Rice LCAs for Arkansas: A simple overview of a complex process

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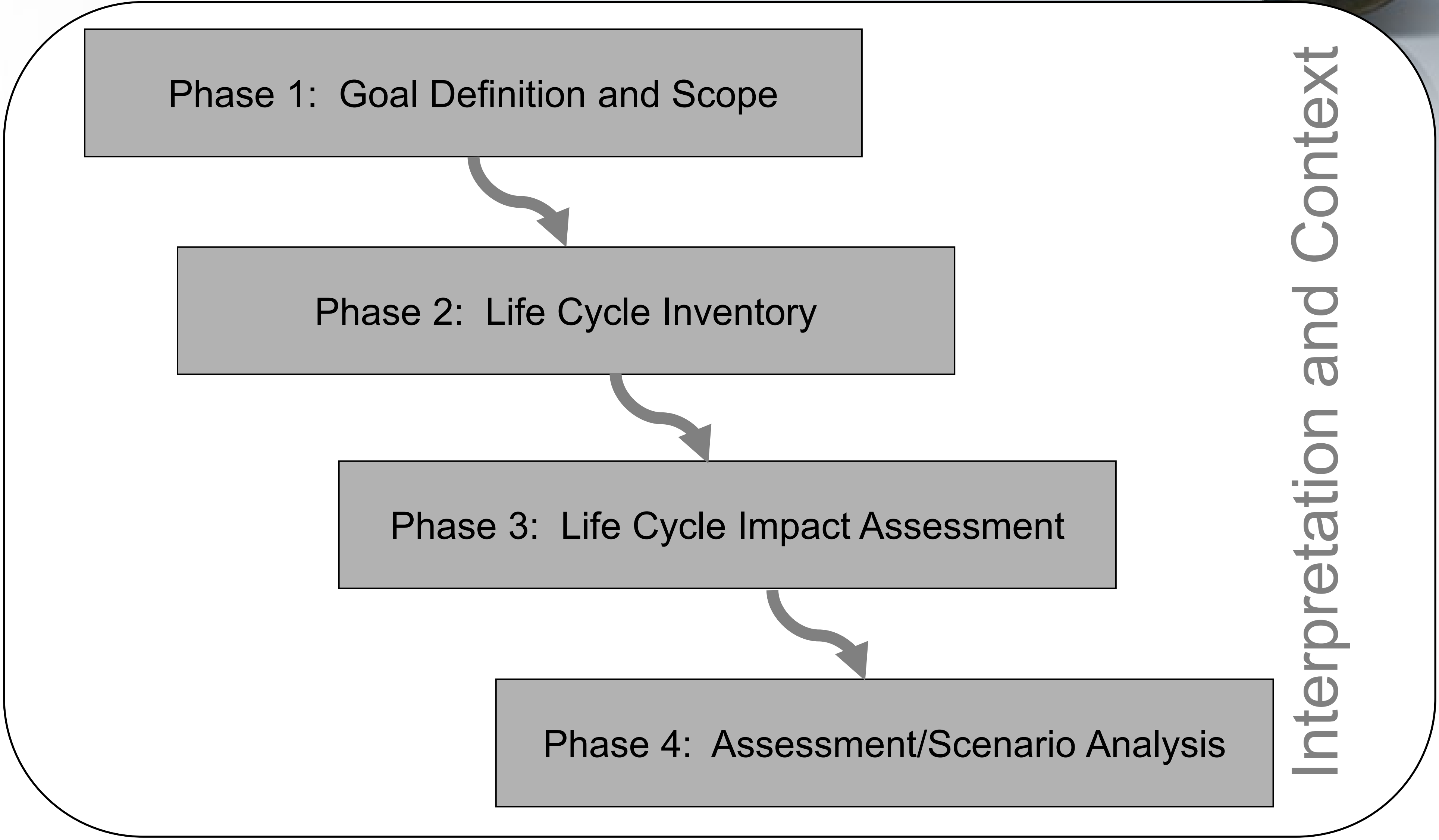
Presentation prepared for the Rice Sustainability Verification Short Course, Jonesboro, Arkansas. January 11, 2024

Four Phases of a Life Cycle Assessment



Phase 1: Goal Definition and Scope

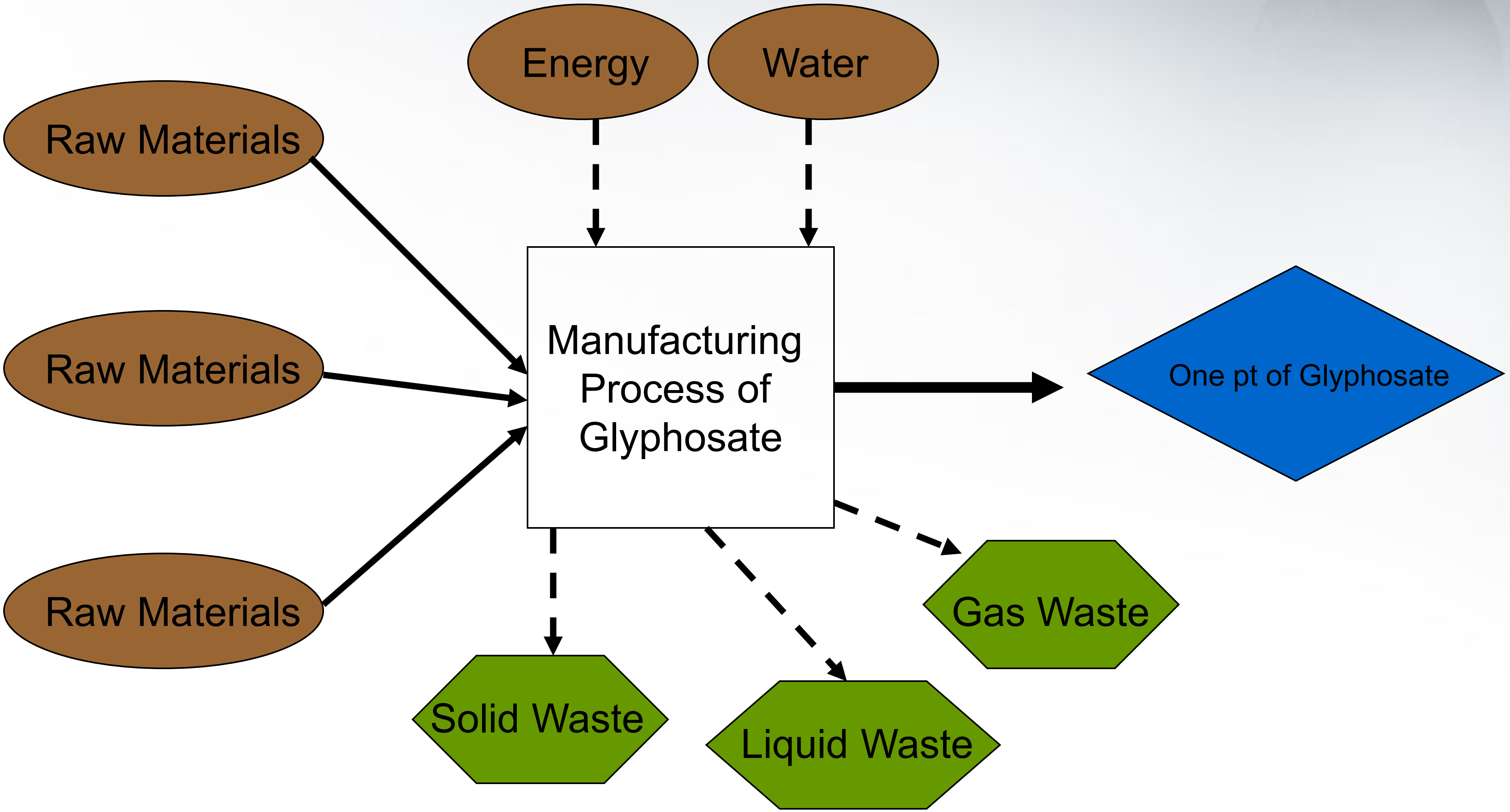
Phase 2: Life Cycle Inventory

Phase 3: Life Cycle Impact Assessment

Phase 4: Assessment/Scenario Analysis

Interpretation and Context

Every process has inputs and outputs



Energy

Water

Raw Materials

Raw Materials

Raw Materials

Manufacturing Process of Glyphosate

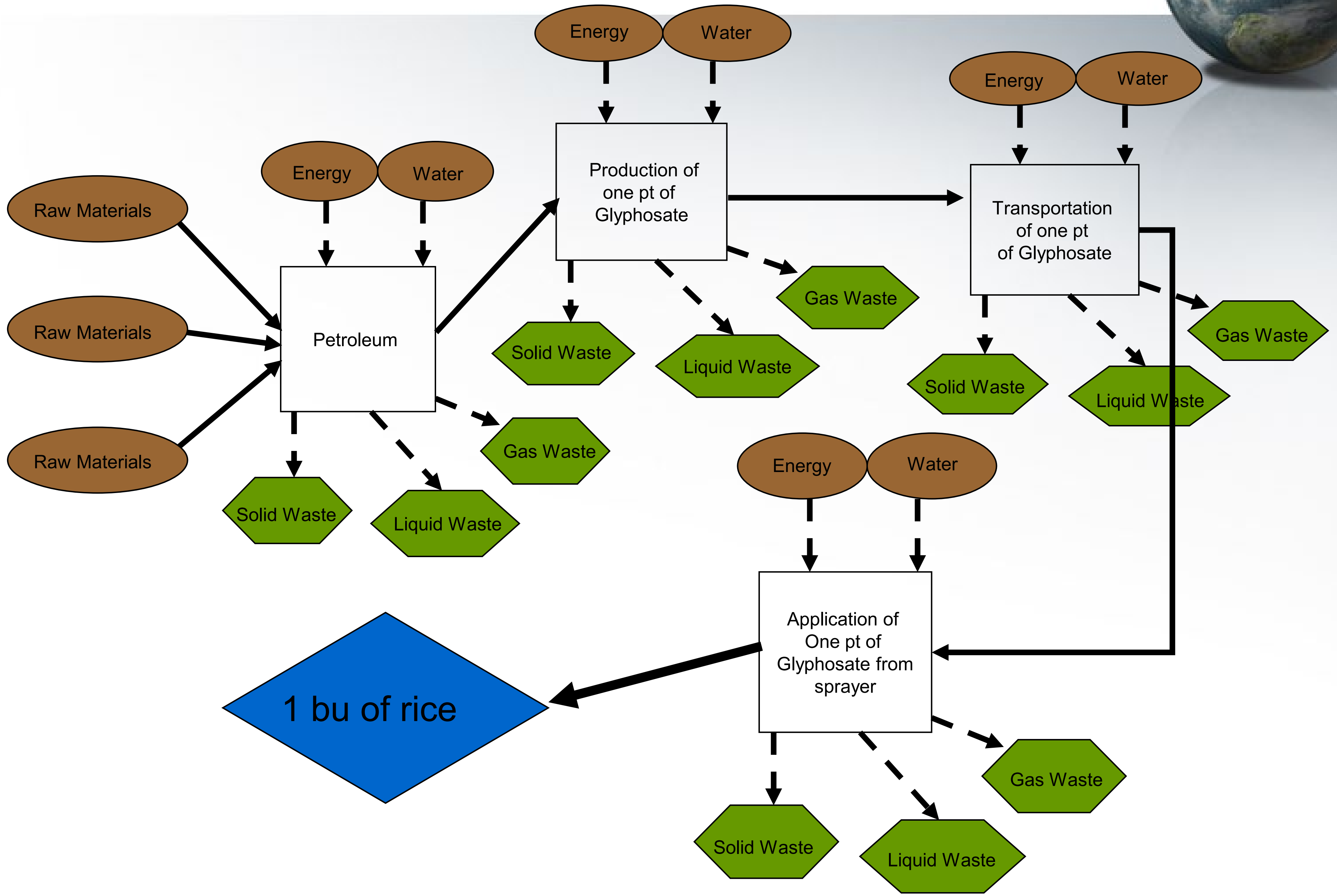
One pt of Glyphosate

Gas Waste

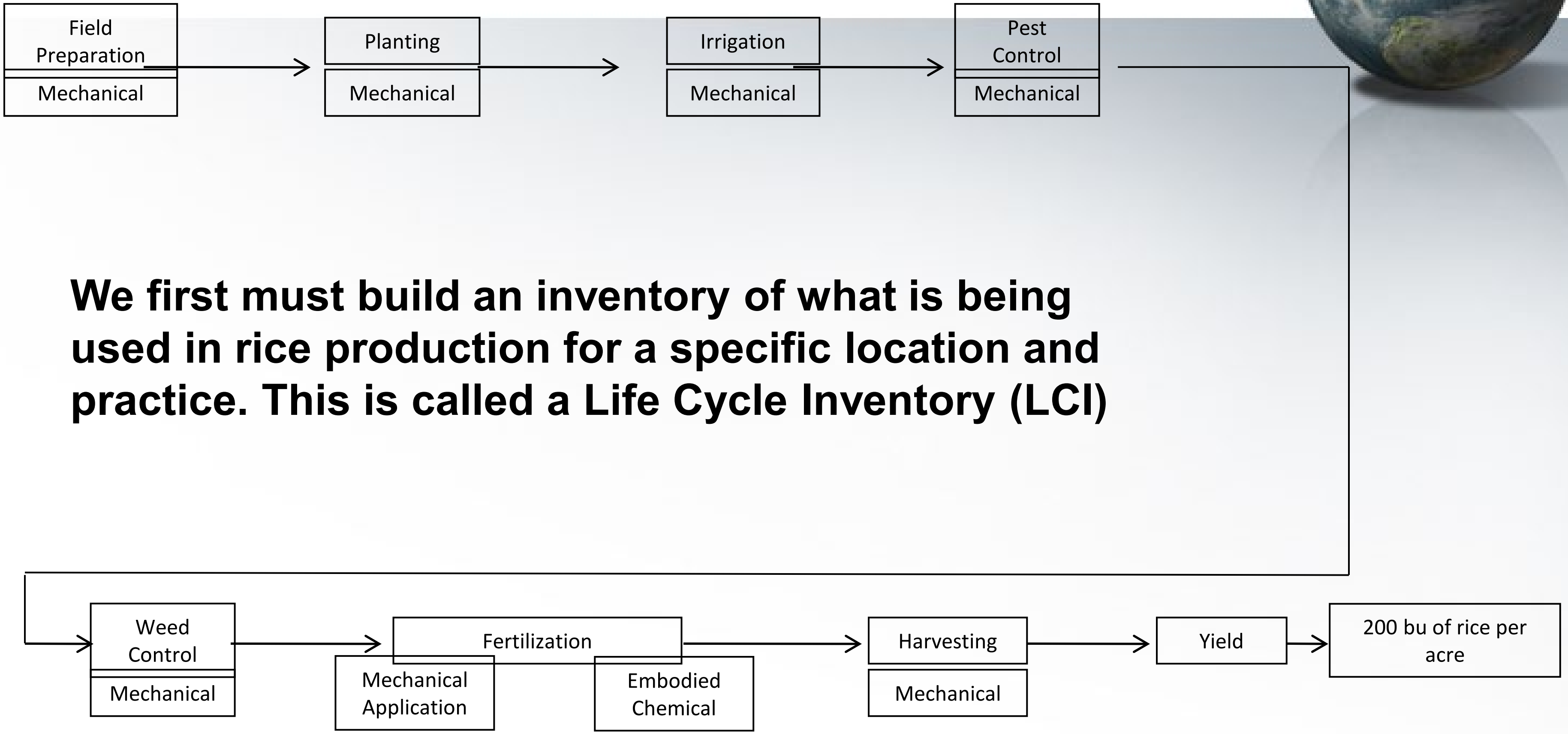
Solid Waste

Liquid Waste

The more processes, the more complexity



Building the Recipe for Rice (LCI)



Field Preparation
Mechanical

Planting
Mechanical

Irrigation
Mechanical

Pest Control
Mechanical

We first must build an inventory of what is being used in rice production for a specific location and practice. This is called a Life Cycle Inventory (LCI)

Weed Control
Mechanical

Fertilization
Mechanical Application
Embodied Chemical

Harvesting
Mechanical

Yield

200 bu of rice per acre

This inventory is important (it's like the "recipe") if you leave something out, your absolute LCA will be subject to omitted variable bias.

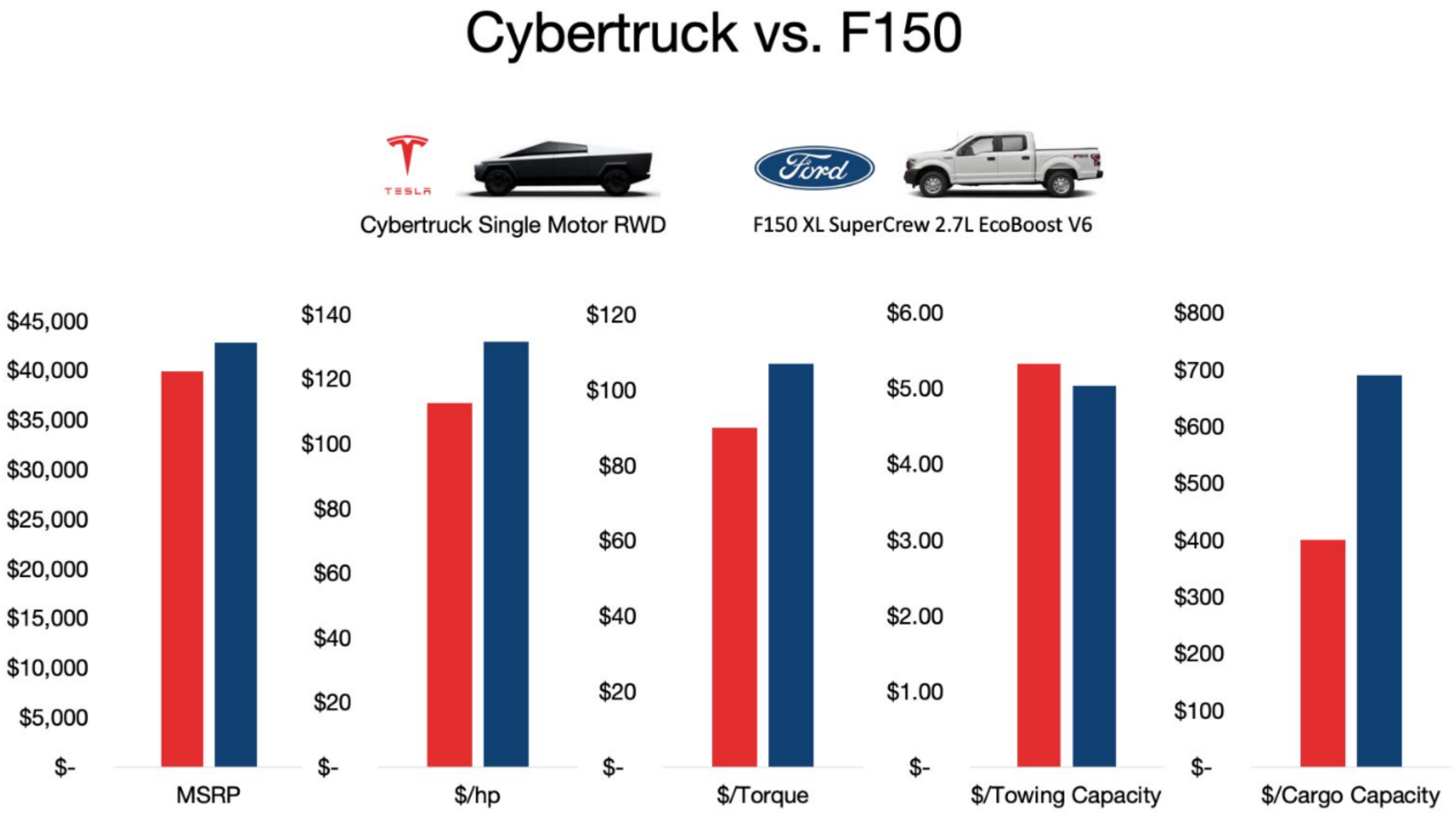
LCA software

- Most LCAs are conducted using pre-populated production methods that have been academically vetted.
  - For instance, in SimaPro, there is a vetted rice production database for China
    - When we want to run an LCA for Arkansas, we have to go into SimaPro “calibrate” variables for Arkansas production processes.
      - These calibration methods are usually taken from production budgets, such as those put out by the Division of Agriculture.

Absolute vs Relative LCA

- Creating an Absolute LCA is difficult. You must pin down everything in the production process and where the inputs were created.
- I have used Relative LCAs in my research.
  - That is, instead of worrying about what country the potash used in production came from, I focused on differences in production practices and find the relative differences
    - Row rice vs conventional irrigation

Absolute vs Relative

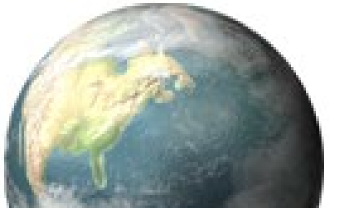


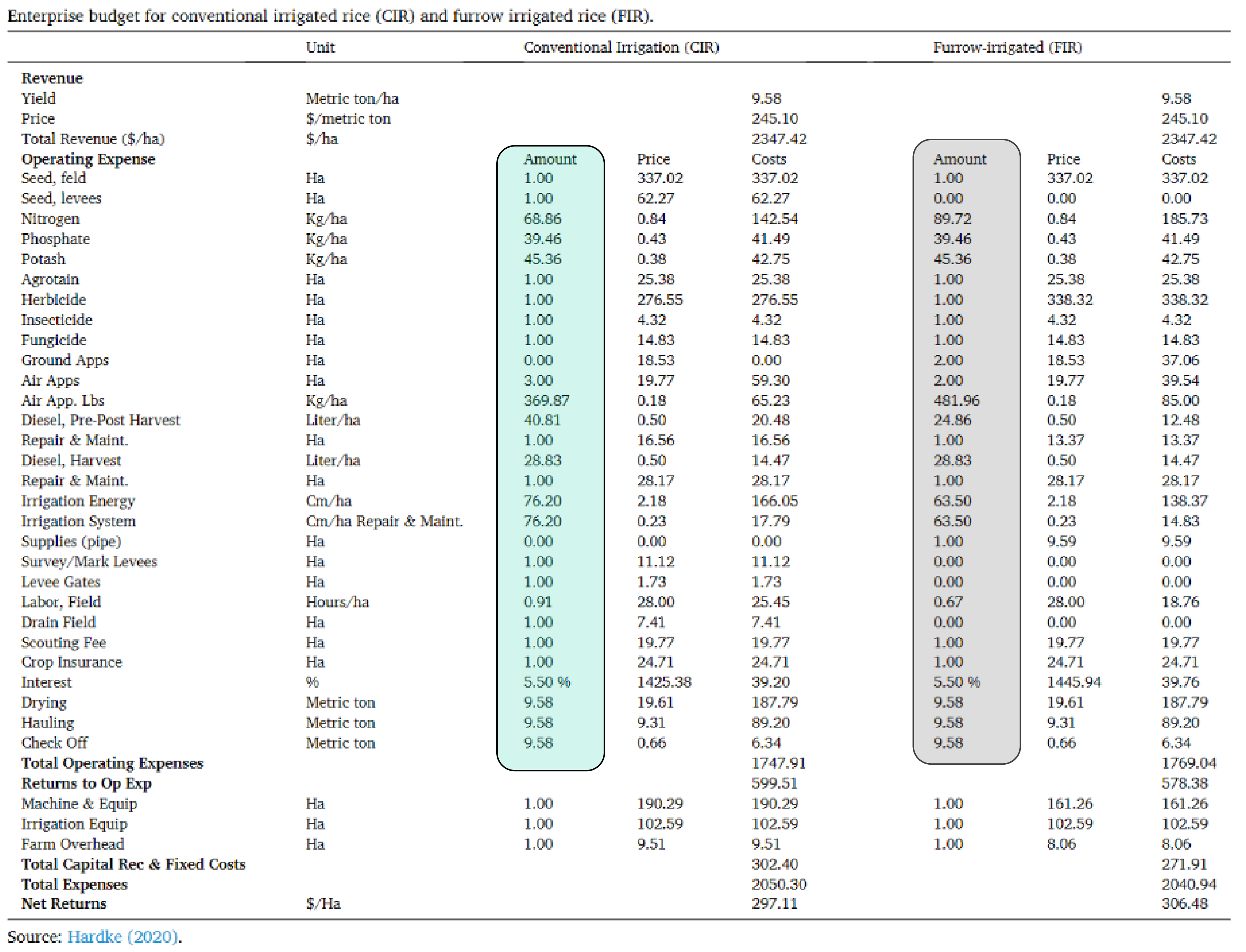
Absolute values are important but when comparing two things (trucks or rice production practices) relative comparisons are used in decision making.

Previous Rice Arkansas Rice LCAs

- 1- Blast resistant vs. non-Blast resistant varieties
- 2- Impact of Newpath resistance
- 3- Impact of the adoption of NSTaR nitrogen testing
- 4- MIRRI vs Conventional irrigation
- 5- Furrow Irrigated Rice vs Conventional Irrigation
- 6- Hybrid vs Purebred Rice Variaties

Furrow Irrigated Rice





Enterprise budget for conventional irrigated rice (CIR) and furrow irrigated rice (FIR).

	Unit	Conventional Irrigation (CIR)			Furrow-irrigated (FIR)		
Revenue							
Yield	Metric ton/ha			9.58			9.58
Price	$/metric ton			245.10			245.10
Total Revenue ($/ha)	$/ha			2347.42			2347.42
Operating Expense		Amount	Price	Costs	Amount	Price	Costs
Seed, feld	Ha	1.00	337.02	337.02	1.00	337.02	337.02
Seed, levees	Ha	1.00	62.27	62.27	0.00	0.00	0.00
Nitrogen	Kg/ha	68.86	0.84	142.54	89.72	0.84	185.73
Phosphate	Kg/ha	39.46	0.43	41.49	39.46	0.43	41.49
Potash	Kg/ha	45.36	0.38	42.75	45.36	0.38	42.75
Agrotain	Ha	1.00	25.38	25.38	1.00	25.38	25.38
Herbicide	Ha	1.00	276.55	276.55	1.00	338.32	338.32
Insecticide	Ha	1.00	4.32	4.32	1.00	4.32	4.32
Fungicide	Ha	1.00	14.83	14.83	1.00	14.83	14.83
Ground Apps	Ha	0.00	18.53	0.00	2.00	18.53	37.06
Air Apps	Ha	3.00	19.77	59.30	2.00	19.77	39.54
Air App. Lbs	Kg/ha	369.87	0.18	65.23	481.96	0.18	85.00
Diesel, Pre-Post Harvest	Liter/ha	40.81	0.50	20.48	24.86	0.50	12.48
Repair & Maint.	Ha	1.00	16.56	16.56	1.00	13.37	13.37
Diesel, Harvest	Liter/ha	28.83	0.50	14.47	28.83	0.50	14.47
Repair & Maint.	Ha	1.00	28.17	28.17	1.00	28.17	28.17
Irrigation Energy	Cm/ha	76.20	2.18	166.05	63.50	2.18	138.37
Irrigation System	Cm/ha Repair & Maint.	76.20	0.23	17.79	63.50	0.23	14.83
Supplies (pipe)	Ha	0.00	0.00	0.00	1.00	9.59	9.59
Survey/Mark Levees	Ha	1.00	11.12	11.12	0.00	0.00	0.00
Levee Gates	Ha	1.00	1.73	1.73	0.00	0.00	0.00
Labor, Field	Hours/ha	0.91	28.00	25.45	0.67	28.00	18.76
Drain Field	Ha	1.00	7.41	7.41	0.00	0.00	0.00
Scouting Fee	Ha	1.00	19.77	19.77	1.00	19.77	19.77
Crop Insurance	Ha	1.00	24.71	24.71	1.00	24.71	24.71
Interest	%	5.50 %	1425.38	39.20	5.50 %	1445.94	39.76
Drying	Metric ton	9.58	19.61	187.79	9.58	19.61	187.79
Hauling	Metric ton	9.58	9.31	89.20	9.58	9.31	89.20
Check Off	Metric ton	9.58	0.66	6.34	9.58	0.66	6.34
Total Operating Expenses				1747.91			1769.04
Returns to Op Exp				599.51			578.38
Machine & Equip	Ha	1.00	190.29	190.29	1.00	161.26	161.26
Irrigation Equip	Ha	1.00	102.59	102.59	1.00	102.59	102.59
Farm Overhead	Ha	1.00	9.51	9.51	1.00	8.06	8.06
Total Capital Rec & Fixed Costs				302.40			271.91
Total Expenses				2050.30			2040.94
Net Returns	$/Ha			297.11			306.48

Source: Hardke (2020).

FIR Environmental Metrics

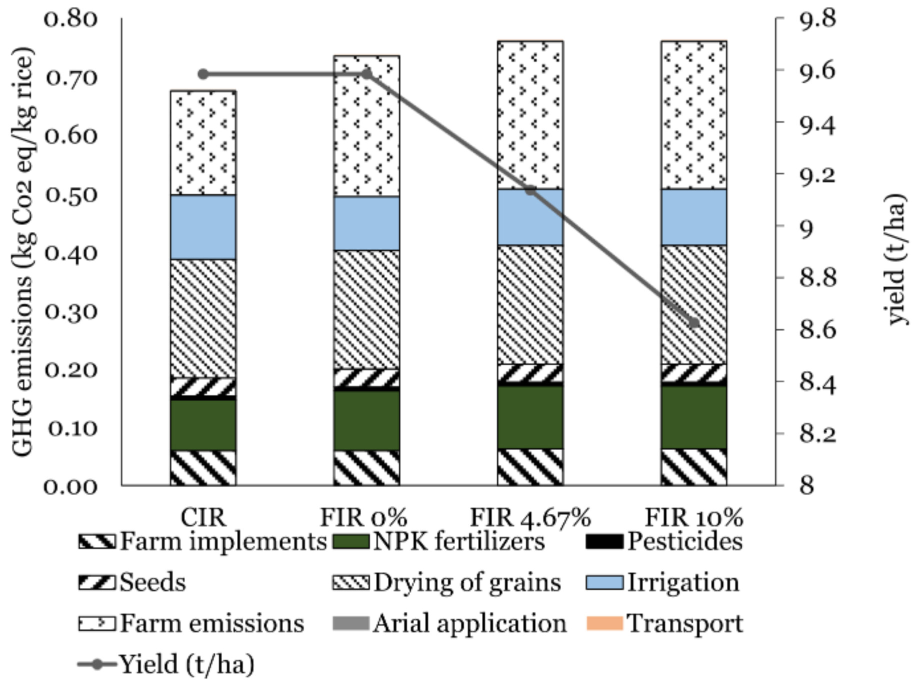
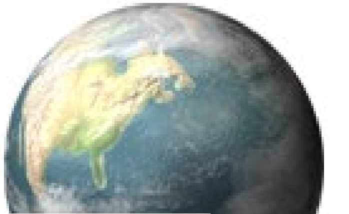


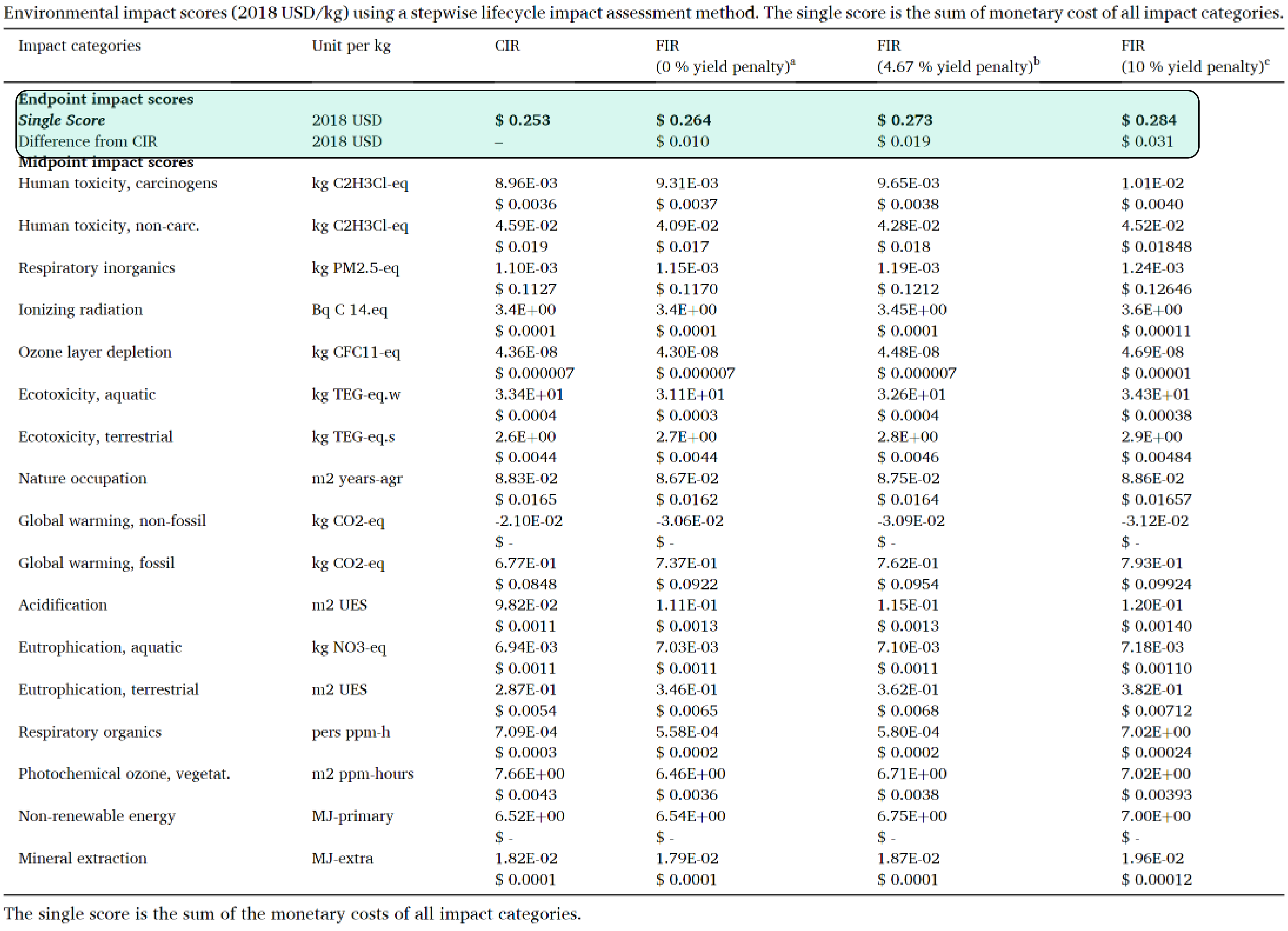
Fig. 1. Greenhouse gas emissions per kg of rice produced by conventionally-irrigated rice (CIR) and furrow-irrigated rice (FIR) under three yield loss (% relative to CIR) scenarios.

Typically, LCAs will standardize into a single metric, like CO_2e, like in the figure above.

However, with a Stepwise LCA, we can use USD as our metric.



Results (Environmental)

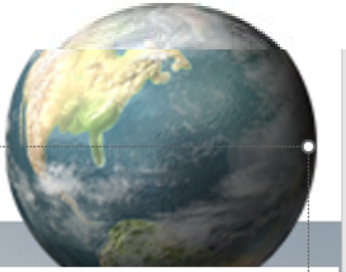


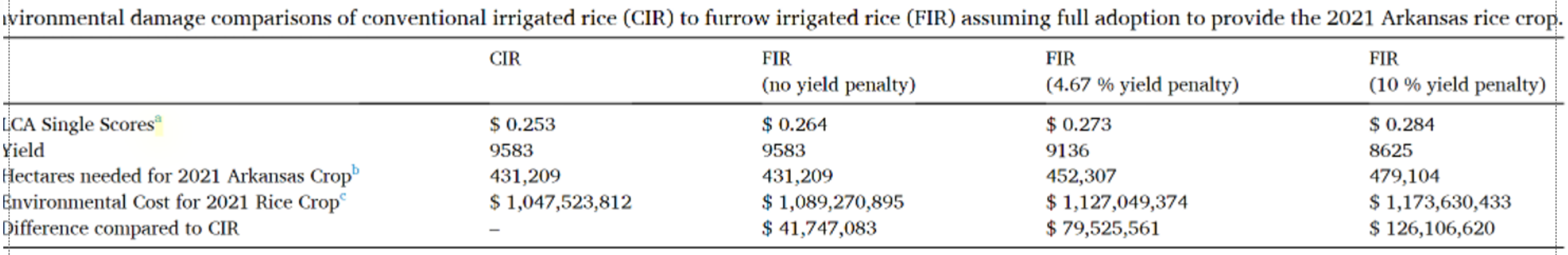
Environmental impact scores (2018 USD/kg) using a stepwise lifecycle impact assessment method. The single score is the sum of monetary cost of all impact categories.

Impact categories	Unit per kg	CIR	FIR (0 % yield penalty)[a]	FIR (4.67 % yield penalty)[b]	FIR (10 % yield penalty)[c]
Endpoint impact scores					
Single Score	2018 USD	**$ 0.253**	**$ 0.264**	**$ 0.273**	**$ 0.284**
Difference from CIR	2018 USD	–	$ 0.010	$ 0.019	$ 0.031
Midpoint impact scores					
Human toxicity, carcinogens	kg C2H3Cl-eq	8.96E-03	9.31E-03	9.65E-03	1.01E-02
		$ 0.0036	$ 0.0037	$ 0.0038	$ 0.0040
Human toxicity, non-carc.	kg C2H3Cl-eq	4.59E-02	4.09E-02	4.28E-02	4.52E-02
		$ 0.019	$ 0.017	$ 0.018	$ 0.01848
Respiratory inorganics	kg PM2.5-eq	1.10E-03	1.15E-03	1.19E-03	1.24E-03
		$ 0.1127	$ 0.1170	$ 0.1212	$ 0.12646
Ionizing radiation	Bq C 14.eq	3.4E+00	3.4E+00	3.45E+00	3.6E+00
		$ 0.0001	$ 0.0001	$ 0.0001	$ 0.00011
Ozone layer depletion	kg CFC11-eq	4.36E-08	4.30E-08	4.48E-08	4.69E-08
		$ 0.000007	$ 0.000007	$ 0.000007	$ 0.00001
Ecotoxicity, aquatic	kg TEG-eq.w	3.34E+01	3.11E+01	3.26E+01	3.43E+01
		$ 0.0004	$ 0.0003	$ 0.0004	$ 0.00038
Ecotoxicity, terrestrial	kg TEG-eq.s	2.6E+00	2.7E+00	2.8E+00	2.9E+00
		$ 0.0044	$ 0.0044	$ 0.0046	$ 0.00484
Nature occupation	m2 years-agr	8.83E-02	8.67E-02	8.75E-02	8.86E-02
		$ 0.0165	$ 0.0162	$ 0.0164	$ 0.01657
Global warming, non-fossil	kg CO2-eq	-2.10E-02	-3.06E-02	-3.09E-02	-3.12E-02
		$ -	$ -	$ -	$ -
Global warming, fossil	kg CO2-eq	6.77E-01	7.37E-01	7.62E-01	7.93E-01
		$ 0.0848	$ 0.0922	$ 0.0954	$ 0.09924
Acidification	m2 UES	9.82E-02	1.11E-01	1.15E-01	1.20E-01
		$ 0.0011	$ 0.0013	$ 0.0013	$ 0.00140
Eutrophication, aquatic	kg NO3-eq	6.94E-03	7.03E-03	7.10E-03	7.18E-03
		$ 0.0011	$ 0.0011	$ 0.0011	$ 0.00110
Eutrophication, terrestrial	m2 UES	2.87E-01	3.46E-01	3.62E-01	3.82E-01
		$ 0.0054	$ 0.0065	$ 0.0068	$ 0.00712
Respiratory organics	pers ppm-h	7.09E-04	5.58E-04	5.80E-04	7.02E+00
		$ 0.0003	$ 0.0002	$ 0.0002	$ 0.00024
Photochemical ozone, vegetat.	m2 ppm-hours	7.66E+00	6.46E+00	6.71E+00	7.02E+00
		$ 0.0043	$ 0.0036	$ 0.0038	$ 0.00393
Non-renewable energy	MJ-primary	6.52E+00	6.54E+00	6.75E+00	7.00E+00
		$ -	$ -	$ -	$ -
Mineral extraction	MJ-extra	1.82E-02	1.79E-02	1.87E-02	1.96E-02
		$ 0.0001	$ 0.0001	$ 0.0001	$ 0.00012

The single score is the sum of the monetary costs of all impact categories.

Results Furrow Irrigated





nvironmental damage comparisons of conventional irrigated rice (CIR) to furrow irrigated rice (FIR) assuming full adoption to provide the 2021 Arkansas rice crop.

	CIR	FIR (no yield penalty)	FIR (4.67 % yield penalty)	FIR (10 % yield penalty)
LCA Single Scores[a]	$ 0.253	$ 0.264	$ 0.273	$ 0.284
Yield	9583	9583	9136	8625
Hectares needed for 2021 Arkansas Crop[b]	431,209	431,209	452,307	479,104
Environmental Cost for 2021 Rice Crop[c]	$ 1,047,523,812	$ 1,089,270,895	$ 1,127,049,374	$ 1,173,630,433
Difference compared to CIR	–	$ 41,747,083	$ 79,525,561	$ 126,106,620

- These results are from an initial LCA on Furrow irrigated rice and more input on what producers are doing is needed. However; the results highlight the issue that LCAs can present:
  - A production practice that uses less water
  - Or a production practice that may have higher overall environmental impacts
  - Not all environmental metrics move in the same direction!

NSTaR LCA

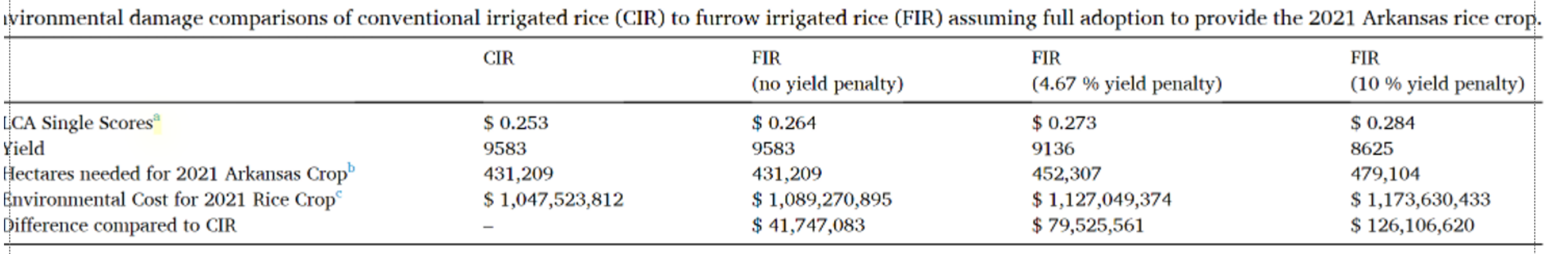
Ecosystem Impact Scores Using Stepwise Life Cycle Analysis per Kg of Rice Produced Conventional Nitrogen (N) Recommendations (Baseline) and N-STaR Production

Impact categories	Unit	Scenarios	
		Baseline	N-STaR
End point impact scores			
Single Scores	US$ 2018	0.3734	0.3603[a]
Global warming, fossil	US$ 2018	0.1977	0.1912
Mid point impact scores			
Human toxicity, carcinogens	kg C2H3Cl-eq	9.65E-03	8.94E-03
	US$ 2018	3.84E-03	3.56E-03
Human toxicity, non-carc.	kg C2H3Cl-eq	5.65E-02	5.61E-02
	US$ 2018	2.31E-02	2.29E-02
Respiratory inorganics	kg PM2.5-eq	1.08E-03	1.03E-03
	US$ 2018	1.11E-01	1.05E-01
Ionizing radiation	Bq C 14.eq	3.55E+00	3.46E+00
	US$ 2018	1.07E-04	1.04E-04
Ozone layer depletion	kg CFC11-eq	7.65E-08	7.41E-08
	US$ 2018	1.19E-05	1.15E-05
Ecotoxicity, aquatic	kg TEG-eq.w	3.10E+01	3.06E+01
	US$ 2018	3.44E-04	3.40E-04
Ecotoxicity, terrestrial	kg TEG-eq.s	2.55E+00	2.43E+00
	US$ 2018	4.25E-03	4.06E-03
Nature occupation	m2 years-agr	8.78E-02	8.77E-02
	US$ 2018	1.64E-02	1.64E-02
Global warming, non-fossil	kg CO2-eq	1.38E+00	1.38E+00
	US$ 2018	0.00E+00	0.00E+00
Global warming, fossil	kg CO2-eq	1.58E+00	1.53E+00
	US$ 2018	1.98E-01	1.91E-01
Acidification	m2 UES	7.59E-02	6.98E-02
	US$ 2018	8.86E-04	8.14E-04

A total of 1,117 rice producers' N samples were analyzed and subsequently given a N recommendation by the N-STaR program and compared to the blanket recommendation of 180 lbs/ac for clay soils and 150 lbs/ac for silt loam soils

- The LCA single score for a kg of traditional rice is estimated at $0.3734, and for N-STaR, it was estimated at $0.3603, a reduction of $0.0131 for every kg of rice produced with N-STaR.
- That's $0.27 per bushel or $48.13 per acre (assuming a 180 bu/yield)

Results Furrow Irrigated



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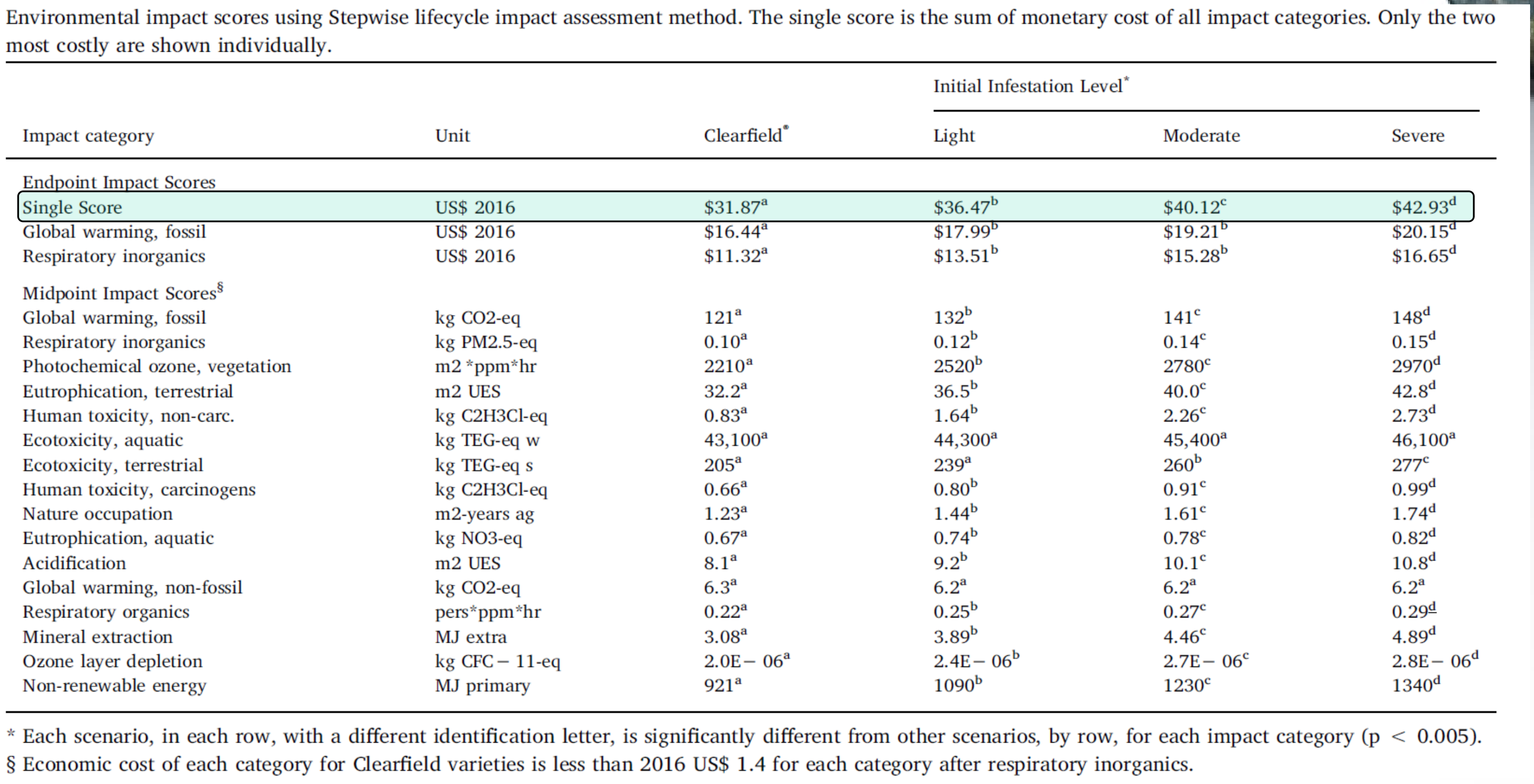
Clearfield LCA



Environmental impact scores using Stepwise lifecycle impact assessment method. The single score is the sum of monetary cost of all impact categories. Only the two most costly are shown individually.

			Initial Infestation Level*		
Impact category	Unit	Clearfield*	Light	Moderate	Severe
Endpoint Impact Scores					
Single Score	US$ 2016	$31.87[a]	$36.47[b]	$40.12[c]	$42.93[d]
Global warming, fossil	US$ 2016	$16.44[a]	$17.99[b]	$19.21[b]	$20.15[d]
Respiratory inorganics	US$ 2016	$11.32[a]	$13.51[b]	$15.28[b]	$16.65[d]
Midpoint Impact Scores§					
Global warming, fossil	kg CO2-eq	121[a]	132[b]	141[c]	148[d]
Respiratory inorganics	kg PM2.5-eq	0.10[a]	0.12[b]	0.14[c]	0.15[d]
Photochemical ozone, vegetation	m2 *ppm*hr	2210[a]	2520[b]	2780[c]	2970[d]
Eutrophication, terrestrial	m2 UES	32.2[a]	36.5[b]	40.0[c]	42.8[d]
Human toxicity, non-carc.	kg C2H3Cl-eq	0.83[a]	1.64[b]	2.26[c]	2.73[d]
Ecotoxicity, aquatic	kg TEG-eq w	43,100[a]	44,300[a]	45,400[a]	46,100[a]
Ecotoxicity, terrestrial	kg TEG-eq s	205[a]	239[a]	260[b]	277[c]
Human toxicity, carcinogens	kg C2H3Cl-eq	0.66[a]	0.80[b]	0.91[c]	0.99[d]
Nature occupation	m2-years ag	1.23[a]	1.44[b]	1.61[c]	1.74[d]
Eutrophication, aquatic	kg NO3-eq	0.67[a]	0.74[b]	0.78[c]	0.82[d]
Acidification	m2 UES	8.1[a]	9.2[b]	10.1[c]	10.8[d]
Global warming, non-fossil	kg CO2-eq	6.3[a]	6.2[a]	6.2[a]	6.2[a]
Respiratory organics	pers*ppm*hr	0.22[a]	0.25[b]	0.27[c]	0.29[d]
Mineral extraction	MJ extra	3.08[a]	3.89[b]	4.46[c]	4.89[d]
Ozone layer depletion	kg CFC − 11-eq	2.0E− 06[a]	2.4E− 06[b]	2.7E− 06[c]	2.8E− 06[d]
Non-renewable energy	MJ primary	921[a]	1090[b]	1230[c]	1340[d]

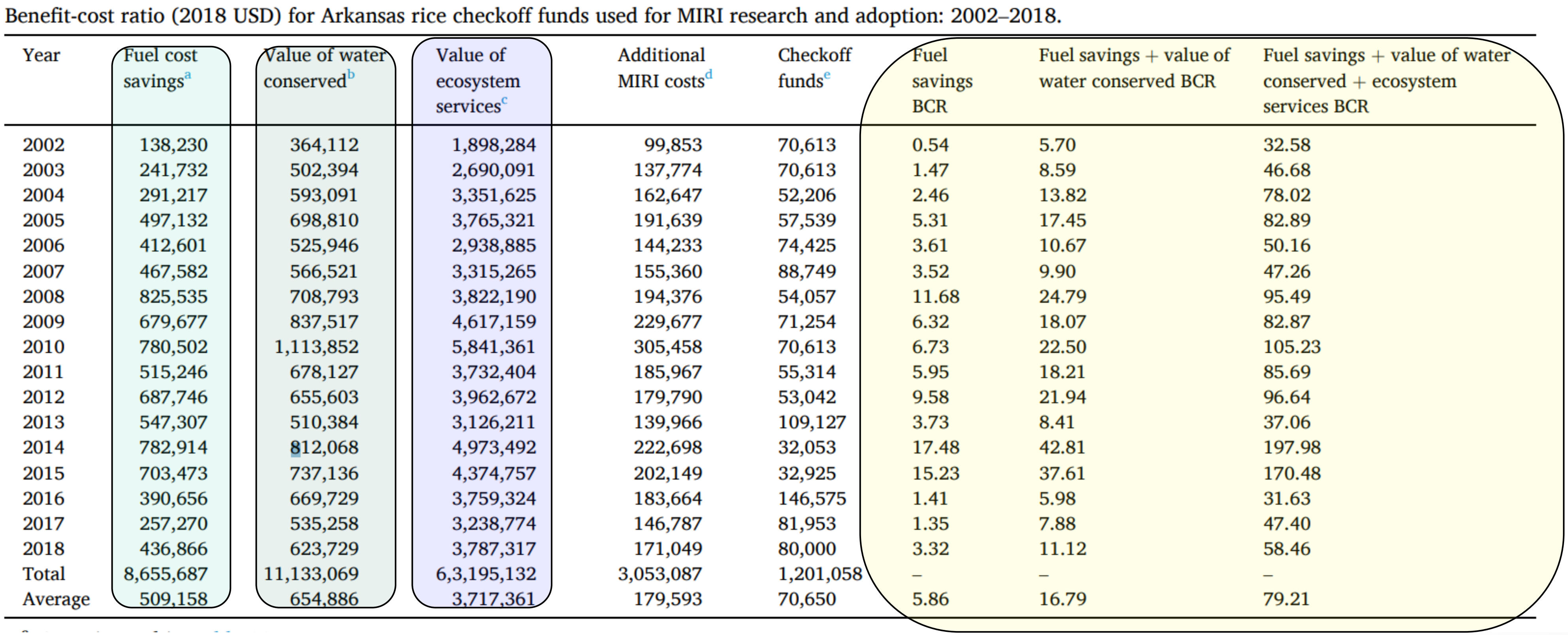
* Each scenario, in each row, with a different identification letter, is significantly different from other scenarios, by row, for each impact category ($p < 0.005$).

§ Economic cost of each category for Clearfield varieties is less than 2016 US$ 1.4 for each category after respiratory inorganics.

In this study we estimated the impact of red rice infestations because of NewPath resistance, so we used an LCA to "value" a technology.

Here, our metric was how much does it cost in environmental damage to meet the global average per capita rice consumption (126.1 lbs/year)

Ecosystem vs Tangible Benefits



Benefit-cost ratio (2018 USD) for Arkansas rice checkoff funds used for MIRI research and adoption: 2002–2018.

Year	Fuel cost savings[a]	Value of water conserved[b]	Value of ecosystem services[c]	Additional MIRI costs[d]	Checkoff funds[e]	Fuel savings BCR	Fuel savings + value of water conserved BCR	Fuel savings + value of water conserved + ecosystem services BCR
2002	138,230	364,112	1,898,284	99,853	70,613	0.54	5.70	32.58
2003	241,732	502,394	2,690,091	137,774	70,613	1.47	8.59	46.68
2004	291,217	593,091	3,351,625	162,647	52,206	2.46	13.82	78.02
2005	497,132	698,810	3,765,321	191,639	57,539	5.31	17.45	82.89
2006	412,601	525,946	2,938,885	144,233	74,425	3.61	10.67	50.16
2007	467,582	566,521	3,315,265	155,360	88,749	3.52	9.90	47.26
2008	825,535	708,793	3,822,190	194,376	54,057	11.68	24.79	95.49
2009	679,677	837,517	4,617,159	229,677	71,254	6.32	18.07	82.87
2010	780,502	1,113,852	5,841,361	305,458	70,613	6.73	22.50	105.23
2011	515,246	678,127	3,732,404	185,967	55,314	5.95	18.21	85.69
2012	687,746	655,603	3,962,672	179,790	53,042	9.58	21.94	96.64
2013	547,307	510,384	3,126,211	139,966	109,127	3.73	8.41	37.06
2014	782,914	812,068	4,973,492	222,698	32,053	17.48	42.81	197.98
2015	703,473	737,136	4,374,757	202,149	32,925	15.23	37.61	170.48
2016	390,656	669,729	3,759,324	183,664	146,575	1.41	5.98	31.63
2017	257,270	535,258	3,238,774	146,787	81,953	1.35	7.88	47.40
2018	436,866	623,729	3,787,317	171,049	80,000	3.32	11.12	58.46
Total	8,655,687	11,133,069	6,3,195,132	3,053,087	1,201,058	–	–	–
Average	509,158	654,886	3,717,361	179,593	70,650	5.86	16.79	79.21

- In this study, we conducted an LCA looking at the benefits (environmental, water savings, and fuel) from actual **MIRI adoption** in Arkansas and compared that to funding the Rice Board provided for MIRI research.
- Accounting for Ecosystem services can make a big difference in how you look at the bottom line

Conclusion

- While many stakeholders want a “one size fits all” LCA to represent their industry, in reality, establishing a baseline LCA first and then highlighting production or technology changes is ideal.
- These “ecosystem benefits,” although monetized in several of these studies, are likely not going to be payments for producers.
  - But when you want to market your product against another, they are valuable information for buyers who want to pass this information on to consumers

Conclusion

- My thoughts on LCAs boil down to what your objective is.
  - If it’s comparing US rice to Thai rice, a simple baseline LCA for both countries would work
  - If it's quantifying a “more sustainable rice” produced in the USA, then a baseline is needed, and several LCAs where single changes from that baseline can be summed.
    - If you change too many things at once, you can't tell what is driving the change.
- Knowing what you want and who your target audience is, is vital prior to starting.