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(54) **CATALYSTS, REACTORS AND METHODS OF PRODUCING HYDROGEN VIA THE WATER-GAS SHIFT REACTION**

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(58) **Field of Classification Search** 502/102, 502/439, 308, 326, 330, 344, 349
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,461,183	A *	8/1969	Hepp et al.	585/434
4,472,533	A	9/1984	Moskovits	502/320
4,975,406	A	12/1990	Frestad et al.	502/332
5,030,440	A	7/1991	Lywood et al.	423/655
5,075,277	A	12/1991	Saiai et al.	502/333
5,366,719	A	11/1994	van Wingerden et al.	423/659
5,422,331	A	6/1995	Galligan et al.	502/333
5,482,680	A	1/1996	Wilkinson et al.	422/177
5,674,301	A	10/1997	Sakai et al.	48/61
5,866,734	A	2/1999	Flick et al.	585/260
5,935,529	A *	8/1999	Saito et al.	422/177
6,025,297	A	2/2000	Ogura et al.	502/300

(Continued)

FOREIGN PATENT DOCUMENTS

EP 0406896 A1 1/1991

(Continued)

OTHER PUBLICATIONS

International Search Report from PCT/US 02/04528 (Oct. 2002).

(Continued)

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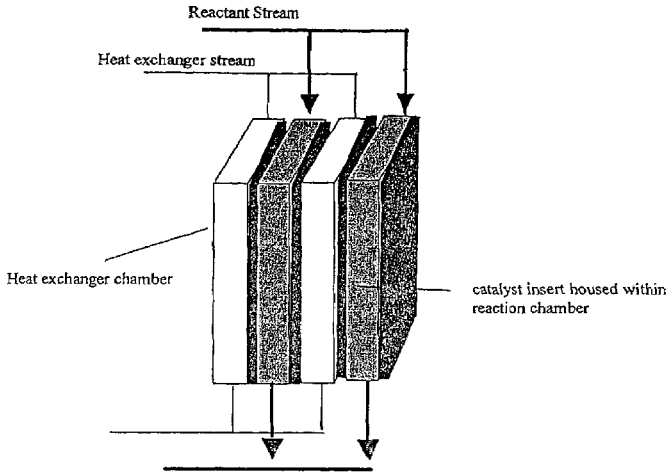
(57) **ABSTRACT**

The reaction of carbon monoxide with steam over an alkali-modified ruthenium-on-zirconia catalyst has been found to yield surprisingly high yields of hydrogen gas at relatively low temperatures. Catalyst structures, reactors, hydrogen production systems, and methods for producing hydrogen utilizing the alkali-modified ruthenium-on-zirconia catalyst are described. Methods of making catalysts are also described.

18 Claims, 3 Drawing Sheets