

IHS Chemical

Process Economics Program

Report 287
Bio-Based Aromatics

By Michael Arné

December 2013

ihs.com/chemical



IHS Chemical agrees to assign professionally qualified personnel to the preparation of the Process Economics Program's reports and will perform the work in conformance with generally accepted professional standards. No other warranties expressed or implied are made. Because the reports are of an advisory nature, neither IHS Chemical nor its employees will assume any liability for the special or consequential damages arising from the Client's use of the results contained in the reports. The Client agrees to indemnify, defend, and hold IHS Chemical, its officers, and employees harmless from any liability to any third party resulting directly or indirectly from the Client's use of the reports or other deliverables produced by IHS Chemical pursuant to this agreement.

For detailed marketing data and information, the reader is referred to one of the IHS Chemical programs specializing in marketing research. THE IHS CHEMICAL ECONOMICS HANDBOOK Program covers most major chemicals and chemical products produced throughout the world. In addition the IHS DIRECTORY OF CHEMICAL PRODUCERS services provide detailed lists of chemical producers by company, product, and plant for the United States, Europe, East Asia, China, India, South & Central America, the Middle East & Africa, Canada, and Mexico.

PEP Report 287

Bio-Based Aromatics

By Michael Arné

December 2013

Abstract

This report covers the technology and costs to make aromatics from biological feedstocks. We have concentrated on processes to make para-xylene. para-Xylene is a key intermediate in the manufacture of polyethylene terephthalate (PET). When combined with bio-sourced ethylene, bio-based para-xylene offers the opportunity for a 100% plant-based PET bottle.

Three processes are presented: two for the manufacture of para-xylene from corn, and one for its manufacture from cellulosic biomass (wood). The Gevo process uses fermentation to produce para-xylene from corn via isobutanol. The Virent process feeds corn-derived glucose to a two-step catalytic synthesis to give aromatics. The Anellotech fast pyrolysis process makes aromatics from finely ground wood in a modified FCC unit.

Contents

1. Introduction	1-1
2. Summary	2-1
Gevo process	2-1
Virent process.....	2-1
Anellotech process	2-2
Comparison of process economics	2-2
3. Industry status	3-1
Industry forecast: supply	3-2
Industry forecast: demand	3-3
4. Technology review	4-1
The challenge: para-xylene from sugars	4-1
The challenge: para-xylene from cellulosic biomass	4-2
Recent technology developments	4-2
Gevo.....	4-2
Virent	4-6
Anellotech.....	4-9
5. para-Xylene from corn via the Gevo process	5-1
Chemistry	5-1
Process description.....	5-2
Process discussion.....	5-21
General considerations.....	5-21
Fermentation.....	5-22
para-Xylene from isobutanol	5-25
DDGS recovery	5-27
Utilities	5-28
Waste treatment	5-28
Cost estimates.....	5-29
Capital costs.....	5-29
Production costs.....	5-30
6. para-Xylene from corn via the Virent process	6-1
Chemistry	6-1
Process description.....	6-2
Process discussion.....	6-11
General considerations.....	6-11
Wet milling.....	6-12
Aqueous phase reforming.....	6-12
Condensation reaction	6-15
Aromatics unit	6-15
Materials of construction	6-16
Waste treatment	6-16

Contents (concluded)

Use of external hydrogen for a bio-para-xylene	6-19
Cost estimates.....	6-19
Capital costs.....	6-19
Operating costs	6-20
7. para-Xylene from biomass via Anellotech process	7-1
Process description.....	7-1
Process discussion.....	7-19
General considerations.....	7-20
Feed pretreatment	7-20
Pyrolysis and cracking.....	7-20
Balance of reaction and recovery	7-21
Styrene recovery	7-22
Hydrotreater.....	7-23
Aromatics processing.....	7-23
Utilities balance	7-24
Waste treatment	7-25
Logistics issues	7-28
Cost estimates.....	7-28
Capital costs.....	7-28
Production costs.....	7-29
Appendix A: Patent summary tables.....	A-1
Appendix B: Cited references	B-1
Appendix C: Process flow diagrams.....	C-1

Figures

3.1	World PTA demand by region.....	3-1
3.2	World para-xylene demand by region	3-2
3.3	World 2012 para-xylene demand by region	3-3
3.4	World 2012 PTA demand by region.....	3-3
3.5	PTA demand year-on-year growth	3-4
4.1	Gevo fermentation and recovery	4-3
4.2	Fermentation recovery details	4-4
4.3	Gevo proposed route from isobutanol to p-xylene	4-5
4.4	Virent process scheme block flow diagram.....	4-6
4.5	Virent process chemistry	4-7
4.6	Example of Virent APR reaction paths	4-8
4.7	Example of Virent APR reaction path.....	4-9
5.1	para-Xylene from corn via the Gevo process	C-3
5.2	Fermentation Productivity	5-22
5.3	Sensitivity of para-xylene production cost to corn feedstock cost	5-38
5.4	Sensitivity of para-xylene product value including 15% pretax ROI to corn feedstock cost	5-38
6.1	Example of Virent APR reaction paths	6-1
6.2	para-Xylene from corn via the Virent process.....	C-13
6.3	APR effluent distribution of carbon numbers.....	6-14
6.4	Sensitivity of para-xylene production cost to corn feedstock cost	6-25
6.5	Sensitivity of para-xylene product value including 15% pretax ROI to corn feedstock cost	6-25
7.1	para-Xylene from biomass via Anellotech process	C-15

Tables

2.1	Summary of para-xylene production costs	2-4
4.1	Gevo isobutanol recovery—adiabatic flash cases	4-4
4.2	Gevo isobutanol recovery—single-stage isothermal flash cases	4-4
4.3	Gevo isobutanol recovery—multistage isothermal flash case	4-5
5.1	para-Xylene from corn via the Gevo process Composition of corn	5-5
5.2	para-Xylene from corn via the Gevo process Design bases	5-6
5.3	para-Xylene from corn via the Gevo process Major equipment	5-9
5.4	para-Xylene from corn via the Gevo process Major stream flows	5-13
5.5	para-Xylene from corn via the Gevo process Utilities summary	5-20
5.6	para-Xylene from corn via the Gevo process Major waste streams	5-29
5.7	para-Xylene from corn via the Gevo process Total capital investment	5-31
5.8	para-Xylene from corn via the Gevo process Capital investment by section	5-32
5.9	para-Xylene from corn via the Gevo process Production costs	5-34
5.10	para-Xylene from corn via the updated Gevo process Production costs	5-36
6.1	para-Xylene from corn via the Virent process Design bases	6-4
6.2	para-Xylene from corn via the Virent process Major equipment	6-6
6.3	para-Xylene from corn via the Virent process Major stream flows	6-7
6.4	para-Xylene from corn via the Virent process Utilities summary	6-11
6.5	Aqueous-phase reactor breakdown of reactor outlet composition	6-13
6.6	Composition of condensation products (wt%)	6-16
6.7	para-Xylene from corn via the Virent process Major waste streams	6-18
6.8	para-Xylene from corn via the Virent process Total capital investment	6-21
6.9	para-Xylene from corn via the Virent process Capital investment by section	6-22
6.10	para-Xylene from corn via the Virent process Production costs	6-23
7.1	Elemental composition of southern yellow pine	7-4

Tables (concluded)

7.2	para-Xylene from biomass via Anellotech process Design bases	7-5
7.3	para-Xylene from biomass via Anellotech process Major equipment	7-8
7.4	para-Xylene from biomass via Anellotech process Major stream flows	7-11
7.5	para-Xylene from biomass via Anellotech process Utilities summary	7-19
7.6	para-Xylene from biomass via Anellotech process Major waste streams	7-26
7.7	para-Xylene from biomass via Anellotech process Total capital investment	7-30
7.8	para-Xylene from biomass via Anellotech process Capital investment by section.....	7-31
7.9	para-Xylene from biomass via Anellotech process Production costs.....	7-33