# An Interactive Life Cycle Assessment (LCA) Model for U.S. Kelp Aquaculture Based on the Open-Source Platform openLCA

In addition to (and fully-integrated with) the financial planning modules, a Life Cycle Assessment (LCA) model was developed to generate a comprehensive assessment of the environmental impacts and benefits associated with the nursery and growout phases of a kelp aquaculture operation. The model includes assessments of the potential for both bioremediation (i.e., N and P removal) and negative CO<sub>2</sub> emissions resulting from the growout and harvesting of kelp. Although seaweed farming has long been touted as one of the most environmentally friendly forms of aquaculture, user-friendly tools aimed at the quantitative estimation of ecosystem service flows are lacking. The LCA model will allow users to estimate the environmental footprint of a kelp nursery/growout operation by fulfilling a few additional data requirements that build on the information already collected for the financial analysis. Life Cycle Assessments use a standardized methodology to identify and quantify the environmental impacts of any given production system. In this context, a product could include any goods, technologies, and services. Impacts are quantified per the functional unit of the product system based on its output, i.e., one pound of wet kelp at harvest. The outputs of an LCA can be used to identify potential improvements in the production system with the overall aim to minimize environmental impacts such as resource depletion, global warming, (stratospheric) ozone depletion, acidification, eutrophication, etc.

Life Cycle Assessments are conducted more effectively through the use of specialized software, which guide users through the different stages of an LCA, from defining the scope and goals of the study to interpreting the results. The most popular software tools are Simapro, Gabi Sphera, Ecochain Mobius, OneClick LCA, OpenLCA, and Umberto. Out of these options, OpenLCA is the only free, open source software – the other tools require the payment of licensing fees. These instructions contain detailed explanations to conduct an LCA of kelp aquaculture operations. Three general steps are required:

1) The completion of the additional data requirements contained in the LCA-designated worksheets in the financial planning model.

2) The LCA worksheets will compute the material and energy requirements associated with the production of one foot of spool/seedstring (nursery worksheet) and one pound of fresh kelp at harvest (farm worksheet). These requirements are computed in specific cells and must be manually entered in the OpenLCA platform (to be downloaded free-of-charge from

# https://www.openlca.org/).

3) OpenLCA will compute carbon emissions and N/P eutrophication produced by the nursery/farm operation. These estimates must be entered manually in the worksheet '2(b). Start up farm – LCA' in order to compute the additional revenue from negative CO<sub>2</sub> emissions and N and P removal (if any).

The following sections provide fully-detailed instructions on the three steps outlined above.

# 1) Additional Data Requirements (Financial Planning Model)

As mentioned previously, the LCA model requires the estimation of material and energy requirements involved in the production of one foot of spool (nursery phase) and one pound of fresh kelp at harvest (growout phase). These requirements are estimated in three different worksheets: "2(a). Start up nursery – LCA" (cells O45 : AC415); "2(b). Start up farm – LCA" (cells M68 : AA255); and "3. Operating Expenses – LCA" (cells Q57 : Y98). Many of these requirements are expressed in terms of the amount of dollars spent per foot of spool / pound of fresh kelp. These data are calculated automatically as the user enters the information required for the financial analysis in the worksheets "2(a). Start up nursery"; "2(b). Start up farm"; and "3. Operating Expenses", respectively. However, weight data (in kg) are needed for certain budget items:

i. Worksheet "2(a). Start up nursery – LCA": individual weights are required for 31 items (white cells in U column), if listed in the financial model. For example, cell U97 asks for the weight (in kg) of one individual bucket; cell U150 requires the approximate weight of the PVC pipe and fittings set used for the Seawater Filtration/Sterilization System; cell U215 asks for the weight of an individual cutting board (Nursery Tank Culture System). Notice that the reported weight values must correspond to the items whose average cost is listed in column D.

ii. Worksheet "2(a). Start up farm – LCA": individual weights are required for 25 items (white cells in S column), if listed in the financial model. For example, cells S90, S104 and S178 request the weight (in kg) of a steel anchor, a Styrofoam buoy, and a plastic container for holding longline, respectively.

iii. Worksheet "3. Operating Expenses – LCA": in order to compute energy and fuel requirements, the cost of one kWh must be entered in cells T69 and T97 while the average cost of fuel must be entered in cells W70 and W98.

# 2) OpenLCA Platform

The steps indicated below must be followed to conduct the LCA within the OpenLCA platform.

i. Please download the latest version of OpenLCA from https://www.openlca.org/download/. Version 2.3.1 was released in September 2024 - newer versions are released on a frequent

basis.

uninstall it, delete ti computer. openLCA 2.3.1 zip-		· ·			d start openLCA.exe. To ifferent folders on the same
Alternatively, you c					
5.5	zip-archive: op	enLCA_Windows	_x64.zip		
			nstaller below. If y	ou have an older op	penLCA version installed (via
openLCA 2.3.1 inst		LCA Windows yr	64 exe		

ii. In order to operate OpenLCA, databases must be created and/or imported. Please download the following databases to a folder of your choosing in your computer.

• National Renewable Energy Laboratory/USLCI database: visit https://www.lcacommons.gov/lcacollaboration/ National\_Renewable\_Energy\_Laboratory/USLCI\_Database\_Public/datase ts and click on the green 'Download' dropdown menu at the right portion of the page. Select the option 'as JSON-LD (openLCA 2.x)', which will download the zipped folder 'National\_Renewable\_Energy\_Laboratory-USLCI\_Database\_Public'.

s	as JSON-LD (openLCA 2.x) as JSON-LD (openLCA 1.x)
at	as JSON-LD (openLCA 2.x) (Subselect) as JSON-LD (openLCA 1.x) (Subselect)

• US Environmental Protection Agency/USEEIO v2.0: visit https://www.lcacommons.gov/lcacollaboration/

US\_Environmental\_Protection\_Agency/USEEIO\_v2/datasets and click on

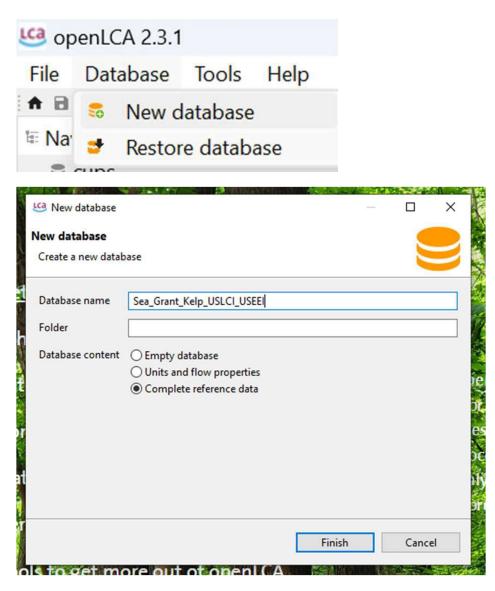
the green 'Download' dropdown menu at the right portion of the page. Select the option 'as JSON-LD (openLCA 2.x)', which will download the zipped folder 'US Environmental Protection Agency-USEEIO v2'.

• Federal LCA Commons/ReCiPe 2016 Impact Assessment Methods: visit https://www.lcacommons.gov/lcacollaboration/ Federal\_LCA\_Commons/ReCiPe/datasets and click on the green 'Download' dropdown menu at the right portion of the page. Select the option 'as JSON-LD (openLCA 2.x)', which will download the zipped folder 'Federal LCA Commons-ReCiPe'.

• Kelp farming LCA model: visit

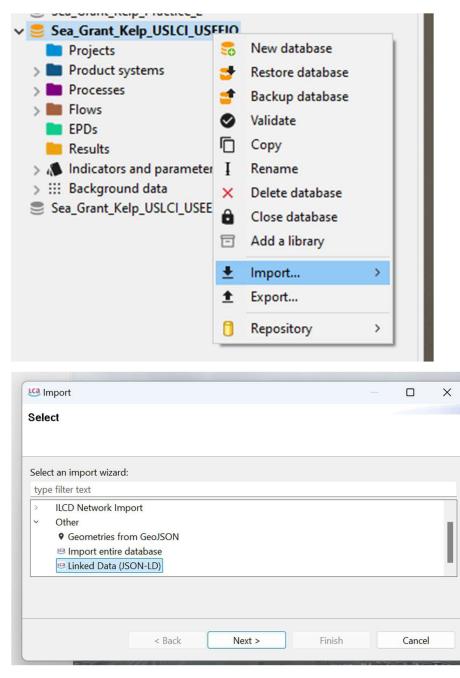
https://seaweedhub.extension.uconn.edu/resources/business/ and download the zipped folder 'Kelp\_USLCI\_USEEIO'.

iii. The next step is to create a database in OpenLCA that can be used to import the databases downloaded in ii). Once you open the platform, click on 'Database' (upper left menu) and then click on 'New Database'. You can type 'Sea\_Grant\_Kelp\_USLCI\_USEEIO' as the Database Name. Click 'Finish'.



iv. Once the database is created, the zipped folders 'National\_Renewable\_Energy\_Laboratory-USLCI\_Database\_Public', 'US\_Environmental\_Protection\_Agency-USEEIO\_v2',

'Federal\_LCA\_Commons-ReCiPe', and 'Kelp\_USLCI\_USEEIO' can be imported. Make sure the newly created database is active (it appears highlighted in colors – if not, click on it with the right mouse button and select 'Open database' in the dropdown menu). After this is done, click on the title with the right mouse button and select 'Import' > 'Other' > 'Linked Data (JSON-LD) > Next.



v. The window 'Import an openLCA data package' will appear on the screen. Click on 'Browse' and select the zipped folder 'National\_Renewable\_Energy\_Laboratory-USLCI\_Database\_Public'. Click on 'Finish'.

	🥴 openLCA JSON-LD Import	— 🗆 X	
nods	Import an openLCA data paci	kage 🗖	
	File	Browse	
	Updating existing data sets in th	e database	
	• Never update a data set that	already exists	
	O Update data sets with newer	versions	
	Overwrite all existing data set	ts	
a c.l	Zip file with openLCA data		CA. vou can model t
Select a	Zip nie with openLCA data		×
$\leftarrow \rightarrow$	✓ ↑	nLCA_Databases_Final_Model $\lor$ C Search op	penLCA_Databases 👂
Organize	New folder		≣ • 🔲 💡
Per:	sonal info	Name	Date modified
🦰 Fina	al Final Model - November 2024	늘 National_Renewable_Energy_Laboratory-USLCI_Database_Public	12/28/2024 1:31
🚞 Plai	nning of Work - Final Product - Sum	💳 US_Environmental_Protection_Agency-USEEIO_v2	12/28/2024 1:33
<mark>–</mark> Joh	anna	Federal_LCA_Commons-ReCiPe	12/28/2024 1:36

vi. openLCA may ask for a supporting library from the LCA Commons website. Click on OK. The Import process will take a few minutes.

	$\times$
Locate library	
Please specify a location for the missing library - elci_6_2024 for uslci_q2_2024_final	
From URL	
https://www.lcacommons.gov/lca-collaboration/ws/public/libraries/elci_6_2024 for uslci_q2_2024_final	
◯ From file	
Brow	se
Cancel OK	

vii. Repeat the above steps to import the zipped folders

'US\_Environmental\_Protection\_Agency-USEEIO\_v2', 'Federal\_LCA\_Commons-ReCiPe', and 'Kelp\_USLCI\_USEEIO'.

viii. Click to expand the 'Sea\_Grant\_Kelp\_USLCI\_USEEIO' database after the zipped folders have been imported. You will find a number of folders (Projects, Product Systems, Processes, Flows and other supporting folders). The LCA model is found in the subfolder 'Sea\_Grant\_Kelp' within the folder 'Processes'.

✓ Sea_Grant_Kelp_USLCI_USEEIO
Projects
> 🖿 Product systems
🗸 🛅 Processes
> 🖿 11: Agriculture, Forestry, Fishing and Hunting
> 🖿 21: Mining, Quarrying, and Oil and Gas Extraction
> 🛅 22: Utilities
> 🛅 23: Construction
> 🛅 31-33: Manufacturing
> 💼 42: Wholesale Trade
> 🖿 44-45: Retail Trade
> 48-49: Transportation and Warehousing
> E 51: Information
> E 52: Finance and Insurance
> 53: Real Estate and Rental and Leasing
54: Professional, Scientific, and Technical Services
55: Management of Companies and Enterprises
> 56: Administrative and Support and Waste Management and Remediation Service
> 💼 61: Educational Services
> E 62: Health Care and Social Assistance
> En 71: Arts, Entertainment, and Recreation
> E 72: Accommodation and Food Services
> 💼 81: Other Services (except Public Administration)
> 🖿 demands
> Dther Activities
> 🖿 Sea_Grant_Kelp
> Flows
EPDs
Results

ix. By expanding 'Sea\_Grant\_Kelp', you will find that the model contains 30 different processes. The processes 'N01a' through 'N12' and 'G02a' through 'G12' correspond to the nursery and growout phases, respectively. The process 'AA: Seed Spool' compiles the information from the nursery processes while "BB: Harvested Kelp" does the same for the growout processes.

- ✓ Sea\_Grant\_Kelp AA: Seed Spool BB: Harvested Kelp G02a: Grow Lines G02b: Mooring/Anchor System G02c: Depth Control (Droppers) G02d: Site Marking and Navigational Aids G03: Storage Facility for Gear 🕢 G04: Boat, Engine, Equipment G05: Truck/Trailer 5 G06: Containers/Totes to Hold Longline for Storage and/or Transport G07: Protective Clothing/Equipment G08: Gear for Setting and Seeding the Farm G09: Gear for Harvesting 🕢 G10: Gear for Off-Season Maintenance G11: Office Equipment G12: Growout Power and Fuel Requirements N01a: Nursery Facility and Capital Expenditures (Water Transported in) N01b: Nursery Facility and Capital Expenditures (Water Pumped In) N02a: Seawater Transport and Containment System (Water Transported In) N02b: Seawater Transport and Containment System (Water Pumped In) N03: Seawater Filtration/Sterilization System N04: Collection of Sorus Tissue N05: Nursery Tank Culture System N06: Light System N07: Aeration System N08: Seed Spools N09: Laboratory Equipment N10: Nutrient Media and Seawater Additives N11: Office Equipment
  - 5 N12: Nursery Power and Fuel Requirements

x. The nursery and growout processes in openLCA are modeled after the tables in the Excel worksheets "2(a). Start up nursery – LCA" (cells O45 : AC415); "2(b). Start up farm – LCA" (cells M68 : AA255); and "3. Operating Expenses – LCA" (cells Q57 : Y98). In order to run the LCA model, the material and energy requirements computed in the worksheets must be transcribed into its corresponding process in OpenLCA. As an example, double-click on the process 'N01a' (Nursery Facility and Capital Expenditures (Water Transported in)). The following window will display:

General informatio	n	
Name	N01a: Nursery Facility and Capital Expenditures (Water Transported in)	
Category	Sea_Grant_Kelp	
Description		^
		~
	Version 00.00.004 🛞 🔅 Last change 2024-06-13 23:10:11 UUID cfbd9d24-7917-437f-a353-8274dad37794	
Tags	Version 00.00.004 (a) (2) Last change 2024-00-13 23:10:11 0000 ctbd9d24-7917-437t-a353-8274dad37794 Add a tag	
Tags Infrastructure process	Add a tag	
-	Add a tag	

xi. Click on the tab 'Inputs/Outputs' in the lower portion of the window. This is the tab that will be used to enter the requirements computed in the worksheets.

	1a: Nursery Facility	and capit	an experio	ares (V	ater ila	цэр	one	s ii	.,					
Inputs													0	
Flow		Category		Amount	Unit		U	A	Provider		D	Description		
Commercial structures	, including farm structures	23: Constru	ction/236	0.00000	💷 USD		n		Commercial	st		Small special p	ourpose building	1
Pickup trucks, vans, an	d SUVs	31-33: Man	ufacturin	0.00000	🚥 USD		n		Dickup truck	s,		Cell R57		
/														
<														
< Outputs													0	;
Outputs	Category	Amount		Costs/Rev.	Uncerta	nty	Avoi	ded p	p Provider	Dat	ta quali	. Location	• Description	;
Outputs			Unit Item(s)	Costs/Rev.	Uncerta none	nty	Avoi	ded p	p Provider	Dat	ta quali	. Location		;
Outputs				Costs/Rev.		nty	Avoi	ded p	p Provider	Dat	ta quali	. Location		>
Outputs				Costs/Rev.		nty	Avoi	ded p	p Provider	Da	ta quali	. Location		>
Outputs				Costs/Rev.		nty	Avoi	ded p	p Provider	Da	ta quali	. Location		
Outputs				Costs/Rev.		nty	Avoi	ded p	p Provider	Da	ta quali	. Location		

xii. This process is defined by only two openLCA flows: 'Commercial structures" and 'Pickup trucks, vans, and SUVs'. The corresponding information is found in the worksheet 'Start

openLCA	Flow			Amount			
Name	Process	Unit	Current USD per foot of spool	Adjustment Factor	2012 USD per foot of spool		
Commercial structures	N01a	Process Unit p	8.33E-02	0.704	5.86E-02		
Pickup trucks, vans, and SUVs	N01a	2012 USD	4.44E-02	0.745	3.31E-0		

up nursery – LCA', cells O51: T57. The Process name is indicated in column P.

xiii. For demonstration purposes, it has been assumed that the following capital expenditures have been made for the nursery: 1) \$50,000 for a small special-purpose building (cells C53 : J53 in worksheet '2(a). Start up nursery', useful life of 20 years); and 2) \$20,000 for a pick-up truck (cells C57: J57 in worksheet '2(a). Start up nursery', useful life of 15 years). It is also assumed that the nursery produces 30,000 feet of seedstring. The corresponding LCA table in the worksheet 'Start up nursery – LCA', cells O51: T57 indicates that the capital expenditure in the building amounts to \$0.0833 per foot of spool (nominal dollars) and \$0.0586 (2012 dollars). The table also indicates that this budget item is modeled as the flow 'Commercial Structures' under process 'N01a' in OpenLCA.

xiv. As implied in ii), flows in the 'Sea\_Grant\_Kelp\_USLCI\_USEEIO' database were obtained from two different sources: the Unit & System Life Cycle Inventory (USLCI) database maintained by the National Renewable Energy Laboratory (NREL), and the U.S. Environmentally-Extended Input-Output Model (USEEIO v2.0) produced by the Environmental Protection Agency (EPA). The combined databases provide a comprehensive set of goods and services for the U.S. economy that can be used for life cycle assessment and related applications. Notice that the functional units of USLCI and USEEIO processes are kg and 2012 U.S. Dollars, respectively.

xv. Because 'Commercial structures' and 'Pickup trucks, vans, and SUVs' are USEEIO processes, the material requirements need to be expressed in terms of 2012 USD per foot of spool. In other words, 2012 \$0.0586 in commercial structures need to be spent per foot of spool (these computations consider the life expectancy of the building). The environmental impact of the special-purpose building is then scaled relative to this expenditure amount. xvi. The material and energy requirements for each openLCA flow is formatted in bold, brown fonts – see for example cells T53 and T57 in '2(a). Start up nursery – LCA'. These estimates need to be entered manually in the openLCA processes, under the column 'Amounts'. This is how openLCA is instructed that the production of one foot of spool requires an expenditure of 2012 \$0.0586 in commercial structures and 2012 \$0.0331 in pickup trucks. Notice that the 'Description' column refers to the specific cells in the

		0	>
Amount Unit Provider Description			_
r 0.05860 📼 USD 🗧 Commercial structures, includ Small special purpose building (i.e	.e. shipping container). Cell T53		
0.03310 📟 USD 🗧 Pickup trucks, vans, and SUVs Cell T57			
			_
		0	ł

worksheet (T53 and T57) that compute the Amount value to be entered in openLCA.

xvii. Please save changes to the Process right after entering the 'Amount' values.

# Image: Save openLCA 2.0.0 File Database Tools Help Image: Save openLCA 2.0.0 Ctrl+S Ctrl+S Image: Save openLCA 2.0.0 Ctrl+S Ctrl+S

xviii. Follow the same procedure to enter all material and energy requirements for processes 'N01b' through 'N12'. The Excel tables for processes 'N01a' through "N11' are found in the worksheet '2(a). Start up nursery – LCA' (cells O45 : AC415) while process 'N12: Nursery Power and Fuel Requirements' is found in the worksheet '3. Operating Expenses – LCA' (cells Q69: Y70).

xix. The process 'AA: Seed Spool' compiles all requirements listed in processes 'N01a' through 'N12'. Open this process and click on the header 'Provider' to order the flows by process number. The 'Amount' values for processes 'N03' through 'N12' should be 1.00 (i.e., one "unit" of each process is considered in the analysis). Please notice that only one of the processes 'N01a' and 'N01b' can be assigned an 'Amount' of 1.00, depending on whether water is transported in or pumped in. The same applies to processes 'N02a' and 'N02b'. The 'Output' of process 'AA: Seed Spool' is one foot of spool.

♠ Welcome 🗙 😓 AA: Seed Spool 🗙

# J Inputs/Outputs: AA: Seed Spool

Inputs												G	Ð
Flow			Amount	Un	nit	Pro	vider			^			-
Nursery Facility and	Capital Expenditures Set		0.00000		Item(s)	Ð	N01a: N	ursery Facility	and Capital	Expenditures (V	Vater Transpo	orted in)	
Nursery Facility and	Capital Expenditures Set		1.00000	-	Item(s)	Ð	N01b: N	ursery Facility	and Capital	Expenditures (	Nater Pumpe	d In)	
Seawater Transport	and Containment System Set		0.00000		Item(s)	Ð	N02a: Se	awater Transp	ort and Con	tainment System	m (Water Tra	nsported In)	
Seawater Transport	and Containment System Set		1.00000	-	Item(s)	Ð	N02b: Se	awater Transp	ort and Con	tainment Syste	m (Water Pu	mped In)	
Seawater Filtration/	Sterilization System Set		1.00000	-	Item(s)	Ð	N03: Sea	water Filtratio	n/Sterilizatio	n System			
Collection of Sorus	Tissue Set		1.00000	<b></b>	Item(s)	Ð	N04: Col	lection of Sor	us Tissue				
3 Nursery Tank Cultur	e System Set		1.00000		Item(s)	Ð	N05: Nu	rsery Tank Cul	ture System				
3 Light System Set			1.00000		Item(s)	Ð	N06: Lig	ht System					
Aeration System Set			1.00000	-	Item(s)	Ð	N07: Aer	ation System					
Seed Spools Set			1.00000		Item(s)	Ð	N08: See	d Spools					
Caboratory Equipme	ent Set		1.00000		ltem(s)	Ð	N09: Lab	oratory Equip	ment				
🕄 Nutrient Media and	Seawater Additives Set		1.00000		Item(s)	Ð	N10: Nut	trient Media a	nd Seawater	Additives			
Office Equipment Sector	et		1.00000		ltem(s)	Ð	N11: Off	ice Equipmen	t				
3 Nursery Power and	Fuel Requirements Set		1.00000		ltem(s)	Ð	N12: Nu	rsery Power a	nd Fuel Requ	irements			
: Dutputs												C	
Flow	Category	Amount 1.00000			Costs/Re	Unc	ertain	Avoided	Provider	Data qual	Location	Descriptio	2

xx. The same procedure is used to enter the material and energy requirements from the worksheets "2(b). Start up farm – LCA" (cells M68 : AA255); and "3. Operating Expenses – LCA" (cells Q97 : Y98) into the processes 'G02a' through 'G12'. The 'Description' column in each process refers to the specific cell in the worksheets computing the material requirement per pound of fresh kelp at harvest. These values are then entered into the 'Amount' column for each process. See the example below for process 'G08: Gear for Setting and Seeding the Farm'.

openLCA Flo	w			Amount			Amount	
Name	Process	Unit	Current USD per Ib of harvested kelp	Adjustment Factor	2012 USD per lb of harvested kelp	kg per individual item	kg - all items	kg per lb of harvested kelp
Urethane and other foam products	G08	2012 USD	1.00E-02	0.395	3.95E-03			
Soft drinks, bottled water, and ice	G08	2012 USD	2.50E-02	0.466	1.16E-02			
Polyethylene, LDPE	G08	kg				5.00	5.00	5.00E-04
Cardboard containers	G08	2012 USD	5.00E-02	0.557	2.78E-02			

Inputs														0	×
Flow	^	C	Amount	Ur	nit	Pr	ovider			Descri	iption				
Cardboard contain	ers	3	0.02780		USD	Ð	Cardboard co	ntainers - US		Cardb	oard or othe	er packing ma	aterial (cell R20	)6)	
Polyethylene, low-	density, LDPE, virgin	3	0.00050		kg	Ð	Polyethylene,	low-density, Ll	)	Transp	oort tube/ Pl	astic Seed spo	ool holders for	cooler (cell U2	05
Soft drinks, bottled	water, and ice	3	0.01160		USD	Ð	Soft drinks, be	ottled water, an	d	Ice pa	cks (cell R20	14)			
Orethane and othe	r foam products	3	0.00395		USD	¢.	Urethane and	other foam pro	od	Coole	r or plastic t	otes to transp	ort spools [ce	II R203]	
<															

xxi. The process 'BB: Harvested Kelp' compiles all requirements listed in processes 'G02a' through 'G12'. Open this process and click on the header 'Provider' to order the flows by process number. The value listed in the 'Amount' column should be 1.00 for each process. The 'Output' of process 'BB: Harvested Kelp' is one pound of fresh kelp at harvest.

Inputs										0	×
Flow	Category	Amount	Unit	Costs/Re	Uncertain	Avoided	Provider	^		Data qual	Ī
🕸 Grow Lines Set		1.00000	💷 ltem(s)		none		G02a:	Grow Lines			
Anchor Sy		1.00000	Item(s)		none		G02b	Mooring/Ancho	or System		
Droppers Set		1.00000	Item(s)		none		G02c:	Depth Control (I	Droppers)		
Site Marking and N		1.00000	Item(s)		none		€] G02d	Site Marking an	d Navigatio		
Storage Facility for		1.00000	📖 Item(s)		none		🞝 G03: 9	Storage Facility fo	or Gear		
🕸 Boat, Engine, Equip		1.00000	💷 ltem(s)		none		🔂 G04: I	Boat, Engine, Equ	ipment		
Truck/Trailer Set		1.00000	💷 Item(s)		none		G05: 1	Truck/Trailer			
Container/Totes Set		1.00000	💷 Item(s)		none		🞝 G06: 0	Containers/Totes	to Hold Lon		
Protective Clothing		1.00000	💷 ltem(s)		none		G07: 1	Protective Clothin	ng/Equipme		
Gear for Setting and		1.00000	💷 Item(s)		none		€] G08: 0	Gear for Setting a	nd Seeding		
🕸 Gear for Harvesting		1.00000	💷 Item(s)		none		& G09: 0	Gear for Harvestin	ng		
🕸 Gear for Off-Season		1.00000	💷 ltem(s)		none		🞝 G10: 0	Gear for Off-Seas	on Mainten		
Office Equipment Set		1.00000	🛄 ltem(s)		none		🞝 G11: (	Office Equipment	t		
low Growout Power and		1.00000	💷 ltem(s)		none		G12: 0     G	Growout Power a	and Fuel Req		
<											
Outputs										0	>
Flow	Category	Amount	Unit	Costs/Re	Uncertain	Avoided	Provider	Data qual	Location	Description	-
🕸 Fresh Kelp		1.00000	📖 Ib av		none						

xxii. A simplified example is provided below to demonstrate how the simulation is run. Assume that the production of one pound of fresh kelp at harvest involves only the following

Offshore Farm: Two 200-ft grow lines, with five pounds of usable harvest per foot of line						
Item	Unit	Value				
Output: Refere	ence Flow					
Fresh kelp	lb	1				
Inputs: Ma	terials					
Seedstring	ft	0.2				
Fuel	gallon	0.006				
Aluminum, primary	kg	0.00076				
Steel, stainless	kg	0.00234				
Polypropylene (PP)	kg	1.375E-6				
Polyethylene, high density (HDPE)	kg	0.00028				
Polyvinyl chloride (PVC)	kg	0.00015				

(hypothetical) amounts, which will be entered directly into openLCA:

In turn, only the UV sterilizer and electricity consumption will be considered for the production of one foot of spool (seedstring):

											0
Flow Ca	ategory	Amount	Un	it	Pr	ovider			Description		
S Concrete pipe, bricks 31	1-33: Manufacturing/	0.00000		USD	Ð	Concrete pipe, bricks, and bl	ocks - US		Counter weights	(cell R103)	
Polyethylene terepht 31	1-33: Manufacturing/	0.00000		kg	a	Polyethylene terephthalate, I	PET, virgin resi	Polyline (5/16 in)	to go in drop	per [cell U100]	
1 Polyethylene, high d 31	1-33: Manufacturing/	0.00028		kg	Ð	Polyethylene, high density, h	Spindle washers (	cell U102)			
Dolystyrene, exapnd 31	1-33: Manufacturing/	0.00000	<b></b>	kg	Dolystyrene, expanded, EPS, virgin resin; batch s Styrophone buoys (cell U10					s (cell U101)	
Polyvinyl chloride, P 31	1-33: Manufacturing/	0.00015		kg	Ð	Polyvinyl chloride, PVC, virg	in resin; at plar	nt - RNA	1" pvc pipe (7-10	ft/dropper) [6	cell U104]
Outputs									1		0

ft Welcome @ G02a: Grow lines @ G02c: Depth Control (Dr... @ G12: Growout Power and... X &.] N03: Seawater Filtration/... @ N12: Nursery Power and ...

@ Inputs/Outputs:G12: Growout Power and Fuel Requirements

Flow       Category       Amount       Unit       Costs/Rev       Uncertainty       Avoided p       Provider       Data quali       Location       Description         6       Growout Power an       1.00000       El Item(s)       none         leome       @ G02a: Grow lines       @ G02e: Depth Control(Dr       @ G12: Growout Power and       @ N03: Seawater Filtration/, X       @ N12: Nursery Power and         puts/Outputs: N03: Seawater Filtration/Sterilization System       Provider       Description       Description         nputs       Category       Amount       Unit       Provider       Description       O         60       Filted meters and countin,       31-33: Manufactur       0.00000       El USO       @ Filted meters and counting devices: US       Digital flow meters (cell R154).       UV rtcrilizer (cell R151).         5       Polyethylene, high densi       31-33: Manufactur       0.00000       El kg       @ Polyethylene, high densi       Storage reservoir/tank/structure (cell U144).         6       Polyethylene, high densi       31-33: Manufactur       0.00000       El kg       @ Polypropylene, PV, virgin resin, at plat       Filter catridges (cell U148).         6       Polyethylene, high densi       31-33: Manufactur       0.000000       El kg       @ Poly	<ul><li>® Electricity, at grid R 22</li><li>\$ Gasoline, combusted 22</li></ul>	Category 2: Utilities/2211: Electr 2: Utilities/2213: Water	Amount Unit 0.00000 El kWh 0.00600 El gal (	Provider @ Electricity, Eastern US, 2014 • US US fl) @ Gasoline, combusted in equipment - F	Description Cell V97. RNA Cell Y98.	
S Growout Power an       1.0000 El Item(s)       none         leome       @ G02a: Grow lines       @ G02e: Depth Control(Dr       @ G12: Growout Power and       @ N03: Seawater Filtration/, X       @ N12: Nursery Power and,         puts/Outputs: N03: Seawater Filtration/Sterilization System         nputs       @       Gagory       Amount Unit       Provider       Description       Digital flow meters (cell R154).       UV rterilizer (cell R155).       UV rterilizer (cell R154). <th>Outputs</th> <th></th> <th></th> <th></th> <th></th> <th>0 3</th>	Outputs					0 3
lcome       @ G02a: Grow lines       @ G02c: Depth Control(Dr       @ G12: Growout Power and       @ N03: Seawater Filtration/, X       @ N12: Nursery Power and,         puts/Outputs: N03: Seawater Filtration/Sterilization System         nputs		Category		5 I	Provider Data quali Location Description	n
puts/Outputs: N03: Seawater Filtration/Sterilization System         nputs         Flow       Category       Amount       Unit       Provider       Description         @ Fluid meters and counti       31-33: Manufactur       0.00000       El       USO       @ Fluid meters and counti       Digital flow meters (cell R154).       UV rtrilizer (cell R151).       Eleventiation apparatuses       UV rtrilizer (cell R151).       Storage reservoir/tank/structure (cell U144).       Storage reservoir/tank/structure (cell U147).       Polypinylchloride, PVC,       Storage reservoir/tank/structure (cell U147).       Pilters (fine) • cell U149.       Pilters (fine) • cell U149.       <	\$ Growout Power an		1.00000 El ltem	(s) none		
puts/Outputs: N03: Seawater Filtration/Sterilization System         nputs         Flow       Category       Amount       Unit       Provider       Description         @ Fluid meters and counti       31-33: Manufactur       0.00000       El       USO       @ Fluid meters and counti       Digital flow meters (cell R154).       UV rtrilizer (cell R151).       Eleventiation apparatuses       UV rtrilizer (cell R151).       Storage reservoir/tank/structure (cell U144).       Storage reservoir/tank/structure (cell U147).       Polypinylchloride, PVC,       Storage reservoir/tank/structure (cell U147).       Pilters (fine) • cell U149.       Pilters (fine) • cell U149.       <						
nputs       Category       Amount       Unit       Provider       Description         @ Fluid meters and counti       31-33: Manufactur       0.00000       El       USO       @ Fluid meters and counting devices: US       Digital flow meters (cell R154).       UV rterilizer (cell R151).         @ Fluid meters and counti       31-33: Manufactur       0.0000       El       W2O       @ Fluid meters and counting devices: US       Digital flow meters (cell R154).       UV rterilizer (cell R151).         @ Polytethylene, high densi       31-33: Manufactur       0.00000       El       kg       @ Polytethylene, high density, HOPE, virgin r       Storage reservoir/tank/structure (cell U144).         @ Polytephylene, high densi       31-33: Manufactur       0.00000       El       kg       @ Polytephylene, high density, HOPE, virgin r       Storage reservoir/tank/structure (cell U144).         @ Polytopylene, PP, virgi       31-33: Manufactur       0.00000       El       kg       @ Polytopylene.PP, virgin resin, at plant       Filter cartridges (cell U148).         B Polytopylene, PP, virgi       31-33: Manufactur       0.00000       El       kg       @ Polytopylene.PP, virgin resin, at plant       Filter cartridges (cell U148).         B Polytopylene, PV, virgi       31-33: Manufactur       0.00000       El       kg       @ Polytopy	elcome @ G02a: Grow l	lines @ G02c: Dept	h Control(Dr	) G12: Growout Power and @ N03: Seawat	ter Filtration/, X @ N12: Nursery Power and,	
nputs       Category       Amount       Unit       Provider       Description         @ Fluid meters and counti       31-33: Manufactur       0.00000       El       USO       @ Fluid meters and counting devices: US       Digital flow meters (cell R154).       UV rterilizer (cell R151).         @ Fluid meters and counti       31-33: Manufactur       0.0000       El       W2O       @ Fluid meters and counting devices: US       Digital flow meters (cell R154).       UV rterilizer (cell R151).         @ Polytethylene, high densi       31-33: Manufactur       0.00000       El       kg       @ Polytethylene, high density, HOPE, virgin r       Storage reservoir/tank/structure (cell U144).         @ Polytephylene, high densi       31-33: Manufactur       0.00000       El       kg       @ Polytephylene, high density, HOPE, virgin r       Storage reservoir/tank/structure (cell U144).         @ Polytopylene, PP, virgi       31-33: Manufactur       0.00000       El       kg       @ Polytopylene.PP, virgin resin, at plant       Filter cartridges (cell U148).         B Polytopylene, PP, virgi       31-33: Manufactur       0.00000       El       kg       @ Polytopylene.PP, virgin resin, at plant       Filter cartridges (cell U148).         B Polytopylene, PV, virgi       31-33: Manufactur       0.00000       El       kg       @ Polytopy	nouts/Outputs: N03: 9	Seawater Filtratio	n/Sterilization S	system		
Flow       Category       Amount       Unit       Provider       Description         @ Fluid meters and counti       31-33: Manufactur       0.0000       El       USO       @ Fluid meters and counting devices: US       Digital flow meters (cell R154).         @ Imadiation apparatuses       31-33: Manufactur       0.05785       El       USO       @ Iradiation apparatuses.* US       UV rterilizer (cell R151).         © Polypethylene, high densi       31-33: Manufactur       0.00000       El       kg       @ Polypethylene, high density, HOPE, virgin r       Storage reservoir/tank/structure (cell U144).         © Polypethylene, high densi       31-33: Manufactur       0.00000       El       kg       @ Polypethylene, high density, HOPE, virgin r       Storage reservoir/tank/structure (cell U144).         © Polypropylene, PP, virgi       31-33: Manufactur       0.00000       El       kg       @ Polypropylene.PP, virgin resin, at plant ·       Filter cartridges (cell U148).         © Polypropylene, PP, virgi       31-33: Manufactur       0.00000       El       kg       @ Polypropylene.PP, virgin resin, at plant ·       Filter cartridges (cell U149.         © Polyvinyl chloride, PVC,       31-33: Manufactur       0.00000       El       kg       @ Polyvinyl chloride, PVC, virgin resin; at pl       PVC pipe and fittings (cell U149. </th <th>ipato, e atpato inte e i</th> <th></th> <th></th> <th>yotom</th> <th></th> <th></th>	ipato, e atpato inte e i			yotom		
@ Fluid meters and counti       31-33: Manufactur       0.0000 El       USO       @ Fluid meters and counting devices: US       Digital flow meters (cell R154).         [] Iradiation apparatuses       31-33: Manufactur       0.0000 El       USO       @ Fluid meters and counting devices: US       Digital flow meters (cell R154).         [] Polyethylene, high densi       31-33: Manufactur       0.0000 El       kg       @ Polyethylene, high density, HOPE, virgin r       Storage reservoir/tank/structure (cell U144).         [] Polyethylene, high densi       31-33: Manufactur       0.00000 El       kg       @ Polyethylene, high density, HOPE, virgin r       5-Gal plastic carboys/jugs (cell U188).         [] Polypropylene, PP, virgi       31-33: Manufactur       0.00000 El       kg       @ Polypropylene, PP, virgin resin, at plant,       Filter cartridges (cell U148).         [] Polyvinyl chloride, PVC,       31-33: Manufactur       0.00000 El       kg       @ Polyvinyl chloride, PVC, virgin resin; at plant,       Filters (fine) • cell U149.         [] Polyvinyl chloride, PVC,       31-33: Manufactur       0.00000 El       kg       @ Polyvinyl chloride, PVC, virgin resin; at pl,       PVC pipe and fittings (cell U147).         [] Polyvinyl chloride, PVC,       31-33: Manufactur       0.00000 El       kg       @ Polyvinyl chloride, PVC, virgin resin; at pl,       PVC pipe and fittings (cel	Inputs				O	
@ Fluid meters and counti       31-33: Manufactur       0.0000 El       USO       @ Fluid meters and counting devices: US       Digital flow meters (cell R154).         [] Iradiation apparatuses       31-33: Manufactur       0.0000 El       USO       @ Fluid meters and counting devices: US       Digital flow meters (cell R154).         [] Polyethylene, high densi       31-33: Manufactur       0.0000 El       kg       @ Polyethylene, high density, HOPE, virgin r       Storage reservoir/tank/structure (cell U144).         [] Polyethylene, high densi       31-33: Manufactur       0.00000 El       kg       @ Polyethylene, high density, HOPE, virgin r       5-Gal plastic carboys/jugs (cell U188).         [] Polypropylene, PP, virgi       31-33: Manufactur       0.00000 El       kg       @ Polypropylene, PP, virgin resin, at plant,       Filter cartridges (cell U148).         [] Polyvinyl chloride, PVC,       31-33: Manufactur       0.00000 El       kg       @ Polyvinyl chloride, PVC, virgin resin; at plant,       Filters (fine) • cell U149.         [] Polyvinyl chloride, PVC,       31-33: Manufactur       0.00000 El       kg       @ Polyvinyl chloride, PVC, virgin resin; at pl,       PVC pipe and fittings (cell U147).         [] Polyvinyl chloride, PVC,       31-33: Manufactur       0.00000 El       kg       @ Polyvinyl chloride, PVC, virgin resin; at pl,       PVC pipe and fittings (cel						
Imadiation apparatuses       31-33: Manufactur       0.05785       El       USO       @       Irradiation apparatuses.* US       UV rterilizer (cell R151).         Polyethylene, high densi       31-33: Manufactur       0.0000       El       kg       @       Polyethylene, high density, HOPE, virgin r       Storage reservoir/tank/structure (cell U144).         Polyethylene, high densi       31-33: Manufactur       0.00000       El       kg       @       Polyethylene, high density, HOPE, virgin r       5-Gal plastic carboys/jugs (cell U148).         Polypropylene, PP, virgi       31-33: Manufactur       0.00000       El       kg       @       Polypropylene, PP, virgin resin, at plant <sup>+</sup> Filter cartridges (cell U148).         Polypropylene, PP, virgi       31-33: Manufactur       0.00000       El       kg       @       Polypropylene, PP, virgin resin, at plant <sup>+</sup> Filter cartridges (cell U148).         Polyprinylehoride, PVC,       31-33: Manufactur       0.00000       El       kg       @       Polyprinylencide, PVC, virgin resin; at plant <sup>+</sup> Filter cartridges (cell U149.         Polyvinyl chloride, PVC,       31-33: Manufactur       0.00000       El       kg       @       Polyvinylendioride, PVC, virgin resin; at pl       PVC pipe and fittings (cell U147).         Polyvinyl chloride, PVC,	Flow	Category	Amount Unit	Provider	Description	
<ul> <li>Polyethylene, high densi 31-33: Manufactur 0.00000 El kg @ Polyethylene, high density, HOPE, virgin r Storage reservoir/tank/structure (cell U144).</li> <li>Polyethylene, high densi 31-33: Manufactur 0.00000 El kg @ Polypropylene, PP, virgin resin, at plant<sup>+</sup> Filter cartridges (cell U148).</li> <li>Polypropylene, PP, virgi 31-33: Manufactur 0.00000 El kg @ Polypropylene, PP, virgin resin, at plant<sup>+</sup> Filter cartridges (cell U148).</li> <li>Polyvinyl chloride, PVC, 31-33: Manufactur 0.00000 El kg @ Polyvinyl chloride, PVC, virgin resin; at plant<sup>+</sup> Filters (fine) • cell U149.</li> <li>Polyvinyl chloride, PVC, 31-33: Manufactur 0.00000 El kg @ Polyvinyl chloride, PVC, virgin resin; at plant<sup>+</sup> PVC pipe and fittings (cell U153).</li> <li>Polyvinyl chloride, PVC, 31-33: Manufactur 0.00000 El kg @ Polyvinyl chloride, PVC, virgin resin; at pl PVC pipe and fittings (cell U150).</li> <li>Polyvinyl chloride, PVC, 31-33: Manufactur 0.00000 El kg @ Polyvinyl chloride, PVC, virgin resin; at pl PVC pipe and fittings (cell U150).</li> <li>Polyvinyl chloride, PVC, 31-33: Manufactur 0.00000 El kg @ Polyvinyl chloride, PVC, virgin resin; at pl PVC pipe and fittings (cell U150).</li> <li>Polyvinyl chloride, PVC, 31-33: Manufactur 0.00000 El kg @ Polyvinyl chloride, PVC, virgin resin; at pl PVC pipe and fittings (cell U150).</li> <li>Pumps and pumping eq 31-33: Manufactur 0.00000 El USO @ Pumps and pumping equipment - US</li> <li>Pumps and pumping equipment - US</li> <li>Sand, gravel, clay, phosp 21: Mining, Quarry 0.00000 El USO @ Sand, gravel, clay, phosphate, other non</li> </ul>	Ø Fluid meters and counti	31-33: Manufactur	0.00000 El USO	0	Digital flow meters (cell R154).	
cl       Polyethylene, high density,       31-33: Manufactur       0.00000       El       kg       @       Polyethylene, high density, HOPE, virgin r       5-Gal plastic carboys/jugs (cell UIS8).         @       Polypropylene, PP, virgin.       31-33: Manufactur       0.00000       El       kg       @       Polypropylene, PP, virgin resin, at plant       5-Gal plastic carboys/jugs (cell UIS8).         B       Polypropylene, PP, virgin.       31-33: Manufactur       0.00000       El       kg       @       Polypropylene, PP, virgin resin, at plant       Filter cartridges (cell UI48).         B       Polyvinyl-chloride, PVC,       31-33: Manufactur       0.00000       El       kg       @       Polyvinyl chloride, PVC, virgin resin; at pl       PVC pipe and fittings/pipe supports (cell UI47).         B       Polyvinyl-chloride, PVC,       31-33: Manufactur       0.00000       El       kg       @       Polyvinyl chloride, PVC, virgin resin; at pl       PVC pipe and fittings (cell UI53).         B       Polyvinyl-chloride, PVC,       31-33: Manufactur       0.00000       El       kg       @       Polyvinyl chloride, PVC, virgin resin; at pl       PVC pipe and fittings (cell UI53).         B       Polyvinyl-chloride, PVC,       31-33: Manufactur       0.00000       El       WC       Polyvinyl chloride,	Fo Imadiation apparentuces	31-33: Manufactur	0.05785 El USO	② Irradiation apparatuses.• US	UV rterilizer (cell R151).	
Polypropylene, PP, virgin.        31-33: Manufactur             0.0000 El kg             Polypropylene, PP, virgin resin, at plant·,             Filter cartridges (cell U148).               Polypropylene, PP, virgin.,       31-33: Manufactur            0.0000 El kg           @ Polypropylene, PP, virgin resin, at plant·,            Filter s(fine) • cell U149.                 Polyvinyl chloride, PVC,,             31-33: Manufactur            0.0000 El kg           @ Polyvinyl chloride, PVC, virgin resin; at pl,             PVC pipe and fittings (cell U153).               Polyvinyl chloride, PVC,,             31-33: Manufactur,           0.00000 El kg           @ Polyvinyl chloride, PVC, virgin resin; at pl,             PVC pipe and fittings (cell U153).               Polyvinyl chloride, PVC,,             31-33: Manufactur,           0.00000 El kg           @ Polyvinyl chloride, PVC, virgin resin; at pl,             PVC pipe and fittings (cell U150).               Polyvinyl chloride, PVC,,           31-33: Manufactur,           0.00000 El kg           @ Polyvinyl chloride, PVC, virgin resin; at pl,             PVC pipe and fittings (cell U150).               Polyvinyl chloride, PVC,,           31-33: Manufactur,           0.00000 El kg           @ Polyvinyl chloride, PVC, virgin resin; at pl,             PVC pipe and fittings (cell U150).	LCT madiation apparatuses			@ DI 411 111 1 HODE 1 1	Storogo recominis/tenls/structure (coll U144)	
B Polyropylene, PP, virgi.,       31-33: Manufactur,       0.00000       El       kg       @ Polypropylene. PP, virgin resin, at plant <sup>-</sup> ,       Filters (fine) • cell U149.         Polyvinyl chloride, PVC,       31-33: Manufactur       0.00000       El       kg       @ Polyvinyl chloride, PVC, virgin resin; at pl       PVC pipe and fittings (cell U153).         Polyvinyl chloride, PVC,       31-33: Manufactur       0.00000       El       kg       @ Polyvinyl chloride, PVC, virgin resin; at pl       PVC pipe and fittings (cell U153).         Polyvinyl chloride, PVC,       31-33: Manufactur       0.00000       El       kg       @ Polyvinyl chloride, PVC, virgin resin; at pl       PVC pipe and fittings (cell U150).         Polyvinyl chloride, PVC,       31-33: Manufactur       0.00000       El       kg       @ Polyvinyl chloride, PVC, virgin resin; at pl       PVC pipe and fittings (cell U150).         Polyvinyl chloride, PVC,       31-33: Manufactur       0.00000       El       kg       @ Polyvinyl chloride, PVC, virgin resin; at pl       Freshwater inflow/PVC pipe/fittings (cell U156).         Pumps and pumping eq       31-33: Manufactur       0.00000       El       USO       @ Pumps and pumping equipment - US       Peristatic pump/tubing/valves (cell R145).         § Sand, gravel, clay, phosp       21: Mining, Quarry       0.000000	* *	31-33: Manufactur	0.00000 El kg	W Polyethylene, high density, HOPE, virgin r	Storage reservon/tank/structure (cen 0144).	
Polyvinyl chloride, PVC,       31-33: Manufactur       0.0000       El       kg       @       Polyvinyl chloride, PVC, virgin resin; at pl       PVC pipe and fittings/pipe supports (cell U147).         Polyvinyl chloride, PVC,       31-33: Manufactur       0.00000       El       kg       @       Polyvinyl chloride, PVC, virgin resin; at pl       PVC pipe and fittings (cell U153).         Polyvinyl chloride, PVC,       31-33: Manufactur       0.00000       El       kg       @       Polyvinyl chloride, PVC, virgin resin; at pl       PVC pipe and fittings (cell U150).         Polyvinyl chloride, PVC,       31-33: Manufactur       0.00000       El       kg       @       Polyvinyl chloride, PVC, virgin resin; at pl       PVC pipe and fittings (cell U150).         Polyvinyl chloride, PVC,       31-33: Manufactur       0.00000       El       kg       @       Polyvinyl chloride, PVC, virgin resin; at pl       PVC pipe and fittings (cell U150).         Pumps and pumping eq       31-33: Manufactur       0.00000       El       VS       @       Pumps and pumping equipment - US       Peristatic pumpr/ubing/valves (cell R145).         § Sand, gravel, clay, phosp       21: Mining, Quarry       0.00000       El       USO       @       Sand, gravel, clay, phosphate, other non,       Sand fitters (poolfilters) • cell R146.	Polyethylene, high densi !el Polyethylene, high densi		e	@ Polyethylene, high density, HOPE, virgin r		
el Polyvinyl chloride, PVC,       31-33: Manufactur       0.0000       El kg       @ Polyvinyl chloride, PVC, virgin resin; at pl       PVC pipe and fittings (cell U153).         Polyvinyl chloride, PVC,       31-33: Manufactur       0.0000       El kg       @ Polyvinyl chloride, PVC, virgin resin; at pl       PVC pipe and fittings (cell U153).         Polyvinyl chloride, PVC,       31-33: Manufactur       0.0000       El kg       @ Polyvinyl chloride, PVC, virgin resin; at pl       PVC pipe and fittings (cell U150).         Polyvinyl chloride, PVC,       31-33: Manufactur       0.00000       El kg       @ Polyvinyl chloride, PVC, virgin resin; at pl       PVC pipe and fittings (cell U150).         Pumps and pumping eq       31-33: Manufactur       0.00000       El USO       @ Pumps and pumping equipment - US       Peristaltic pump/tubing/valves (cell R145).         Rubber and plastic belts       31-33: Manufactur       0.00000       El USO       @ Rubber and plastic belts and hoses: US       Hose (cell R157).         §l Sand, gravel, clay, phosp       21: Mining, Quarry       0.00000       El USO       @ Sand, gravel, clay, phosphate, other non,       Sand filters (poolfilters)• cell R146.	<ul> <li>Polyethylene, high densi</li> <li>Polyethylene, high densi</li> <li>Polypropylene, PP, virgi</li> </ul>	31-33: Manufactur 31-33: Manufactur	0.00000 El kg	<ul> <li>@ Polyethylene, high density, HOPE, virgin r</li> <li>@ Polypropylt!!ne., PP, virgin resin, at plant</li> </ul>	5-Gal plastic carboys/jugs (cell U1S8). Filter cartridges (cell U148).	
Polyvinyl chloride, PVC,       31-33: Manufactur       0,0000       El       kg       @       Polyvinyl chloride, PVC, virgin resin; at pl       PVC pipe and fittings (cell U150).         Polyvinyl chloride, PVC,       31-33: Manufactur       0.00000       El       kg       @       Polyvinyl chloride, PVC, virgin resin; at pl       PVC pipe and fittings (cell U150).         Pumps and pumping eq       31-33: Manufactur       0.00000       El       USO       @       Pumps and pumping equipment - US       Peristaltic pump/tubing/valves (cell R145).         Rubber and plastic belts       31-33: Manufactur       0.00000       El       USO       @       Rubber and plastic belts and hoses: US       Hose (cell R157).         §l Sand, gravel, clay, phosp       21: Mining, Quarry       0.00000       El       USO       @       Sand, gravel, clay, phosphate, other non,       Sand filters (poolfilters) • cell R146.	<ul> <li>Polyethylene, high densi</li> <li>Polyethylene, high densi</li> <li>Polypropylene, PP, virgi</li> <li>Polypropylene, PP, virgi</li> </ul>	31-33: Manufactur 31-33: Manufactur 31-33: Manufactur,	0.00000 El kg 0.00000 El kg 0.00000 El kg	<ul> <li>@ Polyethylene, high density, HOPE, virgin r</li> <li>@ Polypropylt!!ne., PP, virgin resin, at plant</li> <li>@ Polypropylene. PP, virgin resin, at plant,</li> </ul>	5-Gal plastic carboys/jugs (cell U188). Filter cartridges (cell U148). Filters (fine) • cell U149.	
Polyvinyl chloride, PVC,       31-33: Manufactur       0.00000       El       kg       @ Polyvinyl chloride, PVC, virgin resin; at pl       Freshwater inflow/PVC pipe/fittings (cell U156).         Pumps and pumping eq       31-33: Manufactur       0.00000       El       USO       @ Pumps and pumping equipment - US       Peri5taltic pump/tubing/valves (cell R145).         Rubber and plastic belts       31-33: Manufactur       0.00000       El       USO       @ Rubber and plastic belts and hoses: US       Hose (cell R157).         §l Sand, gravel, clay, phosp       21: Mining, Quarry       0.00000       El       USO       @ Sand, gravel, clay, phosphate, other non,       Sand filters (poolfilters) cell R146.	<ul> <li>Polyethylene, high densi</li> <li>Polyethylene, high densi</li> <li>Polypropylene, PP, virgi</li> <li>Polypropylene, PP, virgi</li> <li>Polyvinyl chloride, PVC,</li> </ul>	31-33: Manufactur 31-33: Manufactur 31-33: Manufactur, 31-33: Manufactur	0.00000 El kg 0.00000 El kg 0.00000 El kg	<ul> <li>@ Polyethylene, high density, HOPE, virgin r</li> <li>@ Polypropylt!ne., PP, virgin resin, at plant</li> <li>@ Polypropylene. PP, virgin resin, at plant,</li> <li>@ Polyvinyl chloride, PVC, virgin resin; at pl</li> </ul>	5-Gal plastic carboys/jugs (cell U1S8). Filter cartridges (cell U148). Filters (fine) • cell U149. PVC pipe and fittings/pipe supports (cell U147).	
Pumps and pumping eq       31-33: Manufactur       0.00000       El       USO       @ Pumps and pumping equipment - US       Peri5taltic pump/tubing/valves (cell R145).         Rubber and plastic belts       31-33: Manufactur       0.00000       El       USO       @ Rubber and plastic belts and hoses: US       Hose (cell R157).         §I Sand, gravel, clay, phosp       21: Mining, Quarry       0.00000       El       USO       @ Sand, gravel, clay, phosphate, other non,       Sand filters (poolfilters) • cell R146.	<ul> <li>Polyethylene, high densi</li> <li>Polyethylene, high densi</li> <li>Polypropylene, PP, virgi</li> <li>Polypropylene, PP, virgi</li> <li>Polypropylene, PV, virgi</li> <li>Polyvinyl chloride, PVC,</li> <li>Polyvinyl chloride, PVC,</li> </ul>	<ul> <li>31-33: Manufactur</li> <li>31-33: Manufactur</li> <li>31-33: Manufactur,</li> <li>31-33: Manufactur</li> <li>31-33: Manufactur</li> </ul>	0.00000 El kg 0.00000 El kg 0.00000 El kg 0.00000 El kg 0.00000 El kg	<ul> <li>@ Polyethylene, high density, HOPE, virgin r</li> <li>@ Polypropylt!ne, PP, virgin resin, at plant,</li> <li>@ Polypropylene. PP, virgin resin, at plant,</li> <li>@ Polyvinyl chloride, PVC, virgin resin; at pl</li> <li>@ Polyvinyl chloride, PVC, virgin resin; at pl</li> </ul>	5-Gal plastic carboys/jugs (cell U1S8). Filter cartridges (cell U148). Filters (fine) • cell U149. PVC pipe and fittings/pipe supports (cell U147). PVC pipe and fittings (cell U153).	
Rubber and plastic belts       31-33: Manufactur       0.00000       El       USO       @ Rubber and plastic belts and hoses: US       Hose (cell R157).         §1 Sand, gravel, clay, phosp       21: Mining, Quarry       0.00000       El       USO       @ Sand, gravel, clay, phosphate, other non,       Sand filters (poolfilters) cell R146.	<ul> <li>Polyethylene, high densi</li> <li>Polyethylene, high densi</li> <li>Polypropylene, PP, virgi</li> <li>Polypropylene, PP, virgi</li> <li>Polyvinyl chloride, PVC,</li> <li>Polyvinyl chloride, PVC,</li> <li>Polyvinyl chloride, PVC,</li> </ul>	<ol> <li>31-33: Manufactur</li> <li>31-33: Manufactur</li> <li>31-33: Manufactur</li> <li>31-33: Manuf actur</li> <li>31-33: Manufactur</li> <li>31-33: Manufactur</li> </ol>	0.00000         E1         kg	<ul> <li>@ Polyethylene, high density, HOPE, virgin r</li> <li>@ Polypropylt!ne, PP, virgin resin, at plant,</li> <li>@ Polypropylene. PP, virgin resin, at plant,</li> <li>@ Polyvinyl chloride, PVC, virgin resin; at pl</li> <li>@ Polyvinyl chloride, PVC, virgin resin; at pl</li> <li>@ Polyvinyl chloride, PVC, virgin resin; at pl</li> </ul>	5-Gal plastic carboys/jugs (cell U1S8). Filter cartridges (cell U148). Filters (fine) • cell U149. PVC pipe and fittings/pipe supports (cell U147). PVC pipe and fittings (cell U153). PVC pipe and fittings (cell U150).	
§I Sand, gravel, clay, phosp 21: Mining, Quarry 0.00000 El USO @ Sand, gravel, clay, phosphate, other non, Sand filters (poolfilters)* cell R146.	<ul> <li>Polyethylene, high densi</li> <li>Polyptopylene, PP, virgi</li> <li>Polypropylene, PP, virgi</li> <li>Polypropylene, PP, virgi,</li> <li>Polyvinyl chloride, PVC,</li> <li>Polyvinyl chloride, PVC,</li> <li>Polyvinyl chloride, PVC,</li> </ul>	<ol> <li>31-33: Manufactur</li> <li>31-33: Manufactur</li> <li>31-33: Manufactur,</li> <li>31-33: Manufactur</li> <li>31-33: Manufactur</li> <li>31-33: Manufactur</li> <li>31-33: Manufactur</li> </ol>	0.00000         El         kg	<ul> <li>@ Polyethylene, high density, HOPE, virgin r</li> <li>@ Polypropylt!ne, PP, virgin resin, at plant,</li> <li>@ Polypropylene. PP, virgin resin, at plant,</li> <li>@ Polyvinyl chloride, PVC, virgin resin; at pl</li> </ul>	5-Gal plastic carboys/jugs (cell U1S8). Filter cartridges (cell U148). Filters (fine) • cell U149. PVC pipe and fittings/pipe supports (cell U147). PVC pipe and fittings (cell U153). PVC pipe and fittings (cell U150). Freshwater inflow/PVC pipe/fittings (cell U156).	
	<ul> <li>Polyethylene, high densi</li> <li>Polypropylene, PP, virgi</li> <li>Polypropylene, PP, virgi</li> <li>Polyvinyl chloride, PPC,</li> <li>Polyvinyl chloride, PVC,</li> <li>Pumps and pumping eq</li> </ul>	<ul> <li>31-33: Manufactur</li> </ul>	0.00000         El         kg	<ul> <li>@ Polyethylene, high density, HOPE, virgin r</li> <li>@ Polypropyltt!ne, PP, virgin resin, at plant</li> <li>@ Polyvinyl chloride, PVC, virgin resin; at pl</li> <li>@ Polysinyl chloride, PVC, virgin resin; at pl</li> <li>@ Polysinyl chloride, PVC, virgin resin; at pl</li> </ul>	5-Gal plastic carboys/jugs (cell U1S8). Filter cartridges (cell U148). Filters (fine) • cell U149. PVC pipe and fittings/pipe supports (cell U147). PVC pipe and fittings (cell U153). PVC pipe and fittings (cell U150). Freshwater inflow/PVC pipe/fittings (cell U156). Peri5taltic pump/tubing/valves (cell R145).	
	<ul> <li>Polyethylene, high densi</li> <li>Polypropylene, PP, virgi</li> <li>Polypropylene, PP, virgi</li> <li>Polypropylene, PP, virgi</li> <li>Polyvinyl chloride, PVC,</li> <li>Polyvinyl chloride, PVC,</li> <li>Polyvinyl chloride, PVC,</li> <li>Polyvinyl chloride, PVC,</li> <li>Polysinyl chloride, PVC,</li> <li>Polysinyl chloride, PVC,</li> <li>Rubber and pumping eq</li> <li>Rubber and plastic belts</li> </ul>	<ul> <li>31-33: Manufactur</li> </ul>	0.00000         El         kg           0.00000         El         kg	<ul> <li>@ Polyethylene, high density, HOPE, virgin r</li> <li>@ Polypropyltt!ne., PP, virgin resin, at plant</li> <li>@ Polypropylene. PP, virgin resin, at plant,</li> <li>@ Polyvinyl chloride, PVC, virgin resin; at pl</li> <li>@ Pulyvinyl chloride, PVC, virgin resin; at pl</li> <li>@ Pulyvinyl chloride, PVC, virgin resin; at pl</li> <li>@ Rubber and plastic belts and hoses- US</li> </ul>	5-Gal plastic carboys/jugs (cell U1S8). Filter cartridges (cell U148). Filters (fine) • cell U149. PVC pipe and fittings/pipe supports (cell U147). PVC pipe and fittings (cell U153). PVC pipe and fittings (cell U150). Freshwater inflow/PVC pipe/fittings (cell U156). Peri5taltic pump/tubing/valves (cell R145). Hose (cell R157).	
	<ul> <li>Polyethylene, high densi</li> <li>Polyethylene, high densi</li> <li>Polypropylene, PP, virgi</li> <li>Polypropylene, PP, virgi</li> <li>Polyvinyl chloride, PVC,</li> <li>Polyvinyl chloride, PVC,</li> <li>Polyvinyl chloride, PVC,</li> </ul>	<ol> <li>31-33: Manufactur</li> <li>31-33: Manufactur</li> <li>31-33: Manufactur</li> <li>31-33: Manuf actur</li> <li>31-33: Manufactur</li> <li>31-33: Manufactur</li> </ol>	0.00000         E1         kg	<ul> <li>@ Polyethylene, high density, HOPE, virgin r</li> <li>@ Polypropylt!ne, PP, virgin resin, at plant,</li> <li>@ Polypropylene. PP, virgin resin, at plant,</li> <li>@ Polyvinyl chloride, PVC, virgin resin; at pl</li> <li>@ Polyvinyl chloride, PVC, virgin resin; at pl</li> <li>@ Polyvinyl chloride, PVC, virgin resin; at pl</li> </ul>	5-Gal plastic carboys/jugs (cell U1S8). Filter cartridges (cell U148). Filters (fine) • cell U149. PVC pipe and fittings/pipe supports (cell U147). PVC pipe and fittings (cell U153). PVC pipe and fittings (cell U150).	
	Polyethylene, high densi Polypthylene, high densi Polypropylene, PP, virgi Polypropylene, PP, virgi Polyvinyl chloride, PVC, Polyvinyl chloride, PVC, Polyvinyl chloride, PVC, Polyvinyl chloride, PVC, Pumps and pumping eq Rubber and plastic belts	<ul> <li>31-33: Manufactur</li> </ul>	0.00000         El         kg           0.00000         El         kg	<ul> <li>@ Polyethylene, high density, HOPE, virgin r</li> <li>@ Polypropyltt!ne., PP, virgin resin, at plant</li> <li>@ Polypropylene. PP, virgin resin, at plant,</li> <li>@ Polyvinyl chloride, PVC, virgin resin; at pl</li> <li>@ Pulyvinyl chloride, PVC, virgin resin; at pl</li> <li>@ Pulyvinyl chloride, PVC, virgin resin; at pl</li> <li>@ Rubber and plastic belts and hoses- US</li> </ul>	5-Gal plastic carboys/jugs (cell U1S8). Filter cartridges (cell U148). Filters (fine) • cell U149. PVC pipe and fittings/pipe supports (cell U147). PVC pipe and fittings (cell U153). PVC pipe and fittings (cell U150). Freshwater inflow/PVC pipe/fittings (cell U156). Peri5taltic pump/tubing/valves (cell R145). Hose (cell R157).	
	Polyethylene, high densi Polyethylene, high densi Polypropylene, PP, virgi Polypropylene, PP, virgi Polyvinyl chloride, PVC, Polyvinyl chloride, PVC, Polyvinyl chloride, PVC, Polyvinyl chloride, PVC, Rubber <b>and</b> plastic belts Sand, gravel, clay, phosp Shelving and lockers	<ul> <li>31-33: Manufactur</li> </ul>	0.00000         E1         kg           0.00000         E1         USO           0.00000         E1         USO	<ul> <li>@ Polyethylene, high density, HOPE, virgin r</li> <li>@ Polypropylt!ne, PP, virgin resin, at plant,</li> <li>@ Polypropylene. PP, virgin resin, at plant,</li> <li>@ Polyvinyl chloride, PVC, virgin resin; at pl</li> <li>@ Pumps and pumping equipment - US</li> <li>@ Rubber and plastic belts and hosses US</li> <li>@ Sand, gravel, clay, phosphate, other non,</li> </ul>	5-Gal plastic carboys/jugs (cell U1S8). Filter cartridges (cell U148). Filters (fine) • cell U149. PVC pipe and fittings/pipe supports (cell U147). PVC pipe and fittings (cell U153). PVC pipe and fittings (cell U150). Freshwater inflow/PVC pipe/fittings (cell U156). Peri5taltic pump/tubing/valves (cell R145). Hose (cell R157). Sand filters (poolfilters) • cell R146. Racks/table (cell R155).	
Outputs	<ul> <li>Polyethylene, high densi</li> <li>Polyethylene, high densi</li> <li>Polypropylene, PP, virgi</li> <li>Polypropylene, PP, virgi</li> <li>Polyvinyl chloride, PVC,</li> <li>Solyvinyl chloride, P</li></ul>	<ul> <li>31-33: Manufactur</li> </ul>	0.00000         E1         kg           0.00000         E1         USO           0.00000         E1         USO	<ul> <li>@ Polyethylene, high density, HOPE, virgin r</li> <li>@ Polypropylt!ne, PP, virgin resin, at plant,</li> <li>@ Polypropylene. PP, virgin resin, at plant,</li> <li>@ Polyvinyl chloride, PVC, virgin resin; at pl</li> <li>@ Pumps and pumping equipment - US</li> <li>@ Rubber and plastic belts and hosses US</li> <li>@ Sand, gravel, clay, phosphate, other non,</li> </ul>	5-Gal plastic carboys/jugs (cell U1S8). Filter cartridges (cell U148). Filters (fine) • cell U149. PVC pipe and fittings/pipe supports (cell U147). PVC pipe and fittings (cell U153). PVC pipe and fittings (cell U150). Freshwater inflow/PVC pipe/fittings (cell U156). Peri5taltic pump/tubing/valves (cell R145). Hose (cell R157). Sand filters (poolfilters) • cell R146. Racks/table (cell R155).	0
	<ul> <li>Polyethylene, high densi</li> <li>Polypropylene, PP, virgi</li> <li>Polypropylene, PP, virgi</li> <li>Polypropylene, PP, virgi</li> <li>Polyvinyl chloride, PVC,</li> <li>Rubber and plastic betts</li> <li>t§l Sand, gravel, clay, phosp</li> <li>Shelving and lockers</li> </ul>	<ul> <li>31-33: Manufactur</li> <li>21: Mining, Quarry</li> <li>31-33: Manufactur</li> </ul>	0.00000         El         kg           0.00000         El         USO           0.00000         El         USO           0.00000         El         USO	<ul> <li>@ Polyethylene, high density, HOPE, virgin r</li> <li>@ Polypropylt!!ne, PP, virgin resin, at plant,</li> <li>@ Polypropylene. PP, virgin resin, at plant,</li> <li>@ Polyvinyl chloride, PVC, virgin resin; at pl</li> <li>@ Pumps and pumping equipment - US</li> <li>@ Rubber and plastic belts and hoses: US</li> <li>@ Sand, gravel, clay, phosphate, other non,</li> <li>@ Shelving and lockers: US</li> </ul>	5-Gal plastic carboys/jugs (cell U1S8). Filter cartridges (cell U148). Filters (fine) • cell U149. PVC pipe and fittings/pipe supports (cell U147). PVC pipe and fittings (cell U153). PVC pipe and fittings (cell U150). Freshwater inflow/PVC pipe/fittings (cell U156). Peristaltic pump/tubing/valves (cell R145). Hose (cell R157). Sand filters (poolfilters)• cell R146. Racks/table (cell R155).	

# @ Inputs/Outputs: N12: Nursery Power and Fuel Requirements

Inputs							<b>Ox</b> 11
-	icity, at grid • RNA ine., combu5ted in equipment	Category 22: Utilities/ 22: Utilities/	Amount Unit 0.01100 El kWh 0.00000 El gal (US	Provider @ Electricity, Eastern US, 2014 • @ Gasoline, combusted in equip			
т Outputs							<b>0</b> x ,.,
Flow \$ Nurse	Category ery Power and		Amount Unit 1.00000 El ltem(s)	Costs/Rev Uncertainty Avoided none	p Provider	Data quali Loca	ation Description

#### 

# 🗟 Inputs/Outputs: AA: Seed Spool

-	In	DU	40

Flow	Amount	Unit	Provider	Data qu
Nursery Facility and Capital Expenditures Set	0.00000	💷 ltem(s)	N01a: Nursery Facility and Capital Expenditures (Water Transported in)	
🕸 Nursery Facility and Capital Expenditures Set	1.00000	💷 ltem(s)	N01b: Nursery Facility and Capital Expenditures (Water Pumped In)	
🕸 Seawater Transport and Containment System Set	0.00000	💷 ltem(s)	N02a: Seawater Transport and Containment System (Water Transported In)	
🕸 Seawater Transport and Containment System Set	1.00000	💷 ltem(s)	N02b: Seawater Transport and Containment System (Water Pumped In)	
Seawater Filtration/Sterilization System Set	1.00000	🛄 ltem(s)	N03: Seawater Filtration/Sterilization System	
Collection of Sorus Tissue Set	1.00000	💷 ltem(s)	N04: Collection of Sorus Tissue	
Nursery Tank Culture System Set	1.00000	💷 ltem(s)	N05: Nursery Tank Culture System	
🕸 Light System Set	1.00000	🛄 ltem(s)	N06: Light System	
Aeration System Set	1.00000	💷 ltem(s)	N07: Aeration System	
🕸 Seed Spools Set	1.00000	💷 ltem(s)	N08: Seed Spools	
Laboratory Equipment Set	1.00000	💷 ltem(s)	N09: Laboratory Equipment	
Nutrient Media and Seawater Additives Set	1.00000	💷 ltem(s)	N10: Nutrient Media and Seawater Additives	
Office Equipment Set	1.00000	💷 ltem(s)	N11: Office Equipment	
3 Nursery Power and Fuel Requirements Set	1.00000	Item(s)	N12: Nursery Power and Fuel Requirements	

¢

(

### - Outputs

Flow Seed Spool	Category	Amount 1.00000	Costs/Rev	Uncertainty none	Avoided p	Provider	Data quali	Location	Description

## ♠ Welcome 🔄 BB: Harvested Kelp 🗙

# 5 Inputs/Outputs: BB: Harvested Kelp

•	Inputs
---	--------

Flow	Amount	Unit	Provider	Data quali
🕸 Grow Lines Set	1.00000	Item(s)	G02a: Grow Lines	
Mooring/Anchor System Set	1.00000	💷 Item(s)	G02b: Mooring/Anchor System	
🕸 Droppers Set	1.00000	💷 Item(s)	G02c: Depth Control (Droppers)	
Site Marking and Navigational Aids Set	1.00000	💷 Item(s)	G02d: Site Marking and Navigational Aids	
🕸 Storage Facility for Gear Set	1.00000	💷 Item(s)	603: Storage Facility for Gear	
🕸 Boat, Engine, Equipment Set	1.00000	💷 ltem(s)	G04: Boat, Engine, Equipment	
Truck/Trailer Set	1.00000	🛄 ltem(s)	G05: Truck/Trailer	
Container/Totes Set	1.00000	🛄 Item(s)	G06: Containers/Totes to Hold Longline for Storage and/or Transport	
Protective Clothing/Equipment	1.00000	💷 ltem(s)	G07: Protective Clothing/Equipment	
🕸 Gear for Setting and Seeding the Farm Set	1.00000	💷 ltem(s)	G08: Gear for Setting and Seeding the Farm	
6 Gear for Harvesting Set	1.00000	💷 ltem(s)	G09: Gear for Harvesting	
Gear for Off-Season Maintenance	1.00000	💷 ltem(s)	G10: Gear for Off-Season Maintenance	
Office Equipment Set	1.00000	🛄 ltem(s)	G11: Office Equipment	
3 Growout Power and Fuel Requirements Set	1.00000	Item(s)	G12: Growout Power and Fuel Requirements	

- Outputs

Flow	Category	Amount	Unit	Costs/Rev	Uncertainty	Avoided p	Provider	Data quali	Location	C
🕸 Fresh Kelp		1.00000	💷 Ib av		none					

xxiv. The next step is to create a Product System that integrates all the information from the model processes to compute the environmental impact assessment associated with one pound of fresh kelp. This is done by clicking the tab 'General Information' in the process 'BB: Harvested Kelp'.

A Welcome	₽ BB: Harvested Kelp ×
<b>₽</b> General	information: BB: Harvested Kelp
	oformation
Name	BB: Harvested Kelp
Category	Sea_Grant_Kelp
Description	
Tags	Version 00.00.008 (a) (c) Last change 2024-07-31 21:57:39 UUID 55204103-a333-4 Add a tag
milastructu	Create product system

xxv. The new Product System will automatically be labeled as 'BB: Harvested Kelp'. There is no need to change any other options. Click on 'Finish' to create the system, which will be stored in the folder 'Product systems'.



xxvi. A 'Calculate' button will be found in the 'General Information' tab of the Product System. Click on it. 🚠 General information: BB: Harvested Kelp

✓ General inf	ormation
Name	BB: Harvested Kelp
Category	- none -
Description	First created: 2024-07-31T22:12:33 Linking approach during creation: Prefer default providers; Preferred pr
	Version 00.00.000 (a) (a) Last change 2024-07-31 22:12:33
Tags	Add a tag
	O Calculate

xxvii. The default options in the 'Calculation Properties' window will suffice for the analysis. 'ReCiPe 2016 – Midpoint/H' can be selected as the Impact Assessment Method. Click on 'Finish'.

Calculation properties		_		$\times$
Calculation properties				
Please select the properties for the	calculation			
Allocation method	As defined in processes			~
Impact assessment method	👷 ReCiPe 2016 - Midpoint/H			~
Normalization and weighting set				~
Calculation type	Lazy/On-demand      Cager/All	O Monte Ca	irlo Simula	tion
	Regionalized calculation			
	Include cost calculation			
	Assess data quality			
	< Back Next >	Finish	Canc	el

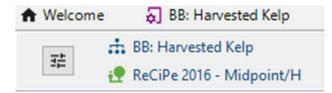
xxviii. A Results panel with nine different tabs will be generated by openLCA. To obtain a quick summary of the results, click on the tab 'Impact Analysis'. This tab presents the results of 18 different impact categories. According to the assumptions used in the example, the production of one pound of fresh kelp releases 0.092 kg CO<sub>2</sub>-eq (Global Warming) and

3.024E-7 kg N-eq to marine water (Marine Eutrophication).

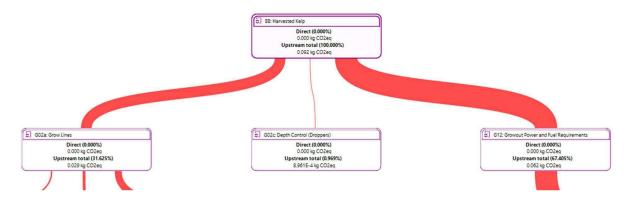
xxix. Notice that impacts can be sub-grouped by flows or processes (upper portion of the panel). Check the radio button for Processes and expand the Global Warming category. The different processes contributing carbon emissions will be listed in descending order of importance. The process 'Gasoline, combusted in equipment – RNA' contributed over 50% (0.04858 kg CO<sub>2</sub>-eq) of total emissions.

Impact analysis - ReCiPe 2016 - Midpoint/H Sub-group by OFlows OProcesses   Don't show	v < 1 🔹 %			
Name	Category	I	Ch	Impact assessment resul
> Ecosystem damage ozone formation	ReCiPe 2016 - Midpoint/H			0.00089 kg NOx-e
> E Fossil resource scarcity	ReCiPe 2016 - Midpoint/H			0.00523 kg oil-e
> Freshwater ecotoxicity	ReCiPe 2016 - Midpoint/H			2.04818E-5 1,4-DCB eq. emitted to freshwate
> Freshwater eutrophication	ReCiPe 2016 - Midpoint/H			1.16094E-7 kg P-eq. to freshwat
Global Warming	ReCiPe 2016 - Midpoint/H			0.09246 kg CO2e
> 🔄 Gasoline, combusted in equipment - RNA	22: Utilities/2213: Water, Sewage and Other Systems			<ul> <li>0.04858 kg CO2e</li> </ul>
> 🔄 Steel, stainless 304, flat rolled coil - RNA	31-33: Manufacturing/3311: Iron and Steel Mills and Ferro			0.01045 kg CO2e
> 😓 Steel, stainless 304, scrap - GLO	31-33: Manufacturing/3311: Iron and Steel Mills and Ferro			0.00817 kg CO2e
> 🔄 Aluminum, primary ingot, at plant - RNA	31-33: Manufacturing/3313: Alumina and Aluminum Prod			0.00690 kg CO2e
> 🔄 Petroleum refining, at refinery - US	31-33: Manufacturing/3241: Petroleum and Coal Products			1 0.00373 kg CO2e
> 🔄 Crude oil, on-shore import, at extraction - US	21: Mining, Quarrying, and Oil and Gas Extraction/2111: O			1 0.00283 kg CO2e
> 5 Crude oil, on-shore domestic, at extraction - US	21: Mining, Quarrying, and Oil and Gas Extraction/2111: O			1 0.00243 kg CO2e
> 🗄 Human carcinogenic toxicity	ReCiPe 2016 - Midpoint/H			0.00047 1,4-DCB eq. emitted to urban a
> 🚊 Human damage ozone formation	ReCiPe 2016 - Midpoint/H			0.00088 kg NOx-e
> 🗄 Human noncarcinogenic toxicity	ReCiPe 2016 - Midpoint/H			0.00535 1,4-DCB eq. emitted to urban a
> E lonizing radiation	ReCiPe 2016 - Midpoint/H			7.13980E5 kBq Co-60 to air e
> 🗄 Land occupation	ReCiPe 2016 - Midpoint/H			0.00079 m2
> 🗄 Marine ecotoxicity	ReCiPe 2016 - Midpoint/H			0.00016 1,4-DCB eq. emitted to seawat
> = Marine eutrophication	ReCiPe 2016 - Midpoint/H			3.02357E-7 kg N-eg to marine wat

xxx. The tab 'Sankey Diagram' offers another useful way to visualize the results. Click on the upper left-hand icon to select the impact category Global Warming.



xxxi. The Sankey Diagram reveals how different processes in the model contribute to the impact category, Global Warming in this case. 'G02a: Grow Lines' contributes about 32% of emissions while 'G12: Growout Power and Fuel Requirements' accounts for 67% of emissions. The impact of 'G02c: Depth Control' is much lower (about 1%). 'Gasoline, combusted in equipment' directly contributes most of the emissions to 'G12' but upstream processes release some emissions as well. Regarding 'G02a: Grow Lines', most emissions are accounted for by 'Steel, stainless' (20% of total). Under the assumptions made, the nursery phase ('AA: Seed Spool') contributes relatively few emissions (4% of total).



# 3) Estimation of Ecosystem Services – Carbon Sequestration and Nutrient Removal.

The results from the openLCA model can be used to estimate potential revenue streams from ecosystem services such as carbon sequestration and nutrient removal. To this end, the user needs to refer back to the '2(b). Start up farm – LCA' worksheet, cells AE68 : AN101.

i. Carbon Sequestration: The openLCA Global Warming impact category in the preceding example revealed that 0.09246 kg CO<sub>2</sub>-eq per pound of fresh kelp were released by the hypothetical farm. This value is to be entered in cell AF97. The remaining cells in the module estimate the amount of CO<sub>2</sub> that is exported from the farm and sequestered in sediments. This amount is separate from the carbon incorporated to the kelp biomass through photosynthesis; in other words, the carbon removed through harvest is not included in the sequestration calculations.

The parameters used in the model will vary according to the type of substrate in the farm: muddy or coarse. This distinction is made as muddy substrates are associated with sheltered locations and a higher rate of sediment deposition. The user is asked to indicate the choice of sediment in cell AG72.

The amount of carbon sequestration is contrasted with the positive emissions from the farm in order to estimate net CO<sub>2</sub> emissions. If negative (i.e., sequestration exceeds positive emissions), an additional revenue flow is computed in cells AF101 : AH101, which assumes a carbon price of \$30 per ton of CO<sub>2</sub>-eq.

ii. Nutrient Removal: this module computes the amount of N and P removed through the harvesting of kelp and compares it to the amounts of N and P eutrophication resulting from the LCA model. In the previous example, Marine Eutrophication was estimated at 3.02357E-7 kg N-eq while Freshwater Eutrophication was found to be 1.16094E-7 kg P-eq.

# E BB: Harvested Kelp

Impact analysis - ReCiPe 2016 - Midpoint/H

Sub-group by OFlows OProcesses | Don't show < 1 🚔 %

Name	Category	Invent	Characte	Impact assessment result
> Ecosystem damage ozone formation	ReCiPe 2016 - Midpoint/H			0.00089 kg NOx-eq
> E Fossil resource scarcity	ReCiPe 2016 - Midpoint/H			0.00523 kg oil-eq
> Freshwater ecotoxicity	ReCiPe 2016 - Midpoint/H			2.04818E-5 1,4-DCB eq. emitted to freshwater
> E Freshwater eutrophication	ReCiPe 2016 - Midpoint/H			1.16094E-7 kg P-eq. to freshwater
> 🗧 Global Warming	ReCiPe 2016 - Midpoint/H			0.09246 kg CO2eq
> 🚊 Human carcinogenic toxicity	ReCiPe 2016 - Midpoint/H			0.00047 1,4-DCB eq. emitted to urban air
> 🗄 Human damage ozone formation	ReCiPe 2016 - Midpoint/H			0.00088 kg NOx-eq
> 🗄 Human noncarcinogenic toxicity	ReCiPe 2016 - Midpoint/H			0.00535 1,4-DCB eq. emitted to urban air
> E lonizing radiation	ReCiPe 2016 - Midpoint/H			7.13980E5 kBq Co-60 to air eq
> E Land occupation	ReCiPe 2016 - Midpoint/H			0.00079 m2*a
> \Xi Marine ecotoxicity	ReCiPe 2016 - Midpoint/H			0.00016 1,4-DCB eq. emitted to seawater
> E Marine eutrophication	ReCiPe 2016 - Midpoint/H			3.02357E-7 kg N-eq to marine water
> E Mineral resource scarcity	ReCiPe 2016 - Midpoint/H			0.00160 kg Cu-eq
> E Particulate matter formation	ReCiPe 2016 - Midpoint/H			0.00015 kg PM2.5-eq
> \Xi Stratospheric ozone depletion	ReCiPe 2016 - Midpoint/H			2.87750E-8 kg CFC11-eq
> E Terrestrial acidification	ReCiPe 2016 - Midpoint/H			0.00046 kg SO2-eq
> E Terrestrial ecotoxicity	ReCiPe 2016 - Midpoint/H			0.24594 1,4-DCB eq. emitted to industrial soil
> E Water consumption	ReCiPe 2016 - Midpoint/H			0.05896 m3

These values are to be entered in cells AL83 and AL84, respectively. If the amount of nutrient removal exceeds the nutrient releases from the LCA model, additional revenue streams are computed in cells AL89 : AN90. The N and P prices are estimated at \$20/kg and \$4/kg, respectively.

For questions and further information on the model, contact: Diego Valderrama, Assistant Professor Department of Environmental Science and Policy George Mason University dvalder@gmu.edu https://science.gmu.edu/directory/diego-valderrama

Financial support provided by NOAA Sea Grant award NA21OAR4170087.