day/Week | Uptime Rate |
|---|---|---|---|
| Shipping and Receiving | 8-12 | 5-6 | 100% |
| Log Processing | 8-12 | 5-6 | 80% |
| Dryer | 24 | 7 | 95% |
| Main Processing Area | 24 | 7 | 90% |

5.2    Moisture Content

5.2.1  There are two ways to refer to moisture content in the wood products industry:

Dry Basis        $MC_{db} = W_w/W_{od}$

Wet Basis        $MC_{wb} = W_w/(W_w + W_{od})$

Where:
    $W_w$ = weight of water in a sample.
    $W_{od}$ = weight of oven-dry wood in a sample.

To convert one to the other:

$MC_{wb} = MC_{db}/(1+MC_{db})$

Or:

$MC_{db} = MC_{wb}/(1-MC_{wb})$

Dry basis moisture content is used mainly by solid wood processors such as sawmills and plywood plants.  Biomass facilities usually use wet basis moisture content, but it is a good idea to be conversant in both and be sure that you and your client are using the same terminology.  Dry basis moisture content can often be above 100%, which may be confusing to the "uninitiated".

5.2.2  Oven-dry:  This is effectively the same as "bone dry", but reflects a particular way of drying a sample in an oven at 101-105C until constant

weight is obtained.  It is used mainly in wood processing industries.  Coal processors typically use the term "bone dry".

5.2.3  If the client can provide moisture contents, this is best.  The following are some typical moisture contents for southern tree species.

| Species | Stem Wood | Stem Bark |
|---|---|---|
| Southern Pines | 50% | 50% |
| Mixed Oaks | 41% | 35% |
| Sweetgum | 55% | 47% |

5.3  Bulk Density:

5.3.1  Most published data for wood is in terms of oven-dry specific gravity of solid wood.  When wood is run through a chipper, it experiences an expansion factor that is approximately constant for all species, but increases as target chip size decreases.   Historically, most wood has been chipped to a ¾" target size for paper-mill chips.  However, in biomass applications, a smaller target size is often sought and chippers may be set up to produce 3/8" and some for ¼" chips.  Expansion factors for these chip sizes are 2.8, 3.08 and 3.42 respectively.  Some useful rules of thumb for chip bulk densities follow:

| | Southern Pines | Mixed Oaks | Sweetgum |
|---|---|---|---|
| Solid Wood Specific Gravity | 0.5 | .65 | .45 |
| Solid Wood Density | 31.2 | 40.6 | 28.1 |
| $MC_{wb}$ | 50% | 41% | 55% |
| ¾" OD Wood Bulk Density | 11.14 | 14.5 | 10.0 |
| 3/8" OD Wood Bulk Density | 10.13 | 13.18 | 9.12 |
| ¼" OD Wood Bulk Density | 9.12 | 11.87 | 8.22 |
| ¾" Wet Wood Bulk Density | 22.3 | 24.6 | 22.3 |
| 3/8" Wet Wood Bulk Density | 20.3 | 22.3 | 20.3 |
| ¼" Wet Wood Bulk Density | 18.2 | 20.1 | 18.3 |

Densities are in pounds per cubic foot.

The advantage of working with oven-dry bulk density is that it does not change with moisture content, and as the project progresses, the moisture

content assumption may change at various process locations. If oven-dry bulk density is used, then only one value, moisture content, must be changed at each affected data point. However, oven-dry bulk density does not represent reality and this may cause some confusion. One solution is to list both and let the wet wood bulk density be calculated from the oven-dry bulk density as follows:

Wet bulk density = Oven dry bulk density / (1-MCwb)

This was done on the examples in Section 8.

5.3.1  Bark: Bark for Southern Pines is usually assumed to have a wet bulk density of 16 PCF, or 8 PCF dry bulk density.

5.3.2  Roundwood: Stems or logs as delivered to the plant are collectively referred to as "roundwood". Tree-length roundwood (typically 30'-50' long) and cut to a 3" to 4" top is referred to as stemwood or stems. After they are bucked to length for further processing, they are referred to as logs. This step is usually not required in biomass plants. When roundwood is stacked, the stack will typically contain about 25% air space, so the above solid wood densities should be reduced by a factor of 0.75 to yield stacked wood density. For conservatism, a factor of 0.70 is suggested. This is useful for calculating required storage area for roundwood.

5.4  Design Factor: A design factor is a factor, usually greater than 1.0 that is multiplied by the average flow to obtain design flow. Several issues may be considered in determining the design factor. Among these are:

5.4.1  Lack of certainty regarding input data (moisture content, bulk density, uptime rate).

5.4.2  Lack of certainty that the vendor design will be adequate. Under bidding conditions, vendors will typically bid to the bare minimum.

5.4.3  Natural process variations. For example, log feed to a chipper is not constant and may vary by as much as +/- 50%. So the chipper discharge conveyors should be designed to handle the higher rate. On the other hand, chips are fed from a silo at a steady rate.

5.4.4 Upstream equipment capacities.  A chipper will usually be fed to near capacity even if it is not required to meet process needs.  Therefore, the chipper discharge conveyors must be designed for the full chipper capacity.

5.4.5 Some typical design factors are as follows:

- Conveyors with steady feed rate:  1.25-1.50.
- Conveyors with uncontrolled, variable feed rate such as debarker or chipper discharge conveyors:  2.0 or capacity of upstream equipment, whichever is greater.
- Chippers and hogs:  1.1 or capacity of upstream equipment, whichever is greater.
- Dryers:  1.05 – 1.1.
- Pellet Presses:  1.05-1.1.
- Silo and storage piles:  1.0 (Storage requirement is usually not absolute.  Also, material tends to pack by about 10% giving some inherent conservatism).

5.5  Notes on Flow Identifiers

The calculations are basically simple, but the convolutions of the process can make the overall spreadsheet complex and there are many opportunities for errors of neglect.  This type of error can be reduced by arranging the flow identifiers as much as possible in the order of process flow.  During the course of the project the need to insert flow identifiers inevitably arises, and with it, a new calculation column.  By starting with 1 on each PFD sheet, the re-work involved is minimized.  This of course means that each data point will not have a unique identifier.  It must be identified by both its number and the PFD number.  This does not normally have any negative consequences.  However, some clients that come from chemical process industries will object and insist that no flow identifier be re-used.  In this case, the Engineer will have to "bite the bullet" and do as the Client wishes.

6.0    ERROR CHECKING

There are many opportunities for errors to manifest themselves both due to neglect and logics in the material balance.  One way to check for errors is to check for overall balances.  Each sheet should be checked that:

Oven-Dry Annual Flow In = Oven-Dry Annual Flow Out + Process Consumption

One source of losses is combustion of bark or fines. Another may be in an assumption of windage losses.

The overall balance should also be checked to verify that flow entering the process equals flow leaving.

7.0     EXAMPLE BLOCK FLOW DIAGRAM

A client wishes to construct a wood fuel pellet plant to produce 300,000 metric tons (MT) per year of pellets at 8 percent moisture content.

The proposed process is as follows:
- Scale incoming tree stems and bark fuel.
- Store tree stems.
- Remove bark from stems
- Hog bark to reduce size and improve feeding characteristics.
- Burn bark to fuel dryer(s).
- If enough bark cannot be recovered from the tree stems to fuel the dryer(s), then extra bark will be purchased.
- Chip bark-free stems to 3/8" chips.
- Store chips.
- Dry chips to 8 percent moisture content.
- Store dry chips.
- Hammer-mill dry chips to yield a fine fibrous material.
- Store fiber.
- Pelletize fiber.
- Screen pellets to remove fines
- Recycle fines to fiber storage.
- Store pellets.
- Load pellets onto trucks.

Input Data

Uptime hours

Receiving and shipping scales:  10 hr/day, 6 days/wk 100% uptime:  2,980 hr/yr.

Log processing:  16 hr/day, 5 days/wk, 80% uptime:  3,149 hr/yr.

Dryers:  24 hr/day, 7 days/wk, 95% uptime:  8,002 hr/yr.

Pelletizing:  24 hr/day, 7 days/wk, 90% uptime:  7,589 hr/yr.

Storage Requirements

Tree Stems (logs):  2 weeks
Green Chips:  72 hours
Dry Chips:  8 hours
Dry Ground Fiber:  8 hours
Finished Pellets:  72 hours
Bark Fuel:  72 hours

Raw material

Species:  Southern yellow pine.
Bark content of incoming stems:  12%, dry mass basis

Moisture contents:

Wood:  50%
Bark:  50%
Dry wood:  8%
Pellets:  8%

Bulk densities, dry basis, pounds/cubic foot

Solid wood:  31.2
Tree stems:  21.8
Bark:  8.0
3/8" chips:  10.13
Ground fiber:  9.69

Pellets: 39.48 (Note that the client will usually provide a target pellet density with moisture included, in this case, 42.0 pcf).

Lower Heating Value of Bark: 8,240 Btu/oven-dry pound.

Dryer heat requirement: 1,600 Btu/pound of water evaporated.

Truck loads

Log trucks: 20 MT
Bark delivery trucks: 20 MT
Pellet shipping trucks: 20 MT

Results and Discussion:

The block flow diagram is constructed on an excel spreadsheet and shown below in Figure 1. The plant output requirement is shown below in column 17 as 300,000 MT/yr. This is the only column in which the dry basis flow requirement (276,000 MT/yr.) is calculated from the wet basis flow (300,000 MT/yr.). From this point, we work upstream and downstream, calculating upstream requirements equal to, or some fraction of the upstream or downstream requirement. The hourly flow is used for preliminary equipment sizing. For example, column 13 shows that there will be 40.7 MT/hr. flowing through the pellet presses. Assuming that the presses are capable of producing 5 MT/hr. each, there will be a need for 8 or more presses.

Three columns, 1, 2 and 18 are headed "Trucks". These columns indicate the number of truckloads of tree stems, bark fuel and pellets that will move in and out of the plant. These are respectively, 10.52, 0.64 and 5.03 trucks per hour. Since each truck must cross the scales twice (once empty and once full), the scales will average 32.38 weighments per hour. This plant will likely require two sets of scales, one incoming and one outgoing.

Storage requirements are indicated in yellow, columns 5S, 9S, 11S, 13S, 17S and 22S. The volumetric requirements are used to make a

preliminary assessment of the yard areas that must be allotted for tree stems, green chips and bark fuel, and the size of silos required for dry chips and pellets.

The fuel requirement to the dryer is calculated based on the weight difference between columns 10 and 11, which represents the water evaporated. The net heating value of the bark is calculated in the "Assumptions" block in the lower right corner of the spreadsheet. The total bark requirement is indicated in column 23, using the method discussed in Section 4.5. The bark available from the tree stems is shown in column 20. Column 4 is purchased bark, which is calculated as the difference between columns 23 and 20. If this had been a negative number, then a need for removing excess bark from the plant, or using it in the process, would have been indicated. In this case, the plant will need to purchase 47,240 MT per year of green bark from nearby wood processing plants, or develop a plan to recover slash from logging operations.

Note that column 12 indicates a slight drop in moisture content (from 8% down to 6%) due the drying effect of the hammermills. This moisture will be added at the pellet presses to bring the moisture content back up to the required 8%. A calculation of the water flow requirement could be added if it is deemed critical to the project at this stage

The overall balance should be checked. Flow into the process is found in columns 3 (tree stems) and 4 (purchased bark). Flow out is found in column 17 (pellets). Material consumed is in column 23 (bark burned).
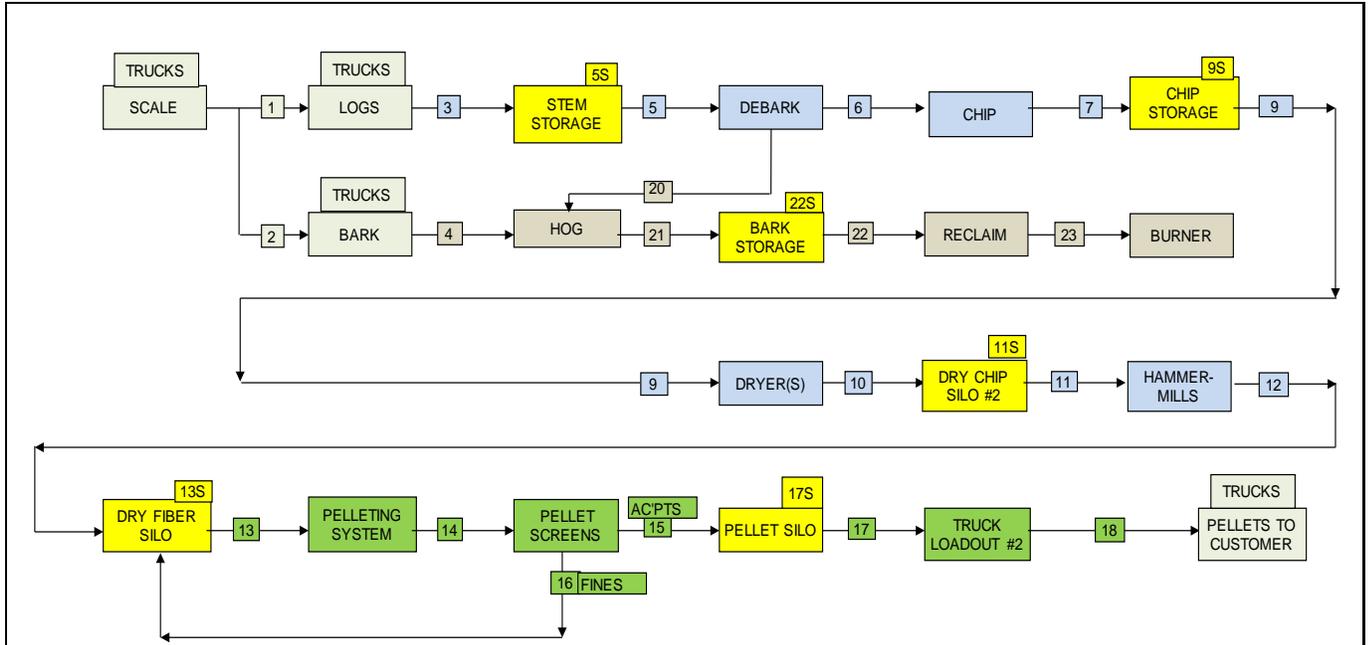
313,636 + 18,961 = 276,000 + 56,597
332,597 =332,597

Confirming that:

Flow in = Flow out plus process consumption.

**Flow Diagram (Figure 1):**

Top row: SCALE (TRUCKS) → [1] → LOGS (TRUCKS) → [3] → STEM STORAGE [5S] → [5] → DEBARK → [6] → CHIP → [7] → CHIP STORAGE [9S] → [9]

Second row: BARK (TRUCKS) → [2], BARK → [4] → HOG → [21] → BARK STORAGE [22S] → [22] → RECLAIM → [23] → BURNER. DEBARK → [20] → HOG.

Third row: [9] → DRYER(S) → [10] → DRY CHIP SILO #2 [11S] → [11] → HAMMER-MILLS → [12]

Fourth row: DRY FIBER SILO [13S] → [13] → PELLETING SYSTEM → [14] → PELLET SCREENS → [15] AC'PTS → PELLET SILO [17S] → [17] → TRUCK LOADOUT #2 → [18] → PELLETS TO CUSTOMER (TRUCKS). PELLET SCREENS → [16] FINES → DRY FIBER SILO.

NOTE: 1.) WHERE COLUMNS ARE HEADED BY "TRUCKS", WEIGHTS REFER TO TRUCK LOADS AND "ANNUAL WET" IS THE NUMBER OF TRUCK LOADS

| FLOW IDENTIFIER | | 1 | 2 | 3 | 4 | 5 | 5S | 6 | 7 | 9 | 9S | 10 | 11 | 11S | 12 | 13 | 13S |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | STEMS | | | | CHIPS | | | DRY CHP | | | DRY FIB |
| | UNITS | TRUCKS | TRUCKS | | | | | | | | | | | | | | |
| ANNUAL UPTIME | HR | 2,980 | 2,980 | 2,980 | 7,560 | 3,149 | | 3,149 | 3,149 | 8,002 | | 8,002 | 8,002 | | 7,589 | 7,589 | |
| BULK DENS., DB | LB/CF | N/A | N/A | 21.80 | 8.00 | 21.80 | | 10.13 | 10.13 | 10.13 | | 10.13 | 10.13 | | 9.11 | 9.11 | |
| BULK DENS., WB | LB/CF | N/A | N/A | 43.60 | 16.00 | 43.60 | | 20.26 | 20.26 | 20.26 | | 11.01 | 11.01 | | 9.69 | 9.69 | |
| MC WET BASIS | % | N/A | N/A | 50.0% | 50.0% | 50.0% | | 50.0% | 50.0% | 50.0% | | 8.0% | 8.0% | | 6.0% | 6.0% | |
| **AN'L FLOW, DB** | **MT/YR** | N/A | N/A | 313,636 | 18,961 | 313,636 | | 276,000 | 276,000 | 276,000 | | 276,000 | 276,000 | | 276,000 | 290,526 | |
| AN'L FLOW, WB | MT/YR | 31,364 | 1,896 | 627,273 | 37,922 | 627,273 | | 552,000 | 552,000 | 552,000 | | 300,000 | 300,000 | | 293,617 | 309,071 | |
| FLOW, DB | MT/HR | N/A | N/A | 105.2 | 2.5 | 99.6 | | 87.6 | 87.6 | 34.5 | | 34.5 | 34.5 | | 36.4 | 38.3 | |
| FLOW, WB | MT/HR | 10.52 | 0.64 | 210.5 | 5.0 | 199.2 | | 175.3 | 175.3 | 69.0 | | 37.5 | 37.5 | | 38.7 | 40.7 | |
| BULK FLOW, CFH | CFH | N/A | N/A | 9,675 | 628 | 9,156 | | 17,339 | 17,339 | 6,823 | | 6,823 | 6,823 | | 8,000 | 8,421 | |
| STARAGE CAP. | HR | | | | | | N/A | | | | 72 | | | 8 | | | 8 |
| WEIGHT STORED | MT | | | | | | 13,068 | | | | 4,967 | | | 310 | | | 326 |
| VOLUME STORED | CF | | | | | | 600,657 | | | | 540,313 | | | 60,035 | | | 67,371 |

| FLOW IDENTIFIER | | 14 | 15 | 16 | 17 | 17S | 18 | 20 | 21 | 22 | 22S | 23 | ASSUMPTIONS | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | PELLET | | | | | BARK | | | | |
| | UNITS | | | | | | TRUCKS | | | | | | | | |
| ANNUAL UPTIME | HR | 7,589 | 7,589 | 7,589 | 2,980 | | 2,980 | 3,149 | 3,149 | 8,002 | | 8,002 | PELLET TRUCK LOAD | 20 | MT |
| BULK DENS., DB | LB/CF | 39.48 | 39.48 | 39.48 | 39.48 | | N/A | 8.00 | 8.00 | 8.00 | | 8.00 | LOG TRUCK LOAD | 20 | MT |
| BULK DENS., WB | LB/CF | 42.91 | 42.91 | 42.91 | 42.91 | | N/A | 16.00 | 16.00 | 16.00 | | 16.00 | BARK TRUCK LOAD | 20 | MT |
| MC WET BASIS | % | 8.0% | 8.0% | 8.0% | 8.0% | | N/A | 50.0% | 50.0% | 50.0% | | 50.0% | PELLET SCREEN FINES | 5.0% | |
| **AN'L FLOW, DB** | **MT/YR** | 290,526 | 276,000 | 14,526 | 276,000 | | N/A | 37,636 | 56,597 | 56,597 | | 56,597 | BARK CONTENT OF LOGS | 12.0% | |
| AN'L FLOW, WB | MT/YR | 315,789 | 300,000 | 15,789 | 300,000 | | 15,000 | 75,273 | 113,195 | 113,195 | | 113,195 | FUEL REQ'T TO DRYER | 1600 | BTU/LB |
| FLOW, DB | MT/HR | 38.3 | 36.4 | 1.9 | 92.6 | | N/A | 12.0 | 18.0 | 7.1 | | 7.1 | LHV OF BARK | 8240 | BTU/LB |
| FLOW, WB | MT/HR | 41.6 | 39.5 | 2.1 | 100.7 | | 5.03 | 23.9 | 35.9 | 14.1 | | 14.1 | MOIST CONTENT OF BARK | 50.0% | |
| BULK FLOW, CFH | CFH | 1,943 | 1,846 | 97 | 4,701 | | N/A | 2,994 | 4,502 | 1,772 | | 1,772 | HEAT TO EVAP WATER | 1116 | BTU/LB |
| STORAGE CAP. | HR | | | | | 72 | | | | | 72 | | NET HEAT VALUE OF BARK | 7124 | |
| WEIGHT STORED | MT | | | | | 7,248 | | | | | 1,018 | | | | |
| VOLUME STORED | CF | | | | | 338,490 | | | | | 127,567 | | | | |

Figure 1.  Example of Block Flow Diagram for a pellet fuel plant.

9.  SUMMARY AND CONCLUSIONS

As in most chemical process projects, a biomass project will require creation of a block flow diagram (BFD) or a process flow diagram (PFD), or both.  The block flow diagram is usually created in the earlier engineering stages to help firm up the basic process and to get the client and engineer both thinking along the same lines. The BFD will include groupings of equipment represented by blocks, whereas the PFD will show every major piece of processing equipment with associated design flow.

Biomass projects differ from most chemical process projects in that some key variables such as daily operating hours, moisture content and bulk density of the material vary at different stages of the process, making calculations based on hourly flow difficult.  The calculations are greatly simplified by balancing the mass flow based on annual dry mass.  Adjustments then are made simply at each designated flow point by incorporating the correct parameters.  For the purpose of sizing equipment and writing equipment specifications, a carefully selected design factor can be incorporated into the PFD calculations.