This document references Chapters and Sections from the ITRC Vapor Intrusion Technical and Regulatory Guidance, and Fact Sheets and Technology Information Sheets from the ITRC Vapor Intrusion Toolkit, published January 2026. These resources can be accessed at: **https://itrcweb.org/vapor-intrusion-toolkit**.

MODEL SENSITIVITY ANALYSIS FACT SHEET

Parameter uncertainty and sensitivity analyses are critical components of any modeling exercise and are often recommended as best practices (USEPA 2015; 2017). For the purposes of this section, uncertainty refers to the lack of knowledge on the part of the model user as to the true value of an input parameter and therefore to the range of values that the model user may apply for a particular parameter. For example, groundwater may fluctuate between 15 and 20 feet below ground surface on an annual basis, so the modeler may decide to run a model using each end range value. Sensitivity refers to the mathematics of the model and dependence of model outputs on model inputs (i.e., how the model output changes when one or more parameters are varied).

For parameters with high sensitivity, making a small change in the input value results in a relatively large change in output values when compared to parameters with low sensitivity. For example, when using the BioVapor model, varying the input value for “Water Filled Porosity Soil Cracks” results in very minimal change in the indoor air concentration predicted by the model, so the sensitivity of this parameter is low. Making small changes to the “Soil Porosity” input results in large changes to the indoor air concentration predicted, so the sensitivity of this parameter is high. If the model user’s uncertainty of which input value to use is high for a parameter with high sensitivity, the resulting potential model output range will be large.

The difficulty in obtaining measurements for some parameter inputs has forced investigators to rely heavily on literature values or professional judgment. To aid in selecting inputs, default parameter ranges and lookup tables have been defined (California DTSC 2024; Johnson 2005; Johnson et al. 2002; Tillman and Weaver 2006; USEPA 2017). Where parameters are both uncertain and sensitive, it is generally best to choose conservative values to be protective of human health. Conservative values are those for which the predicted indoor air concentration, and therefore the associated risk, is highest. For example, choosing coarse sand in the Johnson and Ettinger and BioVapor models results in the highest predicted indoor air concentrations compared to other soil types.

In literature and regulatory guidance, there doesn’t appear to be a standard agreed-upon method for conducting a sensitivity analysis, nor a mathematical formula for quantifying sensitivity as “High,” “Medium,” or “Low.” Numerous approaches and metrics have been used for many industries (Christopher Frey and Patil 2002). Hamby (1994; 1995) and Hoffman and Miller (1983) compare various approaches to conducting sensitivity analyses for radiation exposure and food safety risk models. In general, the relative sensitivity of model input parameters can be compared to each other and ranked from most to least sensitive. Different techniques may result in small variations in the relative ranking order (Hamby 1994).

The simplest way to conduct a sensitivity analysis on parameters is the one-at-a-time (OAT) approach. This technique involves varying only one parameter between each model simulation and is detailed below. Varying more than one parameter at a time can be complicated and time consuming due to the large number of possible model interactions. Hamby and Tarantola (1999) used proprietary software packages to account for interactions between input parameters and summarized multiple techniques for quantifying and ranking parameter sensitivity. The PVIScreen model uses a built-in Monte Carlo simulator to account for parameter uncertainty and to present results as probabilities. For that model, an OAT sensitivity analysis may not be necessary.

For the purposes of this fact sheet, the focus will be on using the OAT approach to run model simulations over a range of input parameters, incrementally varying only one parameter at a time, and evaluating the effect on the model output. Sensitivity is quantified and parameters are ranked according to input and the corresponding outputs. No specialized proprietary software is necessary, but it is helpful to use a spreadsheet for organizing data and performing basic statistical calculations.

There are multiple approaches to starting a model sensitivity analysis. The model user may wish to enter known values for each input parameter. Due to the inherent uncertainty as to the true value of many of these parameters, it is recommended to start by using default values for all input parameters. These default values are often, but not always, the median or high-end value in a range of possible input values. For parameters without default values pre-entered, the user should choose an initial value based on professional judgment or literature guidance. Input parameters that are not subject to the sensitivity analysis, such as contaminants (e.g., benzene or tetrachloroethene), must be selected and kept the same throughout the sensitivity runs.

Once valid values (within the model allowable range) have been entered for all input parameters take the following steps:

1. Run a simulation of the model and record the output value (usually indoor air concentration of the vapor-forming chemical of concern or risk such as hazard quotient or cancer risk).
2. Determine how the input parameters will be varied. For example, the user may wish to vary the parameters between the lowest and highest applicable values allowed in the model. Hamby (1995) described a technique that started with the default and/or median value for each input parameter, then varied the values by ±20 percent. This approach does not require consideration of the full range of applicable input values. Alternatively, the inputs can be varied by ± the standard deviation of the full range of applicable values. This process requires more knowledge of the full range of input possibilities. There are no widely accepted criteria regarding the number of steps to use while varying the parameter. For linear correlations between the output and input, just two steps (e.g., highest and lowest applicable values) are necessary. For many input parameters, the output value is not a linear relationship or may differ between different ranges of input values. Including more steps between the lowest and highest input values used for analysis is helpful for these parameters. Whatever number of steps is chosen, it should be consistent for all input parameters.
3. Run additional simulations of the model, varying just the one parameter, and record the output results.
4. A simple method for visualizing the input/output relationship is to graph the inputs on the x-axis and the outputs on the y-axis of a scatter plot. It can then be determined whether the relationship is linear, exponential, logarithmic, variable, etc.
5. Once model simulations have been completed at all chosen steps for a given parameter, set it back to the default or initial value and repeat steps 3 and 4 for the other parameters.
6. Numerous indices can be used to quantify and rank relative sensitivity using input and/or output values. Hoffman and Gardner (1983) and Hamby (1995) described and compared several techniques, some of which are listed below:
    a. The importance index is calculated by log transforming the input and output data for each parameter, then dividing the variance of the log-transformed parameter values by the variance of the log-transformed output values. Higher numbers indicate relatively higher sensitivity.
    b. The uncertainty factor is determined by calculating the upper 95 percent confidence interval of the output data and dividing by the geometric mean of the output data. Higher numbers indicate relatively higher sensitivity.

c. The modified uncertainty factor (MUF) is calculated in much the same way as the uncertainty factor, but the arithmetic mean is used in place of the geometric mean.

d. The sensitivity index is calculated by dividing the range of output values by the lowest output value.

e. The relative percent range index is calculated by dividing the relative range (range divided by the arithmetic mean) of the output values by the relative range of the input values. Higher absolute values indicate higher sensitivity.

7. Once an index has been calculated for each input parameter, the parameters can be sorted and ranked from high to low.

For the above-described indices, there are no agreed-upon cutoffs for declaring whether the parameter sensitivity is “High,” “Medium,” or “Low.” Since the index values may change depending on the range of input values used and the number of simulation steps analyzed for the range, only relative sensitivities can be ranked and compared.

The sensitivity ranking order may change depending on which index is chosen. Some model users may desire to conduct sensitivity analyses using more than one index for ranking. The weighted average of the rankings can then be used to identify the most sensitive parameters.

The following example illustrates the basic process of conducting a sensitivity analysis using the BioVapor model.

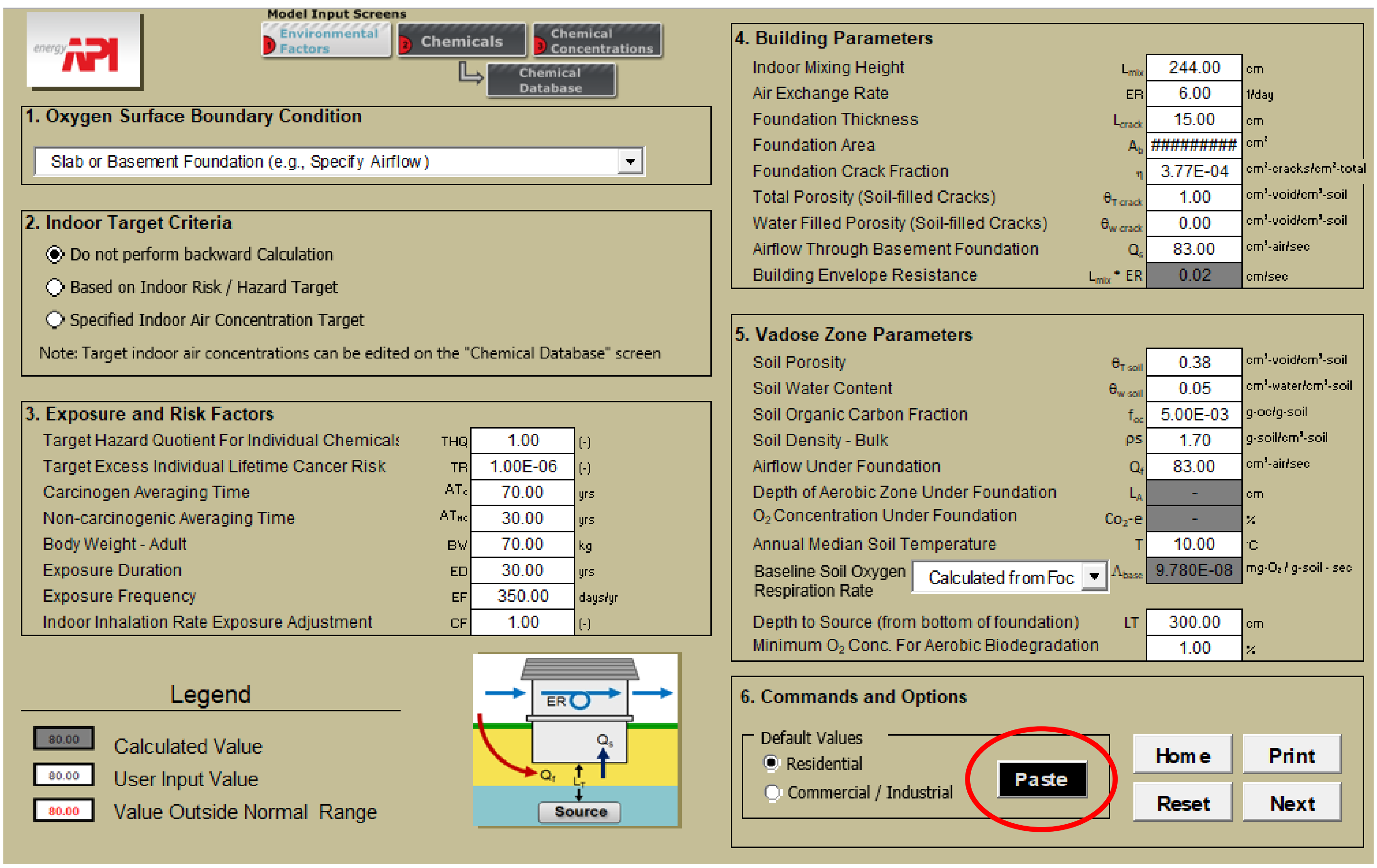
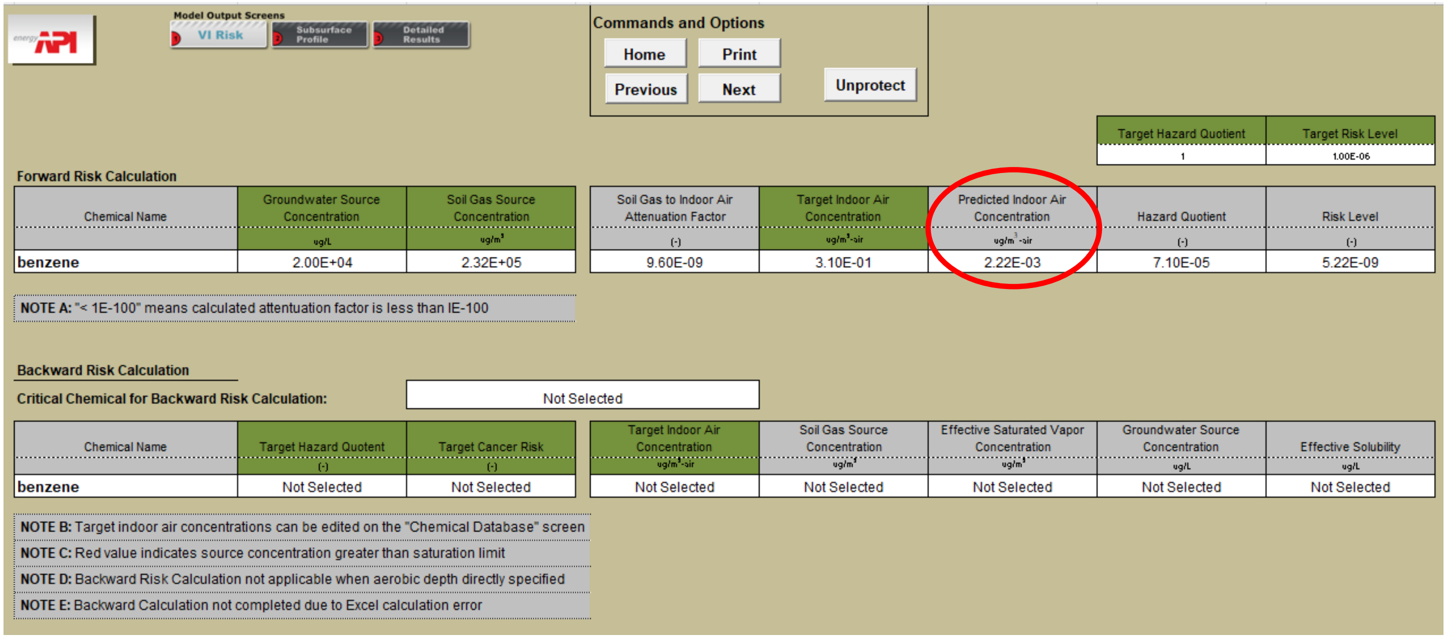


Figure 1. BioVapor default input values.

A sensitivity analysis was conducted on the BioVapor model to determine the relative sensitivity of input parameters on the calculated indoor air concentrations of benzene. Using the Paste button in section 6, residential default values were initially used for the environmental factors. Figure 1 is a screenshot showing the default input values for the initial run. Groundwater was selected as the contaminant source. Benzene was selected as the contaminant of concern, and a concentration of 20,000 micrograms per liter was chosen. The attenuation factor was left at the default of 0.1. The model-predicted indoor air concentration (Figure 2) is 2.22E-03 micrograms per cubic meter, resulting in a Hazard Quotient and Risk Level below the target values (1.0 and 1.00E-06, respectively). For more information on how to use the BioVapor model, please see the BioVapor Model Fact Sheet or Appendix H.



Target Hazard Quotient	Target Risk Level
1	1.00E-06

Chemical Name	Groundwater Source Concentration (ug/L)	Soil Gas Source Concentration (ug/m³)	Soil Gas to Indoor Air Attenuation Factor (-)	Target Indoor Air Concentration (ug/m³-air)	Predicted Indoor Air Concentration (ug/m³-air)	Hazard Quotient (-)	Risk Level (-)
benzene	2.00E+04	2.32E+05	9.60E-09	3.10E-01	2.22E-03	7.10E-05	5.22E-09

Chemical Name	Target Hazard Quotent (-)	Target Cancer Risk (-)	Target Indoor Air Concentration (ug/m³-air)	Soil Gas Source Concentration (ug/m³)	Effective Saturated Vapor Concentration (ug/m³)	Groundwater Source Concentration (ug/L)	Effective Solubility (ug/L)
benzene	Not Selected	Not Selected	Not Selected	Not Selected	Not Selected	Not Selected	Not Selected

Figure 2. Output values for the given scenario using model defaults.

To assess the sensitivity of each input parameter, the parameters were varied, one at a time, in three steps: default value (100 percent value), 1.2 × the default value (120 percent value), and 0.8 × the default value (80 percent value). Input and output values were tracked in a spreadsheet (Table 1).

Table 1. Input and output values and output value statistics.

Sensitivity Analysis for BioVapor

CoC: Benzene	Slab or Basement Foundation
Scenario: Residential	Input Groundwater Concentration: 2.00E+04 µg/L
HQ: 1	Attenuation Factor: 0.1
Target Risk Level: 1.00E-06	
Using all model default values	Baseline Soil Oxygen Respiration Rate Calculated from Foc
Red indicates outside normal range	

	Model Parameter	Input Value	Output Value	Output Value Statistics			Modified Uncertainty Factor
		Varying Units	(Predicted Indoor Air Concentration(µg/m³))	Arithmetic Mean	Standard Deviation	Upper 95% Limit	
	Soil Porosity	0.300	1.18E-04				
Default	Soil Porosity	0.375	2.22E-03	5.55E-03	0.007654	1.42E-02	2.56
	Soil Porosity	0.450	1.43E-02				
	Soil Water Content	0.043	1.45E-02				
Default	Soil Water Content	0.054	2.22E-03	5.68E-03	0.007696	1.44E-02	2.53
	Soil Water Content	0.065	3.23E-04				
	Foc	0.004	1.75E-04				
Default	Foc	0.005	2.22E-03	4.93E-03	0.006548	1.23E-02	2.50
	Foc	0.006	1.24E-02				
	Soil Bulk Density	1.360	1.75E-04				
Default	Soil Bulk Density	1.70	2.22E-03	4.93E-03	0.006548	1.23E-02	2.50
	Soil Bulk Density	2.040	1.24E-02				

	Model Parameter	Input Value	Output Value	Output Value Statistics			Modified Uncertainty Factor
		Varying Units	(Predicted Indoor Air Concentration(μg/m³))	Arithmetic Mean	Standard Deviation	Upper 95% Limit	
	Airflow Under Foundation	66.400	1.75E-02				
Default	Airflow Under Foundation	83.00	2.22E-03	6.67E-03	0.009429	1.73E-02	2.60
	Airflow Under Foundation	99.600	2.88E-04				
	Annual Median Soil Temperature	8.000	1.03E-03				
Default	Annual Median Soil Temperature	10.00	2.22E-03	2.61E-03	0.001801	4.65E-03	1.78
	Annual Median Soil Temperature	12.000	4.57E-03				
	Depth to Source	240.000	3.35E-03				
Default	Depth to Source	300	2.22E-03	2.41E-03	0.000861	3.38E-03	1.40
	Depth to Source	360.000	1.66E-03				
	Minimum O_2 Conc.	0.800	2.01E-03				
Default	Minimum O_2 Conc.	1.00	2.22E-03	2.23E-03	0.000225	2.48E-03	1.11
	Minimum O_2 Conc.	1.200	2.46E-03				
	Indoor Mixing Height	195.200	2.78E-03				
Default	Indoor Mixing Height	244.00	2.22E-03	2.28E-03	0.000468	2.81E-03	1.23
	Indoor Mixing Height	292.800	1.85E-03				
	Air Exchange Rate	4.800	2.78E-03				
Default	Air Exchange Rate	6.00	2.22E-03	2.28E-03	0.000468	2.81E-03	1.23
	Air Exchange Rate	7.200	1.85E-03				
	Foundation Thickness	12.000	2.22E-03				
Default	Foundation Thickness	15.00	2.22E-03	2.22E-03	0	2.22E-03	1.00
	Foundation Thickness	18.000	2.22E-03				

	Model Parameter	Input Value	Output Value	Output Value Statistics			Modified Uncertainty Factor
		Varying Units	(Predicted Indoor Air Concentration(μg/m³))	Arithmetic Mean	Standard Deviation	Upper 95% Limit	
	Foundation Area	848000.000	2.14E-04				
Default	Foundation Area	1.06E+06	2.22E-03	4.28E-03	0.005396	1.04E-02	2.43
	Foundation Area	1272000.000	1.04E-02				
	Foundation Crack Fraction	0.000302	2.22E-03				
Default	Foundation Crack Fraction	3.77E-04	2.22E-03	2.22E-03	0	2.22E-03	1.00
	Foundation Crack Fraction	0.000452	2.22E-03				
	Total Porosity Soil Cracks	0.800	2.22E-03				
Default	Total Porosity Soil Cracks	1.00E+00	2.22E-03	2.22E-03	0	2.22E-03	1.00
	Total Porosity Soil Cracks	1.200	2.22E-03				
	Water Filled Porosity Soil Cracks	0.000	2.22E-03				
Default	Water Filled Porosity Soil Cracks	0	2.22E-03	2.22E-03	0	2.22E-03	1.00
	Water Filled Porosity Soil Cracks	0.000	2.22E-03				
	Airflow Through Basement Foundation	66.400	1.80E-03				
Default	Airflow Through Basement Foundation	83.00	2.22E-03	2.22E-03	0.000415	2.69E-03	1.21
	Airflow Through Basement Foundation	99.600	2.63E-03				

The arithmetic mean and standard deviation for each range of output values for a given parameter were calculated using Excel formulas. The upper 95 percent limit was calculated using the following formula:

$$UL = X + 1.96(sd/\sqrt{3})$$

Where: UL is the upper 95 percent confidence level

X is the arithmetic mean of the output values

sd is the standard deviation of the output values

3 is the number of steps analyzed for each input parameter

The MUF was then calculated by dividing the upper 95 percent confidence level by the arithmetic mean. Note that while the range of input parameters is not directly factored into the equation for the MUF, varying each input value by ±20 percent assures that the relative range of each input value is comparable to the relative range of all of the other input values. One limitation of this approach is that some parameters fell outside of normal or expected ranges, as noted by red values in **Table 1**.

Once the MUF is calculated for each input parameter that can be varied, the parameters can be sorted by MUF (**Table 2**). There are no standard thresholds for determining whether the sensitivity of a parameter is high, medium, or low. The labels proposed in **Table 2** are based on cutoffs: >2.00 for High, >1.25 and ≤2.00 for Medium, and >1.00 and ≤1.25 for Low. For parameters with an MUF of 1.00, the output values did not vary at all with changes of ±20 percent to the input value, so the parameter is not sensitive within that range. Regardless of the category cutoffs selected, relative sensitivities of the parameters can be compared.

Table 2. BioVapor input parameters ranked by relative sensitivity

Input Parameter	Modified Uncertainty Factor	Proposed Relative Sensitivity
Airflow Under Foundation	2.60	High
Soil Porosity	2.56	High
Soil Water Content	2.53	High
Foc	2.50	High
Soil Bulk Density	2.50	High
Foundation Area	2.43	High
Annual Median Soil Temperature	1.78	Medium
Depth to Source	1.40	Medium
Indoor Mixing Height	1.23	Low
Air Exchange Rate	1.23	Low
Airflow Through Basement Foundation	1.21	Low
Minimum O_2 Conc.	1.11	Low
Foundation Thickness	1.00	Not sensitive
Foundation Crack Fraction	1.00	Not sensitive
Total Porosity Soil Cracks	1.00	Not sensitive
Water-Filled Porosity Soil Cracks	1.00	Not sensitive

Changing the source concentration will also result in changes to the output value (predicted indoor air concentration). The source concentration should be well known. In fact, modeling is most often used to answer this question: For a given contaminant concentration (in groundwater or soil vapor), is there a likely potential for the indoor air concentration of that contaminant to exceed target hazard quotient and/or risk values? The model user often has less certainty of the true site-specific values of soil parameters like porosity, bulk density, soil water content, and fraction of organic carbon. Knowing that the model is sensitive to these parameters, it may be beneficial to collect site soil samples for analysis of soil properties to better refine these values.

As noted above, each approach to calculating and comparing sensitivity has its limitations. For this approach, a limitation is that the applicable or likely ranges of some parameters may vary by less than or more than 20 percent. The advantage is that all of the inputs have the same relative range. Note that using different approaches to varying the parameters and/or different steps may result in changes to the calculated MUF and relative sensitivity. For this reason, the “High,” “Medium,” and “Low” rankings for the parameters listed in **Table 2** may not match the rankings found in other guidance or literature.

For more information on model-specific sensitivity analysis, please see these sources:

- Johnson & Ettinger: **Appendix I** or the **Johnson and Ettinger Model Fact Sheet**
- BioVapor: **Appendix H** or the **BioVapor Model Fact Sheet**

Some modeling exercises refer to “uncertainty analysis.” This often involves listing a range of possible outputs based on a range of inputs. Due to the inherent difficulty with running model simulations using end member values for all input parameters, and the large range of outputs that would result, the model user may find it beneficial to conduct a sensitivity analysis similar to the above example first. The sensitivity analysis may help identify parameters for which more data should be collected, if possible, to reduce the uncertainty range. Additionally, the sensitivity analysis can be used to help the model user select a smaller number of parameters to vary to help constrain the uncertainty range.

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